Regional State of the Coast Report

Western Indian Ocean









UNEP

Regional State of the Coast Report

Western Indian Ocean









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FOREWORD

The complex archipelagic system of 115 islands, of which 41 are granitic and 74 are coralline in nature, within an exclusive economic zone of about 1.44 million km2, of the Seychelles, is representative of a truly unique Western Indian Ocean (WIO) region. A region that is world-renown for the vast array of habitats with remarkable natural beauty, spectacular biodiversity and rich natural resources. In the WIO region, we are proud of our leadership and history in the management of the marine environment. Our marine protected areas are among the oldest eg Malindi Marine Park in Kenya, established in 1968, and the Aldabra Atoll in the Seychelles, that was established in 1981 and declared as a World Heritage site in 1982. The Primeiras and Segundas Archipelago in Mozambique is among largest protected area in Africa, covering more than 4020 square miles. The region continues to explore new and innovative options for managing oceans and coasts. We also recognise the transboundary nature of shared ocean resources, and our governments have signed the Nairobi Convention and its protocols as the framework for collaboration in the management of our oceans to sustain cultural and economic opportunities that the marine resources presents to the region as a whole.

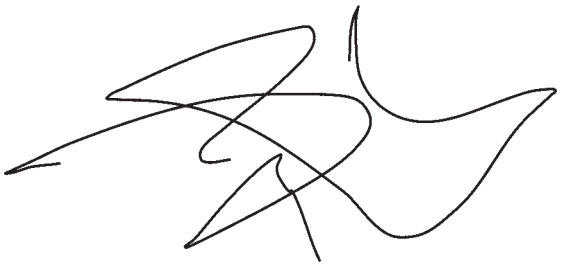
The coastal area in the WIO region is home for over 60 million people, with long and rich cultural traditions on the management of the coastal and marine resources. The Seychelles is a microcosm of our Western Indian Oceans cultural diversity. People with African, Asian and European origin, have brought with them their traditions and customs, contributing to the existing vibrant Seychellois maritime culture.

Seychelles has been in the forefront at regional and global level in promoting a Blue Economy pathway for sustainable growth. We strongly believe that we can reconcile fast economic growth with climate resilience development by harnessing the full array of ocean wealth to accelerate our countries' abilities to produce more goods including food and energy.

Our success in developing a Blue Economy is equally dependent on effective management of the coastal and marine environment. The production of this first Regional State of the Coast Report for the Western Indian Ocean Region, which describes the status of the environment and our ocean's vast array of untapped or under developed resources, is the first step in our efforts to establish a common understanding that will be used as the baseline for future reports, scenario building and forecasting.

This report is also a reflection of our collaborative efforts under the Nairobi Convention to create a link between science and policy making at the regional scale. May I commend all those who have made the production of this report possible for their worthy contribution to the body of knowledge on the coastal and marine environment of the WIO region.

It is my hope that this report will inspire our countries in our pursuit to take more concrete actions towards turning our dreams of developing Blue Economy for our countries into reality.



Didier Dogley
Minister of Environment, Energy and Climate Change
Seychelles

The Western Indian Ocean Region – Taking the lead!

The Regional State of Coast Report for the western Indian Ocean (WIO) is the first comprehensive regional synthesis to provide insights into the enormous economic potential around the WIO, the consequential demand for marine ecosystem goods and services to match the increasing human population, the pace and scale of environmental changes taking place in the region and the opportunities to avoid serious degradation in one of the world's unique and highly biodiverse oceans. The report goes a step further and presents exploratory scenarios and policy analysis to better inform anticipatory planning and management of coastal and marine resources.

Thirty years after the Nairobi Convention was enacted, there is no better way to mark this major milestone than launching this report in 2015 - a report which amongst others, will provide the Convention with the basis for reflection on where it is coming from and where it would wish to be in another thirty years from now. For the Convention to successfully mobilize experts from a range of disciplines, decision-makers at different levels, various UN organizations, partners and donors from within and outside the region, to contribute in meaningful and concrete ways towards the production of this report, is testimony to the recognition of the important role the Convention has played as a regional platform for cooperation in the protection, management and development of the region's marine and coastal environment. We at UNEP, as the hosts to the Convention, are very proud to be associated with this landmark document, not only since different sections of the organization have played an active role in its production, but more importantly, this region has become the first Regional Seas Programme to produce its Regional State of Coast Report, based on the format and structure of the UN-coordinated World Oceans Assessment. This is setting the standard for other Regional Seas Programmes to follow.

Further, by linking the production of this report with the Eighth Meeting of the Contracting Parties to the Nairobi Convention, a new dimension is added to the Convention's efforts to bridge the science-to-policy interface. In addition to providing the basis for some of the key decisions of the Meeting, the report will contribute to the Convention's Work Programme for 2018-2022 and follow-up interventions to be developed.

This report highlights the enormous economic potential and development needs of countries around the WIO and, at the same time, points out the growing natural and anthropogenic pressure imposed on the region coastal and marine environment, and the opportunities to avoid them. It is evident from the report that countries and the region as a whole have placed a high priority on the coastal and marine environment. Nationally and regionally, actions are being taken at different levels to sustainably manage the coastal and marine environment, however, more needs to be done. This report highlights the perils of continued delay on addressing some of the major challenges and also how critical it is to balance economic, social and environmental needs, if the countries are to continue to benefit from the diverse and life-sustaining goods and services provided by the coastal and marine environment for many years to come.



Achim Steiner
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We are grateful for the contributions dedication, generous and thoughtful contributions by experts, policy makers and heads of institutions from all the Western Indian Ocean countries. We truly are indebted to you all for accepting our many demands with such grace and professionalism.
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Dixon Waruinge (Nairobi Convention) and Julius Francis (WIOMSA)

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Part I
Summary

José Paula

Executive Summary

The Western Indian Ocean (WIO) region spans across a large latitudinal range, from the Somalia region, influenced by the strong monsoon regime of the northern Indian Ocean, to the southern temperate regime of the tip of South Africa, where the Agulhas current diverges from the northward moving Atlantic Benguela current. It encompasses tropical and subtropical regions of diverse nature, rich stretches of coast along the mainland countries of Somalia, Kenya, Tanzania, Mozambique and South Africa, and vast oceanic areas surrounding the island states of Madagascar, Seychelles, Comoros, Mauritius and French Territories. Geomorphological and oceanographic features define the character of the WIO. The social tissue of the of the WIO, where much of the population lives at the coast, is an amalgam of diverse populations with different origins, a product of the rich and varied political history, where networks of trade interactions have generated a high ethnic and cultural diversity. The cultural heritage is thus important and matches the natural richness of the region. Most countries in the WIO have high population growth rates, and coastal development is expected to grow accordingly.

The Regional State of the Coast Report (RSOCR) derives from requirements of the Nairobi Convention and contributes to the United Nations-led production of the World Ocean Assessment (WOA) reports as well as to other global and regional processes, such as the Environment Outlooks coordinated by UNEP. The RSOCR aims to integrate the socio-economic and ecological systems of the WIO region by using a uniform methodology based on the Opportunities Framework and the DPSIR (Drivers, Pressures, Status, Impacts, Responses) approach. The RSOCR's approach has been adapted from the WOA framework, however the content and organization of the concluding chapters are based on the distinct needs of the WIO region. While the political agenda included the Contracting Parties and their National Focal Points to the Nairobi Convention, the technical process was guided by WIOMSA (Western Indian Ocean Marine Science Association) and involved a representative set of scientists with broad experience in the region. The RSOCR's main objectives are to i) provide a comprehensive baseline, ii) highlight main opportunities, iii) describe successes and challenges, iv) identify capacity building needs, v) identify knowledge gaps, and vi) propose policy options.

The WIO region is characterised by high biodiversity, both in terms of species and ecosystems, which places it as one of the most rich and interesting ocean regions of the world. The regional countries have in general low income, and as such a large fraction of the population is dependent on coastal and marine resources and ecosystem services. The biodiversity of these systems is thus under direct and indirect pressures through resource exploitation and anthropogenically-driven habitat degradation. The effects and impacts of global climate change add further pressures to local-acting sources of disturbance. The assessment of biodiversity (developed in Part III of the report) addresses the main ecosystems that constitute the major support for biodiversity and living resources, such as the nearshore

habitats, mangroves, salt marshes and seagrass beds, coral reefs, rocky reefs, sediments and pelagic and deep sea environments. The assessment further includes a summary of threatened marine species, as well as the significant social and economic aspects of biodiversity conservation. Regarding the biodiversity assessment it is apparent that marine ecosystems in the WIO region are in a fairly good condition, but the pressures from global climate change acting synergistically with the local anthropogenically-induced drivers are increasingly challenging the natural processes.

Sectorial and specific recommendations have arisen from the RSOCR that target the sustainable use of biodiversity resources and the maintenance of ecosystem quality and associated biodiversity, as derived from the goals of the Convention for the Biological Diversity and its 2020 targets. These relate firstly to the efforts of addressing the engagement of the civil society (such as promoting awareness on the value and vulnerability of the WIO natural marine and coastal capital at varying levels including by resource users and managers, public, politicians and authorities). Secondly, it is recommended that higher levels of funding for marine research are considered, especially targeting knowledge gaps such as the continental shelf and the deep ocean, conservation areas, resilience and habitat restoration and rehabilitation, but also aiming to increase the level of management processes. Another recommendation for the short term is the establishment of comprehensive monitoring schemes for the marine environment, while in the longer term there is a need of a progressively better integration of regional policies and the promotion of cross-sectorial linkages, allowing for more coherent approaches to ecosystem management and transboundary issues.

Over 60 million people inhabit the coastal zone in the WIO region, which has very high rate of population growth and urbanization. Invariably many of the coastal communities rely on the sea for their economic, social and cultural security. Assessment of services from the marine environment, other than provisioning services, is developed in Part IV of the report. The non-provisioning services provided by the WIO may be categorized into regulating, supporting and cultural services. The assessment includes the role of oceans' in the hydrological cycle, sea/air interaction, phytoplankton primary production, ocean-sourced carbonate production and cultural and derived services from the marine environment. The assessment of ecosystems services, other than provisioning services, emphasizes the same global challenges and the increasing pressures of the variety of human activities on the marine and coastal environment.

Ecosystem services should be addressed based on Blue Economy principles, and for this to happen appropriate holistic ecosystem services valuation should be promoted. In the short term, addressing knowledge gaps will have to involve innovative research, targeting trends of ecosystem services, their drivers of change, vulnerability and mitigation actions. A strong recommendation regards knowledge integration, namely the inclusion of traditional management systems together with modern approaches and its recognition in laws and regulations, allowing for a better engagement of communities.

The WIO region is characterised by high marine biodiversity, but contrastingly the biomass of individual species is generally low, with marine productivity depending more on nutrient input from rivers along the coasts of eastern Africa and Madagascar, than on upwelling systems. The assessment of food security from marine resources is dealt with in Part V of the RSOCR, and its most important contributions are the capture fisheries, the growing emergent mariculture activities and their socio-economic impacts. The rapid population growth and global economic expansion over the past 50 years have exponentially increased the pressure on coastal resources, and overfishing and coastal developments have put pressure on the abundance of stocks and the biological diversity. Compared to fishing, mariculture is recent in the SW Indian Ocean and it appears to have positive future prospects, particularly in Madagascar, Mozambique, Tanzania and Kenya.

Overfishing of marine resources should be addressed by authorities by appropriately quantifying fishers, methods and harvests. Evident knowledge points to the need for research to target distribution patterns, biological characteristics and reference points, stock status and the effects of fishing. Research results should be passed to managers and thus there is a need to strengthen the linkages between science and management. This way managers can provide better plans for fisheries and the main target species, adopt holistic ecosystem approaches, and promote co-management of artisanal fisheries and cooperative management of transboundary stocks. Sound management also requires that monitoring, control and surveillance capacities be increased in most WIO countries. But opportunities for increased food production from marine resources are also

present and should be addressed, such as expansion of fisheries into deeper waters and promotion of mariculture.

Assessment of other human activities in the marine environment is developed in Part VI of the RSOCR. It includes a number of important sectorial issues such as maritime activities, oil, gas and renewable energy, coastal mining and coastline stability, tourism and recreation, urbanization, coastal development and vulnerability, marine genetic resources and bio-prospecting. The adoption of a Blue Economy agenda should drive development of human activities that promote economic development and poverty alleviation, while at the same time ensuring sustainable use of resources and maintenance of environmental quality. Some of the analysed emergent activities can turn into opportunities for human development in the WIO region. Maritime activities and mineral extraction from the coast are increasing in the region, as are emergent and fast growing socioeconomic activities such as oil and gas exploration, tourism and bio-prospecting. While these sectors offer vast opportunities for economic development, their potential impacts can challenge sustainability and should be addressed through sound, integrated management strategies.

The pressures and opportunities created by emergent human activities mean that efforts should be invested in increasing our knowledge about resources, their environment and the social aspects of their exploitation. It is desirable that, in the longer term, equitable access to and benefit sharing of coastal and marine resources be promoted. But in the short term there should be an effort to develop mechanisms and tools for handling and processing data, promotion of the production of spatial data products, as well as integrated coastal management and the necessary legal frameworks.

The scenario approach of the RSOCR adopted the DPSIR framework and was integrated based on variables, links, and feedbacks relevant to dynamic modelling of marine social–ecological systems including drivers that influence human behavioural change, such as society, knowledge systems, political and institutional settings and the economy. The assessment used two main scenarios (or opposite worlds): the Conventional World Scenario (CWS) representing a business as usual pathway (BAU), and the Challenge Scenario or Sustainable World Scenario (SWS) representing the Western Indian Ocean Strategic Action Programme (WIO-SAP) aspirations and the Sustainable Development Goals (SDGs). The use of the scenario framework must be adaptive and respond to new challenges, opportunities or threats that undoubtedly emerge. The Nairobi Convention through its management and policy platforms can promote the scenario framework for engagement between actors and also as a basis for decision-making and as tools for planning and environmental monitoring. Scenarios can be used for the creation of options for policy and management aimed at effectively managing the coasts and oceans, promote adaptive management, but also to monitor programmes set for the refining of scenarios in view of observed changes over time.

The governments of the WIO region are Parties to the Nairobi Convention, which offers a regional legal platform for the protection, management and development of the marine and coastal environment, constituting a framework of governance in the WIO region. There are several other institutions, regulatory or policy frameworks with a mandate for governance, including national and regional institutions, regional economic integration organizations, regional and international civil society organizations, and global inter-governmental institutions. Legal and institutional frameworks for addressing the marine and coastal environment include constitutional provisions, framework environmental laws and sector based laws. Governance responses and interventions are constrained by overlapping mandates of different level institutions, giving rise to inefficient use of governance instruments and resources. Nevertheless, legal, institutional and policy responses appear to converge, acknowledging that anthropogenic activities pressuring on coastal and marine zones have environmental impacts that need to be regulated. WIO countries apply Environmental Impact Assessment regulations and these are naturally merged into evolving Integrated Costal Zone Management laws and policies.

Contrasting policy options are open to the countries of the WIO region concerning the sustainability of the coastal and marine environment, both at the national and regional levels, including: i) overarching policy instruments with sector players taking primary responsibility, ii) maintenance of sectorial policies and providing a coordinating mechanism, and iii) maintenance of sector policies as well as sectorial implementation of the policies without having a coordinating mechanism. Irrespective of these options, there are scenarios that countries of the WIO region need to consider so as to mainstream coastal and marine issues for the future: policy instruments which largely or primarily provide incentives for voluntary compliance or, alterna-

tively, countries may consider strengthening the command and control approach in their policy formulation.

The overall human capacity for governance of ocean and coasts in the region is still incipient and currently does not cover the necessary array of disciplines, their up to date methodologies and the complex and multidisciplinary issues in the coastal and marine environments. The many socioeconomic and institutional factors that constrain capacity in the WIO region include limited financial and human resources, low investment in education and training, inadequate knowledge and awareness and lack of legal expertise. Investment and innovative approaches to human capacity development remains a top priority for countries in the WIO.

The Regional State of the Coast Report for the Western Indian Ocean has used a DPSIR framework for the assessment of the relevant components pertaining to the marine and coastal environment. The analysis has highlighted the main drivers of change and the consequential pressures that are exerted on the environment and human livelihoods, described current status and trends of natural and societal processes, and identified impacts. Responses to these challenges were summarized and further translated into recommendations under main sectors, providing linkages and integrative mechanisms for addressing them.

The WIO region is faced with strong challenges regarding the sustainability of its marine and coastal environments, both from global trends that require wider international integration, but also from regional and local sources of disturbance that governance mechanisms need to address. The path towards meeting the natural expectations of the development of the region's societies requires socioeconomic development and the use of the region's rich natural resources. Emergent opportunities are arising and regional capacities growing, both in terms of technology and human capacity, from the civil society to decision making structures. The adoption of a Blue Economy and the will to address socioeconomic development in the region, with emphasis on poverty alleviation, gives a hope for the future of the marine and coastal environment of the WIO region and the associated human wellbeing and livelihoods.



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Part II
The Context of the Assessment

José Paula

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1
Planet: Oceans and Life

Shigalla Mahongo and Rosemarie Mwaipopo

Opposite page: The Suomi NPP blue marble planet centered on the Western Indian Ocean. © NASA/NOAA.

PART I: THE GEOPHYSICAL ENVIRONMENT AND EVOLUTIONARY HISTORY

Unique geological features of the Western Indian Ocean

The Western Indian Ocean (WIO) is construed as an area with unique and age-old geological processes (Obura and others, 2012). Bathymetric features of complex relief and diverse geological origin, in both the deep and shallow water environments, characterize the seafloor topography of the region. The features play a crucial role in influencing water flow, while clearly directing and allowing their passage in intricate pathways (Parson and Evans 2005). The constrained water flow essentially drives all marine ecosystems and species, on evolutionary and ecological scales (Obura and others, 2012). These bathymetric features have significant impacts on the meteorology, ocean circulation, flux of heat and nutrients as well as on the patterns of living marine resources.

Among the prominent features of the WIO region, the Mozambique Channel (>150 million years old) and the Mascarene Plateau (40 million years old) are globally unique, as they comprise distinct elements of the geological history of the Indian Ocean basin (Obura and others, 2012). The Mascarene Plateau, with its emergent land and small islands only at its southern extreme, forms the shallow banks of Saya de Malha, Nazareth and Cargados Carajos, comprising the arcuate collection of shoals, blocks and seamounts (Parson and Evans 2005). Unique habitats of the plateau include the largest seagrass beds in the world, species endemism and significant aggregations of marine mammals and seabirds (Obura and others, 2012). The plateau's water flow fields, and the doming and raising of the elevation of the ocean mixed water layer, influence nutrient concentrations, which in turn affect ocean productivity (Spencer and others, 2005).

The Mozambique Channel's seafloor topography is believed to influence a highly energetic and variable regime of meso-scale eddies. These in turn affect the diversity and productivity of marine ecosystems. It is asserted that the geology (and oceanography) of the Mozambique Channel may have played a key role in driving the evolutionary dynamics of the WIO, maintaining and accumulating species in the Channel's northern area (Obura and others, 2012). It is further believed that the Mozambique Channel forms the main source of genetic diversity for the Indian Ocean (Muths and others, 2014, Obura 2012b, Samoilys and others, 2014).

The coral reefs in the northern Mozambique Channel represent the world's second hotspot of tropical marine biodiversity after the Coral Triangle region (in SE Asia), but with a unique evolutionary history and genetic diversity (Obura, 2012a, Obura and others, 2012). Corals that are unique to the WIO and are of rare and ancient lineage are also found in the Mozambique Channel (Samoilys and others, 2014). The open water food webs in the channel are highly productive and dynamic, resulting in concentrations of fish, marine turtles, marine mammals and seabirds (Obura and others, 2012).

Oceanographic processes

The oceanography of the WIO is driven by three distinct features arising from its geology and tectonic history: the Asian continent in the north; the island of Madagascar and the Mascarene Plateau; and the interactions of these with the equatorial and western boundary currents of the Ocean basin (Obura and others, 2012). Due to the location of Madagascar and the Mascarene Plateau in the path of the South Equatorial Current (SEC), and of the Asian monsoon system with its opposing trade winds, the WIO experiences a highly energetic and seasonally variable western boundary current system found nowhere else on the planet (Obura and others, 2012). The Asian continent drives the seasonal monsoon system that dominates the climate of this region of the globe, while Madagascar and the Mascarene Plateau interact with the currents imparting mesoscale dynamics that are unique to the ocean (Obura and others, 2012).

The main oceanic circulation processes in the WIO region are the South Equatorial Current (SEC), South Equatorial Counter Current (SECC), Somali Current, Northeast and Southeast Madagascar Current (NEMC and SEMC), East African Coastal Current (EACC), Southern Gyre, Great Whirl, Algulhas Current and associated upwelling wedges (Schott and others, 2009). The striking seasonal reversal of the Somali Current is a unique feature of the Indian Ocean. The Agulhas Current, which retroflects and meanders back into the Indian Ocean, is also one of the most dramatic oceanographic features of the WIO region (Spencer and others, 2005).

These oceanographic processes have a substantial impact on the ecology of the region, influencing the availability of nutrients and driving the productivity, distribution and abundance of phytoplankton and fisheries, through convergence/divergence and upwelling. The processes thus affect the health and productivity of the marine ecosystems, including biodiversity. Coastal currents such as the EACC for instance, are especially important as agents of larval dispersal. The currents are mainly important on inshore areas, open fringing reefs and inlets, where local currents coupled with freshwater inputs, provide the major source of food and nutrients to adjacent inshore waters. The currents mix and distribute the nearshore waters with its sediments, plankton, and other floating marine life. Seeds of many coastal plants such as mangroves also depend on currents for their dispersal. Other specialist swimmers use the currents to navigate and carry them to reach feeding and breeding sites. The mixing of these currents also enhances oxygen availability for marine life.

Meteorological and climatic processes

The meteorology of the Indian Ocean is dominated by the seasonal cycle of the Asian and Australian monsoons, with the major reversal of the prevailing winds between winter and summer. The geography of the Indian Ocean, compared to other ocean basins, is quite unique. It is bounded to the north by Asia, the Indian Subcontinent and the Himalayan Mountain range, which exerts a profound influence on the meteorology of the region. This leads to a complex annual cycle associated with substantial seasonal reversal of the annual monsoon winds. The reversal is most pronounced over the WIO, where the strong cross-equatorial winds of the Somali Jet during the Asian summer monsoon force strong coastal upwelling and a dramatic cooling of the ocean surface temperatures (Slingo and others, 2005). Nowhere on earth is the monsoon as pronounced as over this region, where the seasonal reversal is uniquely strong and sustained (Slingo and others, 2005, Spencer and others, 2005).

Nevertheless, the East African Highlands also play a crucial role in establishing the Asian Summer Monsoon flow, in particular the Somali Jet, which has a substantial impact on the WIO. The highlands influence the climate of Africa, India and SE Asia, as well as the heat and salinity within the WIO region (Slingo and others, 2005, Spencer and others, 2005). The Highlands act to focus the monsoon winds along the coast, leading to greater upwelling and cooler sea-surface temperatures (Slingo and others, 2005).

The meteorology of the Western Indian Ocean is also strongly influenced by large-scale climatic phenomena, especially the El Niño Southern Oscillation (ENSO), the Indian Ocean Dipole (IOD) and the Pacific Decadal Oscillation (PDO), with accompanying variations in sea level, SST, wind and precipitation anomalies (Mahongo 2014, Samoilys and others, 2014). ENSO is a system of interactions between the equatorial Pacific Ocean and the atmosphere above it. Due to asymmetry in ENSO teleconnection, El Niño induces more warming over the WIO than the associated cooling generated by La Niña (Roxy and others, 2014). Positive IOD events are generally characterized by anomalous cooling of SST in the southeastern equatorial Indian Ocean and anomalous warming of SST in the western equatorial Indian Ocean. However, IOD events are

often triggered by ENSO but can also occur independently, subject to eastern tropical preconditioning (Schott and others, 2009). The PDO is a long-term fluctuation of the Pacific Ocean that waxes and wanes between cool and warm phases in the central sub-arctic Pacific and along the North American continental shelf. This remote phenomenon imparts substantial decadal climate variability in the western Indian Ocean (Cole and others, 2000, Mahongo 2014).

At sub-seasonal timescales, the meteorology of the WIO is also characterised by significant variability, the dominant mode being associated with the Madden Julian Oscillation (MJO). This mode describes a large-scale, eastward propagating signal in the winds, convection and pressure fields on a timescale of 30-60 days (Slingo and others, 2005). It has a strong influence on both the meteorology of the Indian Ocean and the evolution of the coupled ocean-atmosphere system in the tropical Pacific (Slingo and others, 2005). As part of the planet's Warm Pool, tropical cyclone activity is an important feature of the meteorology of the WIO region. It is more pronounced during austral summer, particularly over the southwest Indian Ocean.

The growth and survival of marine organisms and plants depend on many variables such as temperature, dissolved oxygen, irradiance, calcium carbonate saturation, turbidity, sedimentation, salinity, pH, and nutrients. Consequently, some of the life forms occur only in selected areas of the world's oceans. Whereas meteorological processes can alter these variables, climate processes and extremes can influence the physiological processes responsible for their growth and survival. For instance during the 1998 ENSO event, which caused the strongest oceanic warming in recorded history, many of the coral reefs around the globe suffered high coral mortality due to bleaching, with the WIO region registering the highest mortality (Ateweberhan and McClanahan 2010). Generally, coral bleaching follows anomalously high seawater temperatures, usually interacting with high levels of irradiation.

PART II: OVERVIEW OF SOCIAL, CULTURAL AND ECONOMIC CHARACTERISTICS OF COASTAL COMMUNITIES

Introduction

The coastal communities, residents of the ten states making up the WIO region, comprise a population with a rich and varied political history, cultural heritage, tradition and other social and economic features that together render the region a fascinating amalgam whith unique challenges for coastal and marine environmental management. The recent successful exploration of oil and gas, which give the region increasing potential for social and economic growth, illustrate the pressing need for the states and people to maintain the delicate balance between environmental management and economic pursuits for people's wellbeing (PWC 2014, UNEP 2012). Pertinent issues include the region's ability to govern its resource wealth in an inclusive process to allow for poverty reduction and the achievement of the Millennium Development Goals (MDGs) among other things. This chapter makes an overview of the key social, cultural and economic characteristics of coastal communities in the WIO region that have an implication on the state of the environment, but also inform management practices.

The people of the region

The WIO region includes the dwelling sites of one of the earliest residents of Earth, evidenced by the most significant and oldest paleoanthropological finds in the world. Among these is the existence of hominids belonging to earlier species of the genus *Homo* (the same genus of modern humans – *Homo sapiens*) whose remains were found in Olduvai Gorge, Tanzania, by Dr Leakey (Morell 1995). One of these hominids was named *Homo habilis*, and its remains are dated from 1.85 to 1.6 million years ago. Traces of early people have also been found in the coastal areas of Kenya, Mozambique and on the west coast of South Africa including in the coastal caves at Klasies River from where traces of *Homo sapiens* were dated to more than 60 000 years (Sinclair and Richmond 2011).

The unique composition of the people is a development of the region's rich history of connections with the trade networks throughout the Indian Ocean and Mediterranean Sea, and colonialism since the 1st century. The multiple interactions of people from various continents, Arabia, India, Europe, China and other places who mingled and intermarried with the native residents of the region generated the current cultural and ethnic diversity of the region. For the island states, particularly Comoros, Madagascar, Mauritius, Reunion and Seychelles, the cultural diversity is even more special given their history of plantation economies, serviced by a large number of African slaves and Indian labourers. This gave rise to the development and co-existence of a multiple of traditions from heterogeneous

backgrounds. The evolution of the Creole languages in Mauritius and Madagascar for example, are strongly linked to the resistance by the largely subordinated and enslaved populations to having their traditional cultures subsumed (Selvon and Anata 2012). Similarly, along the East African coast, the Swahili language emerged between the 10th and 14th centuries as the *lingua franca* of the coastal people from southern Somali to northern Mozambique, existing alongside several other local dialects (Sinclair and Richmond 2011). Swahili remains dominant even as globalization makes an impact on the lives of coastal East Africa (Caplan and Topan 2004). Life-long endeavours associated with the ocean have given coastal people a proud sense of identity, as shown by the 'Vezo' people of western Madagascar who refer to the term 'Vezo' to identify people who struggle with the sea and live on the coast (Astuti 1995). The interaction of multiple cultures and people results in the rich and fascinating cultural heritage witnessed today, with "numerous religions, languages, architecture, farming and fishing techniques, boat building practices and other activities" of the people in this region (Sinclair and Richmond 2011).

Current Population sizes and growth

Countries in the WIO region are characterized by high population growth rates, largely attributed to natural growth. Population densities and growth rates in the region vary, particularly between mainland countries and the island states with the exception of Madagascar. The mainland states of Kenya, Tanzania, and Mozambique including Madagascar have growth rates of above 2.0 per cent per year. South Africa, the mainland country with the largest land mass has one of the lowest growth rates (Table 1.1). The pace of population growth in the small island states, while not as significant is however posing one of the biggest challenges to the sustainability of coastal ecosystems because of the high population density and its spread into marginal, environmentally delicate areas. In Reunion for example, it is estimated that the population between 2000 and 2010 grew by 15 per cent and could likely reach over one million by 2020 (Marie and Rallu 2012). The combined population of WIO states in 2014 is estimated to be 212.6 million and expected to double by 2050 as shown in Table 1.1.

Tanzania's population growth rate for 2014 is comparatively the highest in the region, followed by Madagascar and Mozambique, while South Africa and Mauritius are estimated to experience a decrease in population growth by the year 2050 (UN 2012). Population densities are quite high in Comoros, Mauritius and Seychelles as shown in

Table 1.1. Trends in population sizes and growth in the WIO region

S. No	Country	Population sizes and growth (000)									Density (km²) *****
		Size land area (km²)	1950 **	2014* (mid)	2025 **	2050 ***	Growth rates 2010 ****	Growth rates 2013*	Rank 2014 ***	Growth rates 2014 ***	
1	Comoros	2,170	.73	0.7	1.3	1.9	2.6	1.97	62	1.87	395
2	Kenya	582,650	6.2	43.2	44.9	81.3	2.7	2.27	47	2.11	78
3	Madagascar	587,040	4.2	22.4	30.7	52.8	2.8	2.65	25	2.62	39
4	Mauritius	2,040	.49	1.3	1.37	1.4	0.3	0.68	148	0.66	639
5	Mozambique	801,590	6.2	25.1	28.0	63.5	2.6	2.44	34	2.45	33
6	Reunion	2,517	.24	0.9	.91	1.0	-		-		-
7	Seychelles	455	.34	0.1	.11	0.14	0.9	0.90	129	0.87	194
8	Somalia	637,657	2.26	10.8	21.2	27.1	2.6	1.67	70	1.75	17
9	South Africa	1,219,912	13.7	53.7	43.77	64.1	1.3	-0.45	222	-0.48	44
10	Tanzania	946,087	7.88	50.8	60.4	129.4	2.9	2.82	18	2.80	56
	Total		**-**	**212.6**	**-**	**422.64**					

* CIA World Factbook (2014): www.cia.gov/library/publications/resources/the-world-factbook/
** UNFPA (2002)
*** World population prospects: the 2012 revision (Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, 2013): esa.un.org/wpp/
**** HDI Reports (UNDP 2014): hdr.undp.org/en/countries
***** World Bank (IBRD-IDA): worldbank.org/indicator/EN.POP.DNST

Table 1.1. The same is the case for the two islands of Zanzibar (Unguja and Pemba) in Tanzania where a similar high density pattern exists with an average population density of 530 people per km$^{2.}$

Coastal populations

The concentration of populations within coastal areas has increased due to rural-urban migration, with people attracted to the more urbanized and economic centres of the region. Nevertheless, the population density is varied among the states, where "a third of both Mozambicans and South Africans and a quarter of Tanzanians live by the coast, whereas vast tracts of coastal Somalia are almost entirely uninhabited" (Francis and Torell 2004). For the four island states, as illustrated by Table 1.2, there is virtually minimal distinction between coastal and inland populations because of their geographical sizes, except for Madagascar which has a large interior.

With the exception of Kenya, it is expected that by 2020, the mainland countries will have about 50 per cent of their populations living within the coastal zone. The rate of population growth in the Kenyan coastal province is 2.9 per cent almost equivalent to the national rate of 3.0 per cent (Government of Kenya 2009). A significant size of the population in WIO nations is concentrated in coastal urban settlements, which are often national administrative capitals (eg Mogadishu, Dar es Salaam, Maputo, Port Louis) and/or major port cities (Durban and Mombasa). Three African cities - Dar es Salaam, Khartoum and Abidjan - are projected to reach megacity status within a generation from now (UNHABITAT 2014: unhabitat.org/the-state-of-african-cities-2014/, see also Chapter 29). Durban is the second most important manufacturing hub in South Africa (after Johannesburg) and a major centre of tourism, similar to Mombasa and Zanzibar.

The economies in the region

Between the period 2012 and 2014, economies in the WIO region demonstrated some vibrancy, albeit at different rates, gauging from the IMF's estimated African growth of 4.3 per cent and sub-Saharan average growth of 5.5 per cent for 2013. Significant growth rates were experienced by Mozambique, Tanzania, Reunion and Kenya, with the rest having modest growth. Somalia has also shown satisfactory promise, although remains significantly affected by the persistent civil strife. The main drivers of growth reflect some similarities, with areas of significance being the extractive, construction and services sectors, the latter also related to the tourist industry. Policy reforms supporting foreign direct investments (FDI) have enhanced growth, focusing particularly on the extractive industry.

Mozambique's economy has been one of the most dynamic in the region with a 7 per cent rate of real gross domestic product (GDP) growth in 2013 (Table 1.3) and a forecasted growth to 8 per cent for 2014 and 2015 (Almeida-Santos and others, 2014). The economy of Tanzania has also been growing at a significant rate of around 7 per cent for the year 2013 (Table 1.3), driven largely by communications, transport, financial intermediation, construction, mining, agriculture and manufacturing. The potential for further growth is seen in investments in infrastructure, efforts to stabilize power generation, fiscal reforms and the recently discovered natural gas reserves. Kenya on the

Table 1.2. Total population size versus coastal populations. *Sources*: UNEP (2009), CIA World Factbook (2014): www.cia.gov/library/publications/resources/the-world-factbook/.

COUNTRY	Population (mid-2014) in millions	Percentage of Population living along the coast
Comoros	0.7	100
Kenya	43.2	8
Madagascar	22.4	34
Mauritius	1.3	100
Mozambique	25.1	70
Reunion	0.9	100
Seychelles	0.1	100
Somalia	10.8	55
South Africa	53.7	40
Tanzania	50.8	25

Table 1.3. Trends in GDP Growth – 2013-2015. *Source*: Almeida-Santos and others, 2014, Charle and others, 2014, Dabire and Bi 2014, Dualeh 2014, Mpande and Kannan 2014, Odero and Reeves 2014, Phiri and Kannan 2014.

Country	Real GDP Growth			Percentage of GDP for some Sectors (2012/2013)			
	2013e	2014e	2015p	Fishing	Mining	Construction	Hotels and restaurants
Comoros	3.6	3.8	4.1	-	-	2.6	-
Kenya	4.9	5.7	5.9	0.5	0.8	4.7	0
Madagascar	2.5	3.7	5.4		0.3	3.5	-
Mauritius	3.3	3.5	4.1	-	0.3	5.5	6.6
Mozambique	7.0	8.5	8.2	1.9	2.4	3.2	1.6
Reunion	-	-	-	-	-	-	-
Seychelles	3.5	3.6	4.3	0.9		4.8	24.0
Somalia	-	-	-	-	-	-	-
South Africa	1.9	2.7	3.0	0.1	9.6	3.7	1.0
Tanzania	7.0	7.2	7.0	1.6	3.8	8.9	2.5
Africa	3.9	4.8	5.7	-	-	-	-

Key: e=estimates; p=projections.

other hand has experienced moderate growth of 4.4 per cent in 2011 and 4.2 per cent in 2012 (Odero and Reeves 2014) and was expected to reach 4.9 per cent in 2013 and 5.9 per cent in 2014 (see Table 1.3).

Economic growth in Comoros was estimated at 3.6 per cent in 2013 (Table 1.3) and driven mainly by the agricultural sector (agriculture, fisheries and forestry), representing almost half of GDP, as well as retail, tourism, construction, banking and other services (Diabate and Meddeb 2014). The extractive industry in Madagascar has supported the country's growth, which has nevertheless been slow, at 2.5 per cent in 2013 (Table 1.3) from a low of 1.9 per cent in 2012. Mauritius on the other hand experienced a slight slowdown in 2013 when real GDP growth rate slowed to 3.3 per cent (Table 1.3) from 3.4 per cent in 2012, caused by weak sugar and textile exports and a fall in construction (Phiri and Kanna 2014).

Somalia's 200 billion cubic feet (bcf) of proven gas reserves, as well as prospective oil fields in the northern zone and in the Nuggal and Dharoor basins, may eventually provide benefits to its people once peace is restored. Reunion's economy is mostly based on services (accounting for 82 per cent of added value) and secondarily on construction (9 per cent), industry (5 per cent) and agriculture (4 per cent). Over the last 40 years, the country has witnessed an annual growth rate of 5 per cent.

After a sharp collapse in GDP growth from 10.4 per cent in 2007 to -2.1 per cent in 2008, Seychelles' economy has rebounded with a real GDP growth estimated at 3.5 per cent in 2013 (Table 1.3), up from 2.8 per cent in 2012. Growth for South Africa has been sluggish, being 1.9 per cent in 2013 (Table 1.3) compared with 2.5 per cent in 2012. However, projections based on improvements to the global economy and the successful completion of major government projects (including the Medupi Power Station) suggest that growth could rise to 2.7 per cent in 2014. Despite lower than average growth figures compared to the East African countries, South Africa was ranked 3rd out of 148 countries in terms of financial market development by the 2013/14 Global Competiveness Report (Schwab 2013).

Coastal livelihoods and human wellbeing

Livelihoods of coastal people in the region have been evolving and changing in nature due to population changes, policy measures, global economic expansion and institutional linkages (such as to markets), resource conditions and poverty. Artisanal/small-scale fisheries is the main source of livelihood for many coastal communities. Other activities include tourism, agriculture, subsistence forestry, mariculture, small-scale mining (stone and sand quarrying, lime and salt production), petty trading, small livestock husbandry, trade in handicrafts, employment in services industry (including oil and gas production) and those associated with shipping and ports. Each activity faces general constraints due to capacity limitations, whilst reliance on the land to supplement incomes for coastal households is

being compromised because of the re-designation of land uses. This has come about due to a number of factors, including acquisition of land for tourism and large-scale economic investments such as port expansions, areas for economic promotion zones (EPZs) or large-scale plantations.

Poverty is also quite prevalent, as indicated by the performance of MDG goals, with only South Africa showing some promise. With respect to the MDG goals, many of the states in the WIO region have under-performed on most of the goals, with only Mozambique emerging as one of the three overall best performers in Africa by 2013 (UNECA 2013). Although other countries have improved their rate of progress, it has not been significant. In terms of the Human Development Index (HDI), Mauritius and Seychelles maintain the highest HDI records in the region and are ranked among those countries within the high (medium) Human Development Index level (see Table 1.4). In 2013, Seychelles was ranked 1st in terms of human development in Africa and has met most of the Millennium Development Goals (MDGs). South Africa is among those countries with medium HDIs, while the rest are among those countries with low HDIs.

The trends indicate that even though some countries registered increasing GDP rates, this does not automatically translate to high or improved HDI levels and ranking.

Gender and women's issues in the WIO region

The roles and responsibilities of men and women in the WIO region, their status and the relationship between them are evolving and responding to changing social, political and economic contexts and the opportunities or challenges confronting them. The same can be said of women's engagement in coastal and marine resource exploitation, which varies from country to country in the region, depending on traditions, supporting policy mechanisms and infrastructure. Women's traditional areas within the fisheries (eg gleaning, small shrimp catching, octopus harvesting) have in many places become contested because of competing technologies and use of space, increase in fisher populations and the expansion of the market for certain marine species, such as octopus and lobster. The resulting intensification of resource exploitation has sometimes led to the marginalization of women from pursuing viable livelihoods (Mwaipopo 2008). In contrast, the development of alternative production systems such as farming of seaweed, sea cucumbers, pearl oysters, and of crab culture and beekeeping have provided women with alternative livelihood opportunities that they can control (Samoilys and Kanyange 2008). Women are also increasingly present in coastal community based organisations (CBOs). Their involvement in these structures is seen as critical for enhancing resource management and effective participation.

Women's status in terms of general human development measured at the global level, as seen from the available Gender Inequality Index (GII) ratings of 2013, shows Mauritius and South Africa with the lowest gender inequality rates (see Table 1.5). Kenya has made some improvement in narrowing the inequality ratio between 2012 and 2013 with some achievements in reducing Maternal Mortality Rates (MMR) and Adolescent Birth Rates (ABR) and, increasing access of females to secondary education. Somalia, Mozambique and Tanzania have the highest MMR rates, the latter two dropping in their GII ratings between 2012 and 2013, as Table 1.5 illustrates.

Seychelles, South Africa, Mozambique and Tanzania

Table 1.4. Rank in Human Development Index and its components. *Source*: UNDP Human Development Reports (2014a).

HDI rank 2013	COUNTRY	HDI rank 2012	Life expectancy at birth (year) 2012	Mean years of schooling 2012	Expected years of schooling 2012	GNI per capita (2011 in US$) 2013
159	Comoros	169	60.9	2.8	12.8	1 505
147	Kenya	145	61.7	6.3	11.0	2 158
155	Madagascar	151	64.7	5.2	10.3	1 333
63	Mauritius	80	73.6	8.5	15.6	16 777
178	Mozambique	185	50.3	3.2	9.5	1 011
-	Reunion	NA	-	-	-	-
71	Seychelles	46	73.2	9.4	11.6	24 632
-	Somalia	Na	55.1			
118	South Africa	121	56.9	9.9	13.1p	11 788
155	Tanzania	152	61.5	5.1	9.2	1 702

Table 1.5. Gender Inequality Index (GII) ranking (2013). Sources: UNDP Human Development Reports (2014b), Gender Equality Index (UNDP): hdr.undp.org/en/content/table-4-gender-inequality-index

HDI	Country	2012 GII rank	2013 GII rank	2010 MMR ratio	ABR 2010-2015	Seats in parliament 2013	SE (F) 2005-12	SE (M) 2005-12	2012 LF part (F)	2012 LF part (M)
159	Comoros	-	-	280	51.1	3	-	-	35.0	80.2
147	Kenya	130	122	360	93.6	19.9	25.3	31.4	62.0	72,2
155	Madagascar	-	-	240	122.8	15.8	-	-	86.8	90.6
63	Mauritius	70	72	60	30.9	18.8	49.4	58	43.5	74.3
178	Mozambique	125	146	490	137.8	39.2	1.5	6.0	26.3	75.8
Nr	Reunion	-	-	-	-	-	-	-	-	-
71	Seychelles	-	-	-	56.3	43.8	66.9	66.6	-	-
Nr	Somalia			1000	110.4	13.8			37.2	75.6
118	South Africa	90	94	300	50.9	41.1	72.7	75.9	44.2	60
159	Tanzania	119	124	460	122.7	36	5.6	9.2	88.1	90.2
	SIDS	-	0.481	195	61.5	23	50.4	55.2	52.8	73.3
	SSA	-	--	474	109.7	21.7	21.9	31.9	63.6	76.3
	World	-	-	145	47.4	21.1	54.1	64.2	50.6	76.7

Key: MMR = Maternal Mortality Rate; ABR-Adolescent birth rate; SE (F) / SE (M) = Population with at least some secondary education, 25+; LF – Labour force participation rate, 15+.

have attained significant positions with respect to women's representation in leadership. All countries have committed themselves by law and ratification to international obligations such as the Committee on the Elimination of Discrimination against Women (CEDAW), established by the UN in 1982 to protect the rights of women, albeit in nominal form because women in the region still encounter inadequate access to key livelihood services as shown.

Emerging Issues and Policy responses

Coastal communities in the WIO region are experiencing many changes arising from increasing immigration, and widespread poverty affecting sizeable portions of the population, despite its vast economic potential. These changes are leading to cultural transformations and also challenging livelihoods. Important policy considerations include the following:

- Identifying mechanisms for preserving the positive aspects of the region's unique cultural heritage;
- Addressing rapid population growth and the high population densities which have a deleterious impact on marine and coastal environments in the region, including unplanned urbanization, over-exploitation of marine resources, pollution, and habitat destruction;
- Up-scaling education on and family planning awareness in combination with the enhancement of livelihood options; and,
- Addressing women's practical and strategic needs to enhance their status.

References

Almeida-Santos, A., Roffarello, L.M. and Filipe, M. (2014). *Mozambique 2014: African Economic Outlook*. AfDB, OECD, UNDP. OECD Publishing, Paris

Astuti, R. (1995). *People of the Sea. Identity and Descent among the Vezo of Madagascar*. Cambridge University Press, UK

Ateweberhan, M. and McClanahan, T.R. (2010). Relationship between historical sea-surface temperature variability and climate change-induced coral mortality in the western Indian Ocean. *Mar. Pollut. Bull.* 60(7), 964-970

Caplan, P. and Topan, F. (eds.) (2004). *Swahili Modernities: Culture, Politics, and Identity on the East Coast Of Africa*. Africa World Press. New Jersey, USA

Charle, P., Dhliwayo, R. and Loening, J. (2014). *Tanzania 2014: African Economic Outlook*. AfDB, OECD, UNDP. OECD Publishing, Paris

Cole, J.E., Dunbar, R.B., McClanahan, T.R. and Muthiga, N.A. (2000). Tropical Pacific forcing of decadal SST variability in the Western Indian Ocean over the past two centuries. *Science*, 287(5453): 617-619.

Dabire, J.M.V. and Bi, S.Z. (2014). *Madagascar 2014: African Economic Outlook*. AfDB, OECD, UNDP. OECD Publishing, Paris

Diabate, A. and Meddeb, R. (2014). *Comoros 2014: African Economic Outlook*. AfDB, OECD, UNDP. OECD Publishing, Paris

Dualeh, A. (2014). *Somalia 2014: African Economic Outlook 3*. AfDB, OECD, UNDP. OECD Publishing, Paris

Francis, J. and Torell, E. (2004). Human dimensions of coastal management in the Western Indian Ocean region. *Ocean Coast. Manag.* 47, 299-307.

Government of Kenya (2009). *State of the coast report: Towards integrated management of coastal and marine resources in Kenya*. National Environment Management Authority (NEMA), Nairobi

Mahongo, S.B. (2014). Analysis of met-ocean processes in relation to changes in large scale climatic systems in Tanzania and the western Indian Ocean. PhD Thesis, University of Dar es Salaam

Marie, C.V. and Rallu, J.L. (2012). *Demographic and migration trends in the outermost regions: Impacts on territorial (and) social cohesion*. Executive Summary: Martinique. Institut National D'Etudes Demographiques

Morell, V. (1995). *Ancestral Passions: The Leakey Family and the Quest for Humankind's Beginnings*. New York, Simon & Schuster

Mpande, S. and Kannan, A. (2014). *Seychelles 2014: African Economic Outlook*. AfDB, OECD, UNDP. OECD Publishing, Paris

Muths, D., Tessier, E. and Bourjea, J. (2014). Genetic structure of the reef grouper *Epinephelus merra* in the West Indian Ocean appears congruent with biogeographic and oceanographic boundaries. *Mar. Ecol.*

Mwaipopo, R.N. (2008). *The Social Dimensions of Marine Protected Areas: A Case Study of the Mafia Island Marine Park in Tanzania*. Samudra Monograph. International Collective in Support of Fishworkers

Obura, D. (2012a). Evolutionary mechanisms and diversity in a western Indian Ocean center of diversity. In *Proceedings of the 12th International Coral Reef Symposium, Cairns, Australia* (eds. D. Yellowlees and T. P. Hughes) vol. 3, pp. A2. James Cook University, Australia

Obura, D. (2012b). The diversity and biogeography of Western Indian Ocean reef-building corals. *PloS ONE* 7(9), e45013

Obura, D.O., Church, J.E. and Gabrié, C. (2012). *Assessing Marine World Heritage from an Ecosystem Perspective: The Western Indian Ocean*. World Heritage Centre, United Nations Education, Science and Cultural Organization (UNESCO)

Odero, W.O. and Reeves, W. (2014). *Kenya 2014: African Economic Outlook*. AfDB, OECD, UNDP. OECD Publishing, Paris

Parson, L.M. and Evans, A.J. (2005). Seafloor topography and tectonic elements of the Western Indian Ocean. *Phil. Trans. R. Soc. A* 363(1826), 15-24

Phiri, M. and Kannan, A. (2014). *Mauritius 2014: African Economic Outlook*. AfDB, OECD, UNDP. OECD Publishing, Paris

PWC (2014). *On the Brink of a Boom. Africa Oil and Gas review*. Report on current developments in the oil and gas industry in Africa. July 2014. South Africa. http://www.pwc.co.za/en/publications/oil-and-gas-survey.jhtml

Roxy, M.K., Ritika, K., Terray, P. and Masson, S. (2014). The curious case of Indian Ocean warming. *J. Clim.* 27(22), 8501-8509

Samoilys, M. and Kanyange, M.L. (2008). *Assessing links between marine resources and coastal peoples' livelihoods: perceptions from Tanga, Tanzania*. CORDIO/IUCN

Samoilys, M., Pabari, M., Andrew, T., Maina, G.W., Church, J., Momanyi, A., Mibei, B., Monjane, M., Shah, A. and Mutta, D. (2014). *Resilience of Coastal Systems and Their Human Partners in the Western Indian Ocean*.

Schott, F., Xie, S.P. and McCreary, J.P. (2009). Indian Ocean circulation and climate variability. *Rev. Geophys.* 47, 1–46

Schwab, K. (ed.) (2013). *The Global Competitiveness Report 2013–2014: Full Data Edition*. Insight Report. World Economic Forum

Selvon. S and Anata, A. (2012). *A New Comprehensive History of Mauritius: From British Mauritius to the 21st Century*. Sydney Selvon Publisher

Sinclair, P. and Richmond, M. (2011). People of the Coast. In *A Field Guide to the Seashores of Eastern Africa and the western Indian Ocean Islands* (ed. Richmond, M.D.) 3rd edition. SIDA/WIOMSA

Slingo, J., Spencer, H., Hoskins, B., Berrisford, P. and Black, E. (2005). The meteorology of the Western Indian Ocean, and the influence of the East African High-

lands. *Phil. Trans. R. Soc. A* 363(1826), 25-42

Spencer, T., Laughton, A.S. and Flemming, N.C. (2005). Variability, interaction and change in the atmosphere–ocean–ecology system of the Western Indian Ocean. *Phil. Trans. R. Soc. A* 363(1826), 3-13

UN (2012). United Nations Department of Economic and Social Affairs/Population Division. *World Population Prospects: The 2012 Revision, Highlights and Advance Tables*. Paper No. ESA/P/WP.228.

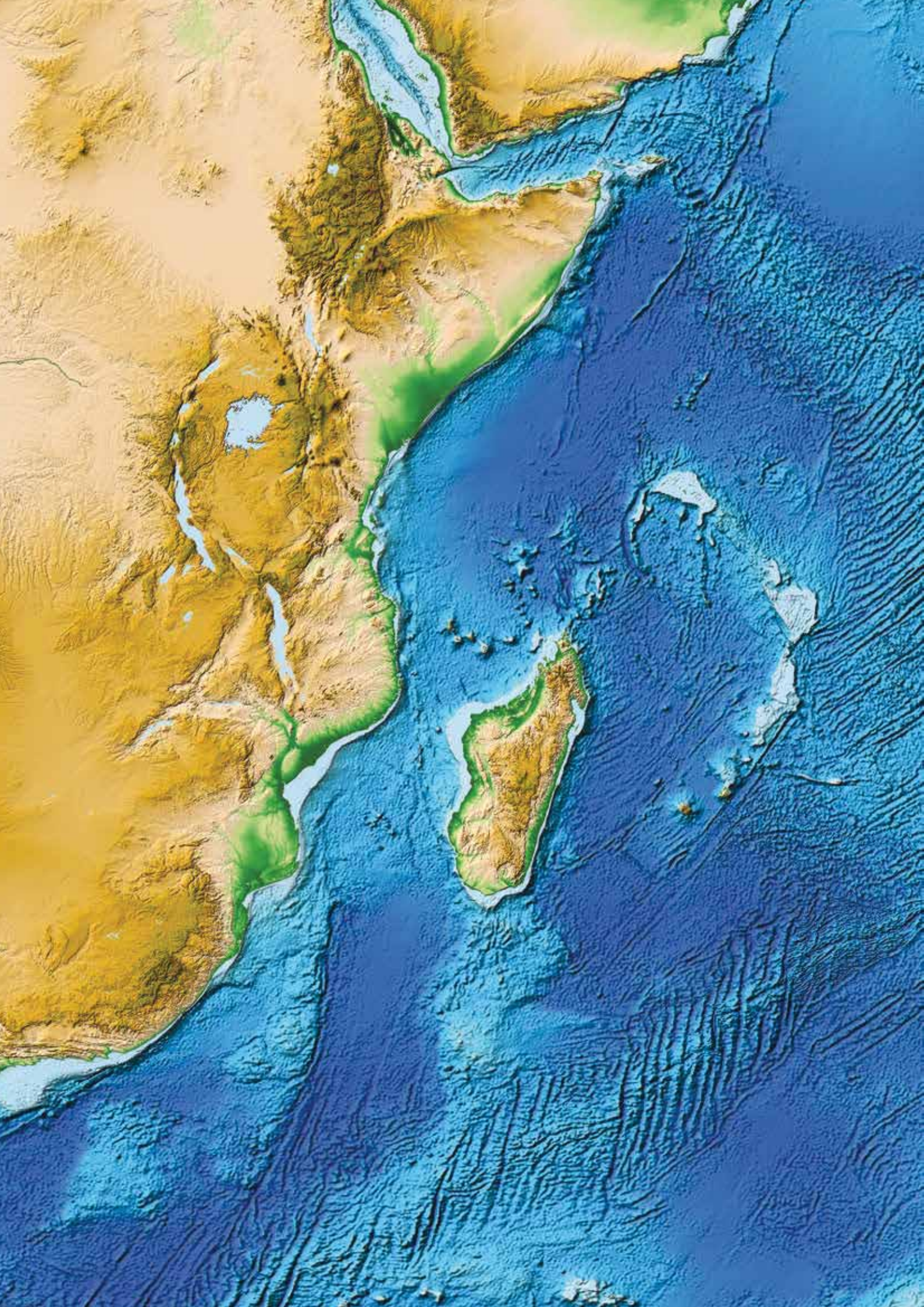
UNDP Human Development Reports (2014a). *Sustaining Human Progress: Reducing Vulnerabilities and Building Resilience*. UNDP. http://hdr.undp.org/en/content/human-development-index-hdi-table

UNDP Human Development Reports (2014b). *Sustaining Human Progress: Reducing Vulnerabilities and Building Resilience*. UNDP. http://hdr.undp.org/en/content/average-annual-population-growth-rate

UNECA (2013). *Assessing Progress in Africa towards the Millennium Development Goals*. MDG Report 2013. Food security in Africa: Issues, challenges and lessons. UNDP. United Nations Economic Commission for Africa. African Development Bank Group, African Union

UNEP (2012). *Oil and Gas Exploration in the South Western Indian Ocean region*. Conference paper. The Seventh Meeting of Contracting Parties to the Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Western Indian Ocean (Nairobi Convention). Maputo, Mozambique 10-14 December. UNEP(DEPI)/EAF/CP.7/Inf/11

UNFPA (2002). UNFPA at work 2001. United Nations Population Fund, New York



2
Mandate and Methodology

Julius Francis

Opposite page: Relief model of the WIO surface that integrates land topography and ocean bathymetry. © Amante and Eakins/ National Geophysical Data Center, NOAA (2009)

The Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Eastern African Region (Nairobi Convention), comprises five mainland states (Somalia, Kenya, Tanzania, Mozambique and South Africa) and five island states (Seychelles, Comoros, Madagascar, Mauritius and France (Reunion). The Convention provides a framework for regional cooperation in the protection, management and development of the region's marine and coastal environment, for sustainable socioeconomic growth and prosperity. Amongst others, the Convention, more specifically:

- **Offers a legal framework and coordinates** the efforts of the countries in the region to plan and develop programmes for strengthening their capacity to protect, manage and develop their coastal and marine environment;
- **Provides a forum for inter-governmental discussions** that lead to better understanding of regional environmental problems and the strategies needed to address them;
- **Promotes the sharing of information and experiences** amongst countries in the WIO region and with the rest of the world; and
- **Facilitates the periodic assessment** by the WIO countries of the state of coastal and marine environment.

The Regional State of the Coast Report (RSOCR) for the WIO is the first comprehensive report of its kind for the region. Beyond providing a good description of the coastal and marine environment of the region, the report is designed to enable the Convention Secretariat meet a statutory obligation to assess periodically the state of the environment in the region. In addition, it meets other broader obligations by providing a basis for not only understanding the environmental concerns among states and strategies required to address them, but also outlines the opportunities that can be harnessed by sharing information and experiences amongst countries and with the rest of the world. Ultimately the Regional State of the Coast Report will lead to enhanced capacities of the WIO countries to protect, manage and develop their coastal and marine environment, using the best available information.

OBJECTIVES OF THE REPORT

The first Authors' Workshop for the WIO RSOCR that was held in Maputo, Mozambique, in April 2013, amongst others things, discussed the methodology and the outline of the Report. The workshop also discussed and agreed that the main objectives of the report are to:

i) Provide a comprehensive baseline on the status of coastal and marine environment in the WIO region;

ii) Highlight main opportunities of coastal and marine resources;

iii) Describe successes and challenges faced in management of coastal and marine resources;

iv) Identify main capacity building needs;

v) Identify existing knowledge gaps; and,

vi) Propose policy options for effective management of coastal and marine resources.

For purposes of trend analysis, 1985 was set as the baseline year. This was the year the Nairobi Convention was approved by the countries of the Region. For scenario analysis, 2050 was set as the reference year.

For the purpose of this report, its geographical coverage is limited to the region or area for which the Convention and its protocols apply. The Nairobi Convention Act (Amended 2010) defines the Convention area to "comprise the riparian, marine and coastal environment including the watershed of the Contracting Parties".

The workshop also agreed on the main target audience for the report as policy-makers at national and regional levels, scientific community, civil society and the general public. The report is expected to serve as reliable source of information for policy-making and environmental management, provide materials for educational and research activities, and provide the basis for identification of new research priorities.

MANDATE

The production and submission of the first comprehensive RSOCR to the Meeting of the Contracting Parties to the Nairobi Convention to be held in June 2015 in the Seychelles, is in line with the requirements of the Convention. Additionally, the report provides an important link and contribution to the global processes such as the UNEP-led production of the GEO-6 and the United Nations-led production of the World Ocean Assessment reports.

In December 2012, the countries of the WIO at their Seventh Meeting of the Contracting Parties to the Nairobi Convention, decided to facilitate and organize regional meetings of experts for the purpose of exchanging and consolidating information that will lead to a State of the Coast Report for the WIO region. The Parties decided that the State of the Coast Report for the WIO region should be prepared in a manner that contributes to the United Nations Regular Process on preparation of the first integrated World Oceans Assessment report.

In Article 18 of the Nairobi Convention (Amended 2010) Contracting Parties are obliged to meet biannually to amongst others 'assess periodically the state of the environment in the Convention Area'. However, Article 18 does not describe how such an assessment will be conducted.

Over the years, there have been attempts by countries of the region to individually prepare status reports. However, the reports have been sector based, the consequently the methodologies and the reports themselves were often not comparable. As a result, a regional report of the state of coastal and marine environment in the WIO region has never been prepared.

The Convention has supported the preparation of different types of national reports, and in 2010 under the GEF/UNEP Project entitled "Addressing land-based Activities in the Western Indian Ocean" (WIO-LaB Project), numerous State of Coast reports, specifically on Land-based Sources and Activities in the WIO, were prepared. However, none of these and other previous similar efforts led to the production of an integrated Regional State of the Coast Report on both socio-economic and ecological systems for the WIO region.

Most countries in the WIO region have a statutory obligation to report on the state of the environment. For instance in Kenya, the Environment Management and Coordination Act, 1999, stipulates under Section 9(2)(p) that the National Environment Management Authority shall prepare and issue an annual report on the state of the environment. Section 175(1) of the Tanzania Environment Management Act of 2004 requires the Director of Environment to publish the report of the state of the environment and environment management for submission to the National Assembly every two years. The preparation of a periodic state of the coast report is also a requirement in the Tanzania National Integrated Coastal Environment Management Strategy. In South Africa, under the Integrated Coastal Management Act of 2008, in Section 93(3), the Minister responsible is required to prepare and regularly update the national report on the state of the coastal environment.

The RSOCR has been based on national state of environment reports where they exist. Further, the regional status report provides a basis for cooperation among environment regulatory frameworks, responsible national institutions and departments to periodically produce a state of coast report at the national level using similar approaches to assess and to manage trans-boundary resources.

One of the key mandates of the United Nations Environment Programme (UNEP) is to assess global, regional and national environmental conditions and trends. In pursuit of this, UNEP coordinates the production of global and regional environment outlooks on a regular basis. These reports present the state, trends and outlook of the environment through an integrated approach that recog-

nizes the interlinkages between the environmental, social and economic dimensions of development. The process to produce the Sixth edition of the Global Environment Outlook (GEO-6) commenced in October 2014. The regional reports resulting from this process will be launched in 2016, while the global report, which will draw from these and other integrated and thematic assessments as appropriate, will be released in 2017.

At the World Summit on Sustainable Development held in Johannesburg, South Africa, in 2002, the member states agreed, in paragraph 36 (b) of the Johannesburg Plan of Implementation (JPOI), to "establish by 2004 a regular process under the United Nations for global reporting and assessment of the state of the marine environment, including socio-economic aspects, both current and foreseeable, building on existing regional assessments". This decision was reaffirmed in Rio + 20 Outcome document, 'The future we want' paragraph 161. Through the Regular Process, the United Nations was mandated to periodically produce the first World Ocean Assessment (WOA) report, which is scheduled to be launched in 2015.

In recognition of the potential contribution to the first World Ocean Assessment, the meeting of the Focal Points to the Nairobi Convention held in Maputo, Mozambique, in August 2012 recommended the production of the Regional State of the Coast Report that is clearly linked to other global processes and products, but more specifically to the World Ocean Assessment report.

METHODOLOGY

The process

Preparation of the RSOCR involved two parallel but complementary processes, namely; a technical process of selecting the best available regional experts as the contributing authors and for the review process to collect, document and collate the most relevant, credible and up to date data and information; and a political process to mobilize national support at the policy level, as well as of the regional scientific community through capacity building workshops.

The Nairobi Convention Secretariat and UNEP's Division of Early Warning and Assessment (DEWA) in collaboration with the Government of Mozambique and the Division for Ocean Affairs and the Law of the Sea of the Office of Legal Affairs of the United Nations (UN/OLA/DOALOS) organized two capacity building workshops in August and December 2012 in Maputo, Mozambique. These workshops were attended by the National Focal Points of the Nairobi Convention and selected scientists from the region. The aim of the workshops was to provide a background to the Regular Process; improve skills and knowledge for conducting integrated assessments of the state of coastal and marine environment; and to introduce a uniform assessment methodology. The workshops presented to the authors the Drivers – Pressures – State – Impact – Response (DPSIR) methodology to be used as a basis for analysis. They also introduced the "opportunities framework" as an underlying theme to be used in the report preparation process. This framework enables appropriate focus to be placed on the need to value, protect and enhance the remaining assets within the coastal and marine environment, rather than dwell on reporting what has already been lost (see Figure 2.1). The capacity building workshops were also used to build consensus on the structure and content of the final report including an agreement on the use of the WOA framework as the basis for preparing the RSOCR. Furthermore, the meetings also made two clear distinctions that set the RSOCR and WOA apart through recommending the inclusion of chapters focusing on governance and policy options, scenario setting and recommendations. The capacity building workshops also played a key role in galvanizing support for the process amongst the government officials and the regional scientific community.

The process for preparation of the RSOCR from its conceptualization to finalization was presented to Contracting Parties at the Seventh Meeting of the Contracting Parties (COP7) and in four meetings of the National Focal Points (Figure 2.2). The COP7 decision provided the political support and mandate for initiation of the report preparation process, whilst the Focal Points meetings were used to report on the progress being made and to provide any further essential guidance. The RSOCR was prepared with the full participation and support of the policy organs of the Convention.

The technical process on the other hand was guided by WIOMSA as the coordinating institution. WIOMSA was appointed to this role by the Nairobi Convention Secretariat because of its multidisciplinary membership, extensive network of regional scientists and broad experience and good reputation in designing and implementing large regional projects/programs.

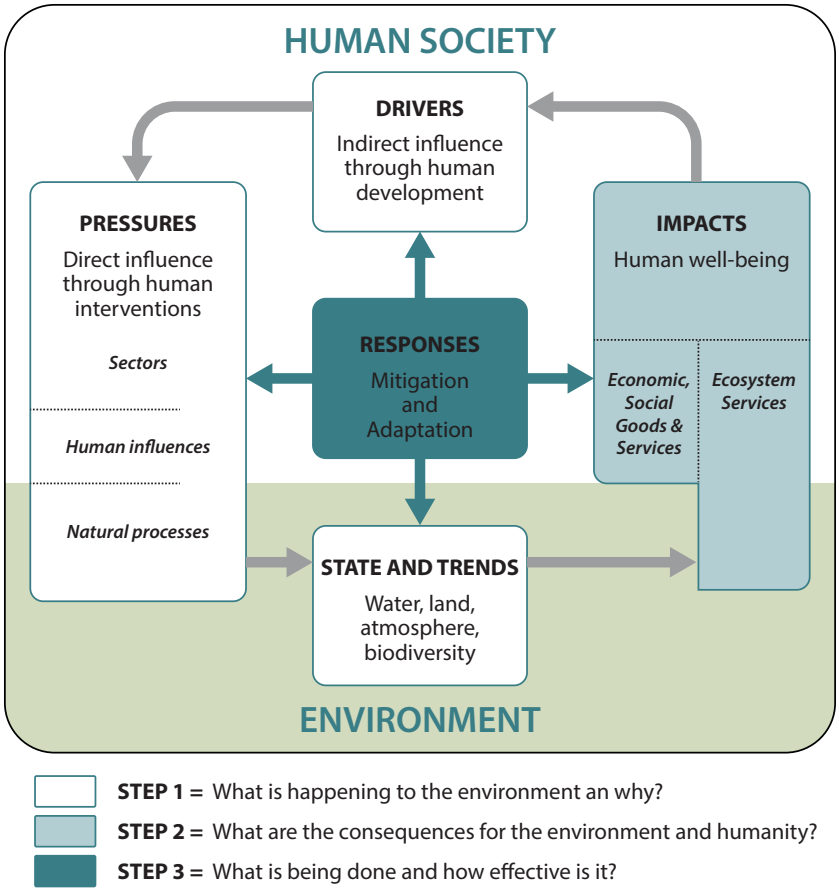


Figure 2.1. The DPSIR Analytical Framework (UNEP 2011).

The Nairobi Convention Secretariat and WIOMSA issued a "Call for Expression of Interest" to participate in the development of the RSOCR. Over 50 regional scientists from all the countries, except Somalia and Comoros, expressed interest to be involved. Based on their CVs, their publishing and reporting record, and their availability to fully engage with the process, the final list of 29 authors was prepared.

Four Authors Meetings were organized during the preparation of the report. The first one was held in Maputo, Mozambique, in April 2013 and focused on introduction of the authors to the process and methodology to be used to develop the report. It was also used to develop the report outline, identify sources of data and information, provide an opportunity for different actors involved in the process to interact and agree on timelines for the process. In the second and third meetings, the emphasis was placed on agreeing on the final structure of the report, identification of visual and graphics needs, facilitation of scenario building and development of policy options, and management of the internal and the external chapter review processes. Analysis of balance and consistency and final report, including its layout, were the main issues discussed in the last Authors Meeting held in May 2015 in Nairobi, Kenya.

Organization structure

Preparation of the RSOCR involved several experts and organizations, including the following:

i) The Contracting Parties and the Focal Points to the Convention. Provision of the mandate, political support and framework for preparation and approval of the report.

ii) The Nairobi Convention Secretariat. The Secretariat provided leadership and financial resources for preparation of the report as well as oversaw the process. It also organized and financially supported the capacity building workshops, Focal Points meetings, the Meeting of the Contracting Parties and Authors Meetings.

iii) WIOMSA. WIOMSA coordinated the technical process of preparing the report, selected and recruited the Editor, Lead authors, authors and researchers and sup-

ported the organization of the Authors Meetings.

iv) UNEP's Division of the Early Warning and Assessments (DEWA). Based on its experience in preparation of global and regional environment outlooks, provided technical support to the whole process. It also contributed financial resources to the process.

v) Editor. The editor played a dual role of supervising the overall technical and style editing of the report and synthesizing the main messages from the report and writing the Parts I (Summary) & VIII (Overall assessment).

vi) Lead authors. Each lead author oversaw the work of the contributing authors in their respective Parts. Each part had three or more chapters written by different contributing authors. Lead authors ensured that they were technically sound and consistent with the recommended guidelines. They were also responsible for writing the Conclusion chapters under their Parts.

vii) Contributing Authors. These were responsible for at least one chapter.

viii) Researchers. WIOMSA selected emerging scientists to assist the Lead authors and authors particularly in undertaking research on specific issues, collecting and compiling data and information needed for specific topic.

Each Chapter was reviewed by at least two external reviewers, who checked and confirmed the adequacy of the chapter in terms of form and contents; accuracy and completeness of facts and information presented, including accuracy of references cited and listed. The appropriate

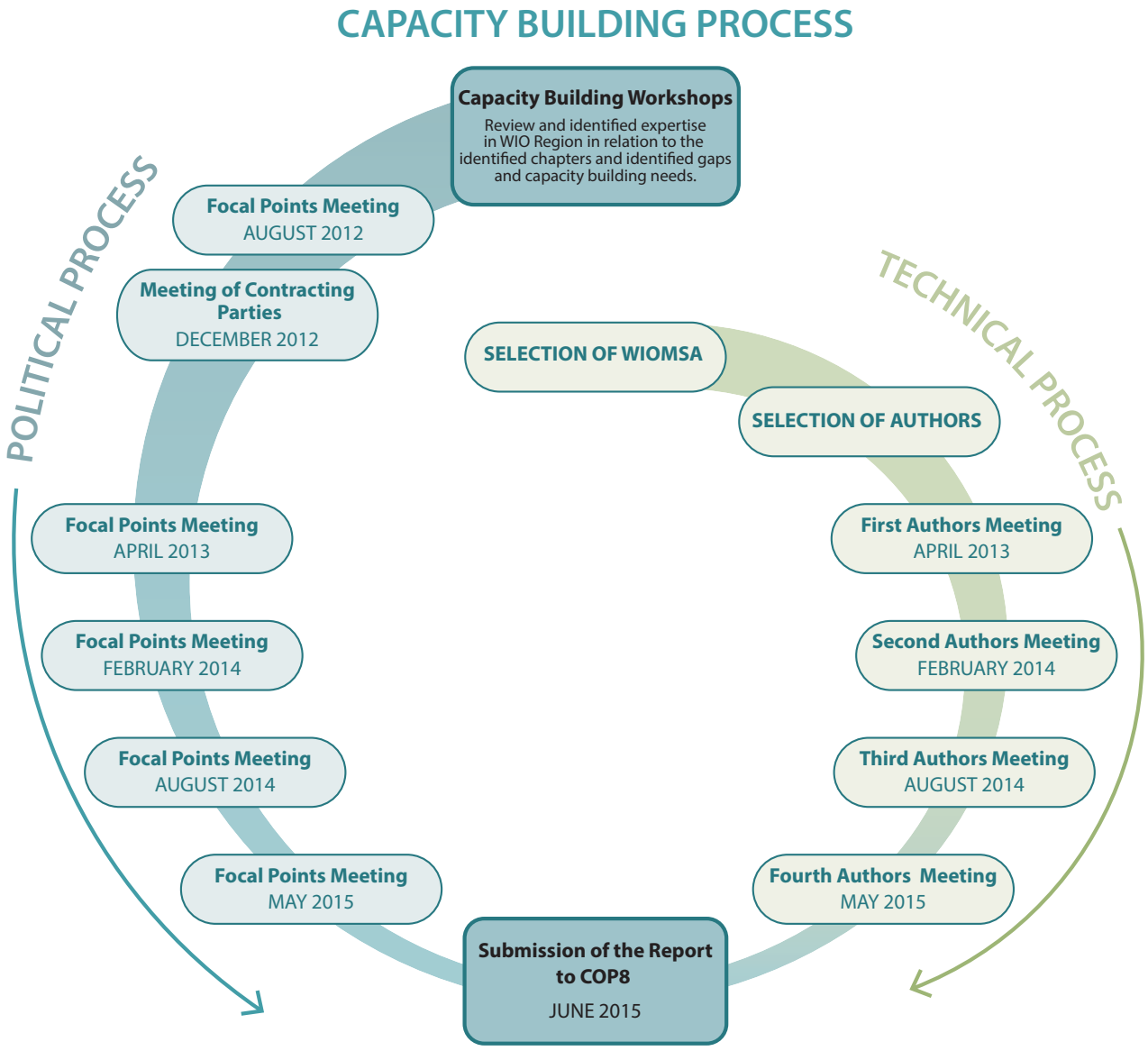


Figure 2.2. Description of the process for development of the RSOCR.

and correctness of language and grammar used as well as consistency of format and presentation for the chapters were checked by the Language Editor.

The production of RSOCR was widely participatory and inclusive of a wide range of expert analysis and opinion. The process has been enriched with inputs from different meetings of the organs of the Convention, UNEP and the Convention staff, involved authors and external reviewers. The RSOCR reflects the commitment and interests of a wide range of stakeholders who ensured it was more than a comprehensive baseline of the status of coastal and marine environment in the WIO region, but also provides policy options and future scenarios for effective management of coastal and marine resources in the WIO region.

References

UNEP (2011). Integrated Environmental Assessment Training Manual. United Nations Environment Programme. http://www.iisd.org/publications/integrated-environmental-assessment-training-manual

Part III
Assessment of Marine Biological Diversity and Habitats

Michael H. Schleyer

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3
Introduction – Biodiversity

Michael H. Schleyer

Opposite page: Diversity of sea star colours at Inhaca Island, Mozambique. © José Paula.

While biodiversity is most simply defined by the Oxford dictionary as the variety of plant and animal life in the world or in a particular habitat, it is given greater complexity within certain disciplines. It can be viewed quite differently, for example, if one considers species diversity not from the more classical approach, but rather according to genetic diversity, where the variation within species at the molecular level is also considered, or ecosystem diversity, in which the same matrix of species can result in different biotopes under different environmental conditions. In the latter case, processes and species interactions within the ecosystem enter consideration, along with species diversity itself.

The importance of biodiversity is manifold. The popular concept of its importance is that the diversity of life in our environment enriches our lives, provoking the sentiment that it should be preserved in perpetuity so that our children will also enjoy what we have. While this sentiment is commendable, it is incomplete. If we are to preserve our biodiversity, it will ultimately be for our survival. Ecosystem services, or the provision of goods and services, enter the picture as well, as it is upon these services that human livelihoods are dependent. We need to sustainably conserve our environment and resources to survive.

This becomes particularly true in poorer communities that live metaphorically close to the soil (or sea). By and large, communities in tropical and subtropical regions fall into this category and this is the case throughout most of the western Indian Ocean (WIO) with its estimated population of 156M people. Population drift to the coast in shore-fringed countries is a global phenomenon and, in sub-Saharan Africa, it is complex (see eg Annez and others, 2010, Parnell and Walawege 2011), much or most of the population being dependent on coastal and marine resources and ecosystem services. This dependence hinges around the biodiversity of these systems (see eg Díaz and others, 2006) and places direct and indirect pressures upon them through resource extraction, pollution and anthropogenically-driven habitat degradation. The effects and consequences of climate change add further pressure to this challenging situation; these and other anthropogenic pressures are summarised in IPCC (2014a, 2014b) documentation and are presented in the WIO context in the ensuing chapters.

The major coastal habitats in the WIO comprise estuarine and coastal systems ranging from mangroves, salt marshes and seagrass beds to beaches, rocky shores and reefs, coral reefs, nearshore sandy substrata, the offshore shelf and deep sea environments. The biodiversity of these is considered in the following chapters, giving consideration to their status and associated threats, and highlighting those that require special attention. While human implications are dealt with in terms of socio-economic considerations here, gaps in our capacity to deal with environmental management issues are dealt with in a later chapter. A summary of the main issues closes the section.

The coastal habitats under consideration in this section comprise the most productive of ecosystems, and the

richest in biodiversity in the world. Valuable additional reading can be found in a Millenium Ecosystem Assessment (Hassan and others, 2005), particularly the chapter on coastal systems (Agardy and others, 2005), which presents the threats these ecosystems face with the associated issues in a global context.

References

Agardy, T., Alder, J., Dayton, P., Curran, S., Kitchingman, A., Wilson, M., Catenazzi, A., Restrepo, J., Birkeland, C., Blaber, S., Saifullah, S., Branch, G., Boersma, D., Nixon, S., Dugan, P., Davidson, N. and Vörösmarty, C. (2005). Coastal systems. In *Ecosystems and Human Well-Being: Current State and Trends* (eds. R. Hassan, R. Scholes and N. Ash), vol. 1, pp. 513–549. Island Press, Washington

Annez, P., Buckley, R. and Kalarickal, J. (2010). African urbanization as flight? Some policy implications of geography. *Urban Forum* 21, 221–234

Hassan, R., Scholes, R. and Ash, N. (2005). *Ecosystems and human well-being: Current state and trends*, Volume 1, Chapter 19. Island Press, Washington

Díaz, S., Fargione, J., Stuart Chapin, F. III and Tilman, D. (2006). Biodiversity loss threatens human well-being. *PLoS Biol.* 4(8): e277, 1300–1305

IPCC (2014a). *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects.* Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (eds. C.B. Field, V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea and L.L. White) Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

IPCC (2014b). *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (eds. V.R. Barros, C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White) Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Parnell, S. and Walawege, R. (2011). Sub-Saharan African urbanisation and global environmental change. *Glob. Environ. Chang.* 21, S12–S20



4
Beaches and the Nearshore

Joseph Maina

Opposite page: The beach at Ulo village near Mocímboa da Praia, North Mozambique. © José Paula

The nearshore environment is generally defined as the area encompassing the transition from sub-tidal marine habitats to associated upland systems. For the purpose of this report, we define the area as that which includes habitats within the land-sea interface, extending to shallow sub-tidal waters (~2 m depth). Strong interactions occur between the marine environment and upland habitats within this interface. For example, a variety of vegetation provides bank stability, shades the upper intertidal zone and provides terrestrial input (eg woody debris as a fish refuge) to the nearshore marine ecosystem. Nearshore habitats are diverse, and include rocky shores, sandy beaches, muddy shores, mangroves, seagrass meadows and coral reefs. Their distribution is largely influenced by climate, geomorphology and coastal land use. Coral reefs, seagrass meadows and mangroves, also classified as nearshore ecosystems/habitats, are addressed in separate chapters in this report.

Coastal and estuarine shorelines are dynamic systems which undergo natural processes of erosion and accretion. Maintenance of these shoreline processes is critical for the sustainability of tidal and beach habitats and the benefits that accrue from them. Shorelines thus constantly change because of these processes, especially those caused by extreme tides and cyclones, the latter being relatively common along the coasts of Madagascar and Mozambique. While sand from the shore is often moved by wave and tidal action, human activities along the shore – including sand harvesting and coastal defence strategies – contribute to or mitigate this movement. The shores on the western boundary of the Indian Ocean have diverse littoral transport systems, with high tidal variability (up to 4 m), which plays a role in shaping the nearshore geomorphology. Natural shoreline processes and buffers maintain diverse and productive tidal fish habitats, providing the dynamic habitat complexity (eg undercut banks, shallow sand flats, snags, etc.) used by fish.

HABITATS

Rocky shores

By nature, rocky shores are relatively stable and are not subject to erosion to the extent of sandy shorelines. Rocky shores in the SWIO are relatively understudied. They consist of platforms, boulder fields, rock pools, and in some cases rocky vertical cliffs, each providing habitat opportunities for different types of plants and animals. Rocky shores are characterised by strong gradients in environmental conditions at small scales, varying within meters and hours, and so exert strong selection pressures that enhance species diversification over time (Lubchenko 1980). These features, widely distributed along the coasts of all WIO countries, constitute unique habitats shaped by a combination of waves, tides and the type of rock present. They support a diverse mix of plants and animals, which have adapted to survive the changes in exposure to water, sunlight and wind that characterize this habitat. Rocky shores are important

fish nurseries. Commercially important fish found associated with rocky shores include octopus, blackfish, yellowfin bream, tarwhine, trevally, yellowtail and samson fish. This habitat also harbours a high diversity of molluscs, including gastropods. The latter have been the subject of three comprehensive studies in the region: one on Kenyan shores (McClanahan 1989, McClanahan 2002) which revealed that the gastropod fauna was characterized by low densities but high diversity and variability in species composition. Significantly, protected reefs were found to have a higher diversity than unprotected reefs (McClanahan 1989, McClanahan 2002). More recently, Postaire and others (2014) reported high endemism in the tropical gastropod genus *Nerita* (Linnaeus) (Postaire and others, 2014).

Sandy beaches

Beaches and dunes constitute sandy habitats found along coastlines, lagoons, estuaries and sand spits. This type of shoreline is extensive in South Africa, Mozambique, Tanzania, Kenya and the island states of the WIO. A small increase in sea level recorded in Mozambique has resulted in significant regression of the high water mark. Typically, these areas were inundated in the previous high stands of sea level around 6 000 years ago. This type of coastline is most common in Mozambique with its wide continental shelf and flat, low coastal plains and river deltas. Beaches provide breeding areas for turtles throughout the region, and habitat for birds and invertebrates. They are popular destinations for human recreation.

Muddy shores, estuaries and mangroves

Estuaries, often associated with mangrove stands, are highly productive systems and comprise coastal ecosystems that are amongst the most threatened in the world (Millennium Ecosystem Assessment 2005). Their functioning is controlled by two main drivers: 1) fresh water river flow and 2) the marine processes of sedimentation and accretion. Some estuaries remain permanently open to the sea, or open and close depending on prevailing conditions, or are permanently closed with seepage being the only connection with the sea. These systems are delicately balanced, so any changes significantly affect their normal functioning, eg frequent mouth breaching which reduces their productivity, while insufficient breaching results in the accumulation of pollutants, leading to low oxygen levels and fish kills.

NEARSHORE BIODIVERSITY

Turtles

Sea turtles are vulnerable reptiles that have been subjected to direct exploitation for centuries, resulting in severe depletion in many cases. Turtles are globally threatened and are particularly vulnerable when they return to their natal beaches to lay their eggs. This they do on reaching maturity some years after hatching and the mothers, eggs and hatchlings fall easy prey to man and other predators. Growing awareness of their dilemma and threatened status has given rise to their protection in many regions, including the WIO. Despite this the threat to sea turtles remains high because of inadequate compliance with regulations and their indirect mortality in certain fisheries. The region has over the past decades seen a huge increase in fishing diversity and effort, resulting in higher turtle mortalities due to both targeted and by-catches. Although protected in most countries, they are also captured at sea by artisanal fishers. Further losses occur when they are accidentally harvested in trawl nets as by-catch or tangled in lost fishing gear (ghost fishing). Finally, sea-grass beds on which green turtles feed are also under threat, reducing their habitat.

The South West Indian Ocean is known to host five species of sea turtle which are all CITES protected (Márquez 1990, Ratsimbazafy 2003, Seminoff 2004). Of these, the green turtle (*Chelonia mydas*, endangered on the IUCN red-list) and hawksbill (*Eretmochelys imbricata*, critically endangered) are the most widely distributed and abundant, with the green turtle being by far the most numerous. These two species have also been the most severely impacted by direct exploitation (Hughes 1974, Hughes and Richards 1974). Loggerheads (*Caretta caretta*) and leatherbacks (*Dermochelys coriacea*) are common in South African waters, and are little exploited (Hughes, 1974, 2010). Relatively little has been documented on the olive ridley (*Lepidochelys olivacea*) and this species is not considered to be more than a vagrant in the region.

Bivalves and gastropods

Mollusc resources are exploited in nearshore habitats, most often by foraging or snorkelling. Molluscs are often collected opportunistically as an additional catch alongside other fishing methods. The main molluscs targeted are the edible and ornamental species such as oysters, clams, whelks and mussels. Most of the shells collected for the curio trade are threatened species (ASCLME 2012a,

BOX 4 .1 TURTLES IN THE WIO by Michael H. Schleyer



A turtle snared in a 'ghost fishing' net, one of the many dangers that are threatening their survival. © Michael H. Schleyer.

Turtles are globally threatened and are particularly vulnerable when they return to their natal beaches to lay their eggs. This they do on reaching maturity some years after hatching and the mothers, eggs and hatchlings fall easy prey to man and other predators. Although protected in most countries, they are also captured at sea by artisanal fishers. Further losses occur when they are accidentally harvested in trawl nets as by-catch or tangled in lost fishing gear (ghost fishing). Finally, the seagrass beds on which green turtles feed are also under threat, reducing their habitat.

Five of the seven extant species of marine turtles occur in the WIO and all are CITES-protected. Loggerhead (IUCN Red-listed as endangered), green (endangered) and hawksbill (critically endangered) turtles are the most common and nest within the region; leatherback turtles are less common and nest only in southern Africa. The olive ridley turtle (endangered) is the rarest and nests at only a few sites in the WIO.

2012b) and their stock status ranges from fully to overexploited (FAO-SWIOFC 2011).

Crustaceans

Crustaceans make up a large proportion of the fisheries in the WIO (FAO-SWIOFC 2011). Shrimp, lobsters and crabs are very common in fished, nearshore areas, and are exploited at both the subsistence/artisanal and commercial scale. Landings for nine countries in the WIO have been estimated to be roughly 35 000 tonnes per year (van der Elst and others, 2009), with the shallow-water penaeid prawn fisheries in Mozambique and Madagascar making up a large proportion of these estimates. Several species of tropical spiny lobsters and crabs are targeted in shallow waters by artisanal and recreational fishers, and caught using simple gear operated from the shore, or from small boats. According to FAO-SWIOFC (2011), most of the crustacean stocks in the region are fully or overexploited (Table 1). However, there is lack of consensus on the status of prawns in most WIO countries, including South Africa, and deep water prawns and lobsters in Mozambique. The deep-water crustaceans in the SWIO region (ie deep-water

Table 4.1. Status of crustacean stocks in the WIO (Source FAO-SWIOFC 2012).

Comoros	Crustaceans (prawns, langoustines, crabs)	Underexploited
Kenya	Spiny and rock lobster	Overexploited
	Shallow-water prawns (commercial)	Fully exploited
	Shallow-water prawns (artisanal)	Unknown
	Crabs	Fully exploited
Madagascar	Langoustine	Fully exploited
	Prawns	Fully exploited
	Crabs	Fully exploited
Mauritius	Deep-water prawns (*Heterocarpus laevigatus*)	Under exploited
Mozambique	Spiny and rock lobster (*Palinurus delagoae*)	Depleted
	Shallow-water prawns (*P. indicus* & *M. monoceros*) (industrial)	Fully exploited
	Shallow-water prawns (semi-industrial & artisanal)	Fully exploited
	Deep-water prawns (*Haliporoides triarthus* & *Aristeomorpha foliacea*)	Moderately exploited
Seychelles	Spiny and rock lobster (*P. longipes*, *P. versicolor*, *P. penicillatus*, *P. ornatus*)	Recovering
	Spanner crab (*Ranina ranina*)	Underexploited
Somalia	Spiny and rock lobster	Overexploited
South Africa	Spiny and rock lobster (*P. gilchristi*, *P. delagoae* & *P. homarus*)	Fully exploited
	Crustaceans (deep & shallow-water prawns, langoustines, scyllarids)	Overexploited
Tanzania	Spiny and rock lobster	Fully exploited
	Shallow-water prawns Depleted	Depleted

prawns, langoustine lobsters, several deep-water spiny lobster species and deep-sea crabs) are only accessible to industrialized trap and trawl fisheries, and therefore the extent and fisheries potential of deep-water stocks are not as well-known as species living in shallower water (Groeneveld and others, 2009). Deep-water crustacean trawl fisheries in the SWIO are far less common than shallow-water prawn trawl fisheries.

Shallow-water prawns are targeted in the artisanal fisheries of Madagascar, Mozambique, Tanzania, Kenya, and Somalia using gill- and seine nets as well as fence traps ('*valakira*') in Madagascar (WIOFish 2011). Catches from the artisanal fishery in Tanzania nearly equal the landings from trawlers (ASCLME 2012a), while inshore populations of prawns are declining in Somalia (ASCLME 2012b). The artisanal fisheries also target spiny lobsters, using tangle nets, traps, spearguns or reef gleaning methods using snorkelling or SCUBA diving. This is a valuable fishery but monitoring is limited and information on stocks is insufficient; its status is currently considered as fully exploited to depleted (FAO-SWIOFC 2011). The exploitation of crabs is common in several countries in the WIO region. The main target species include the mangrove swamp crab, *Scylla serrata*, and swimming crabs; coconut crabs are exploited in Comoros and ghost crabs are caught in the artisanal and recreational fisheries of South Africa (WIOFish 2011).

According to the Scientific Committee of the FAO-SWIOFC (2011), penaeid prawns in the region are fully exploited in all of the countries on the western boundary of the Indian Ocean (South Africa, Mozambique, Tanzania, Kenya and Somalia) as well as Madagascar, mainly by industrial shallow-water trawling. The main target species are *Fenneropenaeus indicus (Penaeus indicus)* and *Metapenaeus monoceros*, which together contribute around 90 per cent of landed shallow water trawled prawn catches. Other commercial shallow-water prawn species (*Penaeus monodon*, *P. semisulcatus*, *P. latisulcatus* and *P. japonicus*) are also caught, but in much lower abundance. With the exception of South Africa, trawled catches of prawns are exported and represent a valuable source of foreign currency, particularly in Mozambique and Madagascar. Mozambique, Tanzania, Kenya, Somalia and Madagascar have substantial small-scale (traditional) fisheries which appear to be growing and are increasingly targeting prawns, leading to user-conflict with the trawl sector. In

Kenya, the trawl fishery was intermittently closed in 2000 and 2001, and again in 2006 due to clashes with artisanal fishers (Ochiewo 2004, Munga and others, 2012). After re-opening in 2007, it was closed again in 2008-2010: as of 2011, only three vessels are licensed of which two fished in 2011 and 2012 (Fennessy 2012).

While there are management measures in place for the shallow-water prawn trawl sector in each country, their objectives are not always clearly quantified, and ensuring compliance with some measures is difficult to achieve. This may have resulted in the declining CPUE observed in Tanzania and Mozambique, although in South Africa declines in prawn catches occurred as a result of the closure of the large St Lucia estuary in 2001, from which about half of the prawns recruit (Fennessy 2012). There are currently no Ecosystem Approach to Fisheries (EAF) management plans developed for the crustacean fisheries in the SWIO, although these have been proposed for the artisanal and commercial fisheries in Kenya, Tanzania and Madagascar (FAO-SWIOFC 2012). In the small-scale sector, there is currently no effort limitation, few management measures and low compliance. Consequently, artisanal catches have declined overall. For example, in Madagascar reports indicate that artisanal catches declined from 750 t in 2003 to just over 100 t in 2009. The fisheries are all managed at a national level, with no regional management strategy. There is, however, no genetic evidence at this stage to indicate that the prioritized shallow-water prawn species are shared, and it is thus appropriate that the stocks in each country continue to be managed separately (Fennessy 2012).

Cephalopods

Squid, cuttlefish and octopus are targeted in fisheries throughout the region, the most widespread being the artisanal octopus fishery. Several countries have reported declines in octopus landings (Table 2) and this is mainly attributed to over-exploitation and habitat loss. The South West Indian Ocean Fisheries Commission (SWIOFC) classified the octopus fishery as overfished in the SWIO region (FAO-SWIOFC 2011). Octopus fishing is usually undertaken by foraging on the reef flat at low tide. The most common fishing technique employed throughout the region is to use a long metal spike, or harpoon, to impale the prey. Squid-jigging in South Africa is an important commercial fishery targeting spawning aggregations of chokka squid (*Loligo vulgaris reynaudii*) in sheltered bays on the south coast (ASCLME 2012c).

Table 4.2. The status of invertebrate stocks in WIO countries (Source FAO-SWIOFC 2012).

Comoros	Cephalopods	Underexploited
	Bivalves	Underexploited
Kenya	Octopus	Fully exploited
	Sea Cucumbers	Overexploited
	Bivalves	Fully exploited
Madagascar	Octopus	Fully exploited
	Sea cucumbers	Overexploited
	Bivalves	Fully exploited
Mauritius	Octopus	Moderately exploited
	Sea cucumbers	Depleted
Seychelles	Sea cucumbers	Overexploited
South Africa	Octopus	Underexploited
	Bivalves	Overexploited
Tanzania	Octopus	Overexploited
	Cuttlefish and squid	Fully exploited
	Sea cucumbers	Overexploited
	Bivalves	Overexploited

Bêche-de-mer

Sea cucumber (or bêche-de-mer) fishing is not a traditional fishery within the SWIO, but it has rapidly and significantly gained importance due to the high export value of the product, mainly to Asian countries. Sea cucumbers are typically targeted by fisherfolk using snorkelling or SCUBA diving, or collected as by-catch by spear fishermen and other gleaners. Fishers typically target the six highest valued species (*Holothuria nobilis*, *H. fuscogilva*, *H. scabra*, *Thelenota ananas* and *Actinopyga mauritiana*). Sea cucumber resources in all SWIO countries are largely over-exploited (FAO-SWIOFC 2011). Management regulations were introduced to control the fishery and processing industry in the Seychelles in 1999 (ASCLME 2012d). Sea cucumber fishing in Comoros has been banned since 2004 (FAO-SWIOFC 2012) and, in Mauritius, a two-year moratorium period was implemented from 1 October 2009 to 30t September 2011; this has now been extended until February 2016 (WIOFish 2011).

Seabirds

Eleven seabird families occur in the WIO as breeding species. They are penguins (Spheniscidae), albatrosses (Diomedeidae), petrels and allies (Procellariidae), storm-petrels (Hydrobatidae), diving-petrels (Pelecanoididae), trop-

icbirds (Phaethonidae), gannets and boobies (Sulidae), cormorants (Phalacrocoracidae), frigatebirds (Fregatidae), skuas (Stercorariidae), and gulls and terns (Laridae). Most of the seabirds found in the WIO fall broadly into three categories: Indo-Pacific species, pan-tropical species (highly migratory Procellariiformes from southern latitudes), and predominantly Atlantic species (with distributions marginal to the WIO). Consequently, the level of endemism is relatively low compared to other regions. There are, however, at least nine extant breeding endemics of which five are listed as globally threatened, including two critically endangered species (BirdLife International 2008). Half of these are from Sub-Antarctic islands, two from Réunion Island and two from the Arabian Sea. In

BOX 4 .2 SAWFISH IN THE WIO by Michael H. Schleyer



A sawfish between sand sharks in an aquarium; they are very seldom seen in the WIO. © J.M. Barre.

Sawfish (*Pristis* spp.) are iconic fish that were once abundant on East African shores but are now listed on the IUCN Red List as globally critically endangered. They are cartilaginous shark-like rays that live in shallow tropical and subtropical coastal waters and estuaries, and have not been seen in the WIO for some decades. The saw-like rostrum which gives them their name is used to capture prey but it has also caused their demise as they are easily ensnared in gill and trawl nets. They have thus been over-fished and habitat degradation in coastal and estuarine waters has exacerbated the situation. Two species were fairly common in WIO waters, the largetooth sawfish *Pristis pristis* and the green sawfish *P. zijsron*. Sawfish have been known to reach 7 m in size but since they are slow-growing, slow to mature and not fecund, they are prone to overfishing. Efforts to rehabilitate their stocks pose problems as the shallow waters in which they live are heavily fished. Furthermore, the live pups are dropped in rivers or estuaries where they live for some years before entering the sea. The mothers and maturing juveniles are thus prone to capture during their movement between freshwater and the marine environment and all adults are susceptible to coastal fishing activities.

addition to some endemic and very range-restricted species, the WIO region is host to globally important numbers of more widespread seabirds. The Seychelles and French islands together harbour significant proportions of tropical seabird populations, some in huge breeding numbers.

SOCIO-ECONOMIC SIGNIFICANCE

Nearshore habitats are of great socio-economic significance in the western Indian Ocean; 65 million people live within 10 km of the coast in the greater Indian Ocean region (Burke and others, 2011). For example, reports indicate that two thirds of the Mozambican population live along the coast and depend on resources in these areas to sustain their livelihoods. Preliminary results of the last Mozambican population census in 2007 indicate that it has 20.5 million people, with an annual growth rate of about 2.4 per cent. Most of the cities in the country are located on the coast. Similarly, some of the largest cities in Kenya and Tanzania are located along the coast (eg Mombasa and Dar es Salaam); these adversely affect the coastal biodiversity.

Human activities on the coast in the region focus largely on gleaning the available resources, resulting in intense exploitation of nearshore resources by recreational and subsistence fishers. It is also in this land-sea interface where trading of fisheries-related goods and services is prevalent. Seaweed farming is another important socio-economic activity in these areas. While seaweed farming, mostly undertaken by women, has been successful in supporting coastal communities on the Tanzanian coast, the same has not been true in other parts of the region.

Moreover, tourism is one of the most important economic sectors in the Western Indian Ocean and makes a substantial contribution to the GDP and total foreign exchange earnings. It is also a vital sector, which creates less resource-intensive streams of income and subsequently reduces the pressure on coastal resources.

Many coastal invertebrate stocks in the WIO are overexploited (Table 1) and significant declines have been recorded in both targeted and non-targeted species. As an example, the stock status of various fisheries in East Africa is given as: cephalopods offshore – underexploited; bivalves inshore - moderately exploited; sea cucumber – overexploited; octopus offshore – underexploited; and cephalopods inshore – underexploited.

THREATS

Climate change, changes in land-use and conversion of land (LULCC) represent the primary challenges that most ecosystems will face this century (Brook 2008) (Figure 4.1). The effects of climate change on ecosystems often involve very long time-scales (centuries), yet the trajectory of change in a specific region can be punctuated by shifts in land-use over short time-frames, even days in some cases. Shallow marine habitats are strongly affected by tectonics, eustatic sea-level changes, physical disturbances and run-off from land, impacts that continually modify habitats over various time-scales (DiBattista and others, 2013). Nearshore environments provide biophysical linkages between the coast and ocean and are therefore subject to human and climate-mediated alteration. In the WIO, sea level rise, shoreline hardening, coastal land development and nutrient enhancement are some of the pressures that are currently being experienced.

CLIMATE DRIVERS

The effects of climate change are already being experienced in nearshore habitats and estuaries in the region, with serious ecological and socio-economic consequences. Changes in sea level and coastal erosion are compromising the integrity of ecological processes in nearshore habitats. Studies that combine ground-truth data and satellite observations of the Indian Ocean sea level with simulations of factors related to climate change have identified a clear spatial pattern in sea level rise since the 1960s (eg Han and others, 2010). These studies indicate that there is a N-S latitudinal gradient of increasing sea level in some areas of the Indian Ocean, but substantial declines in southern tropical parts. More recent sea-level analysis in the region has shown that the rate of sea-level change varies in the region (Mather 2007, Mather and others, 2009). Tide gauges in the region have recorded a sea level rise (3-5 mm/year) with the exception of Zanzibar (-3.6 mm/year).

Climate change and ENSO-forced climate variability influence precipitation and hydrology in coastal watersheds and this has been profound in the WIO, evidenced by the amount of freshwater and sediment being discharged into the ocean, thereby affecting nearshore ecosystems such as estuaries and coral reefs (Maina and others, 2012). These changes, coupled with land-use

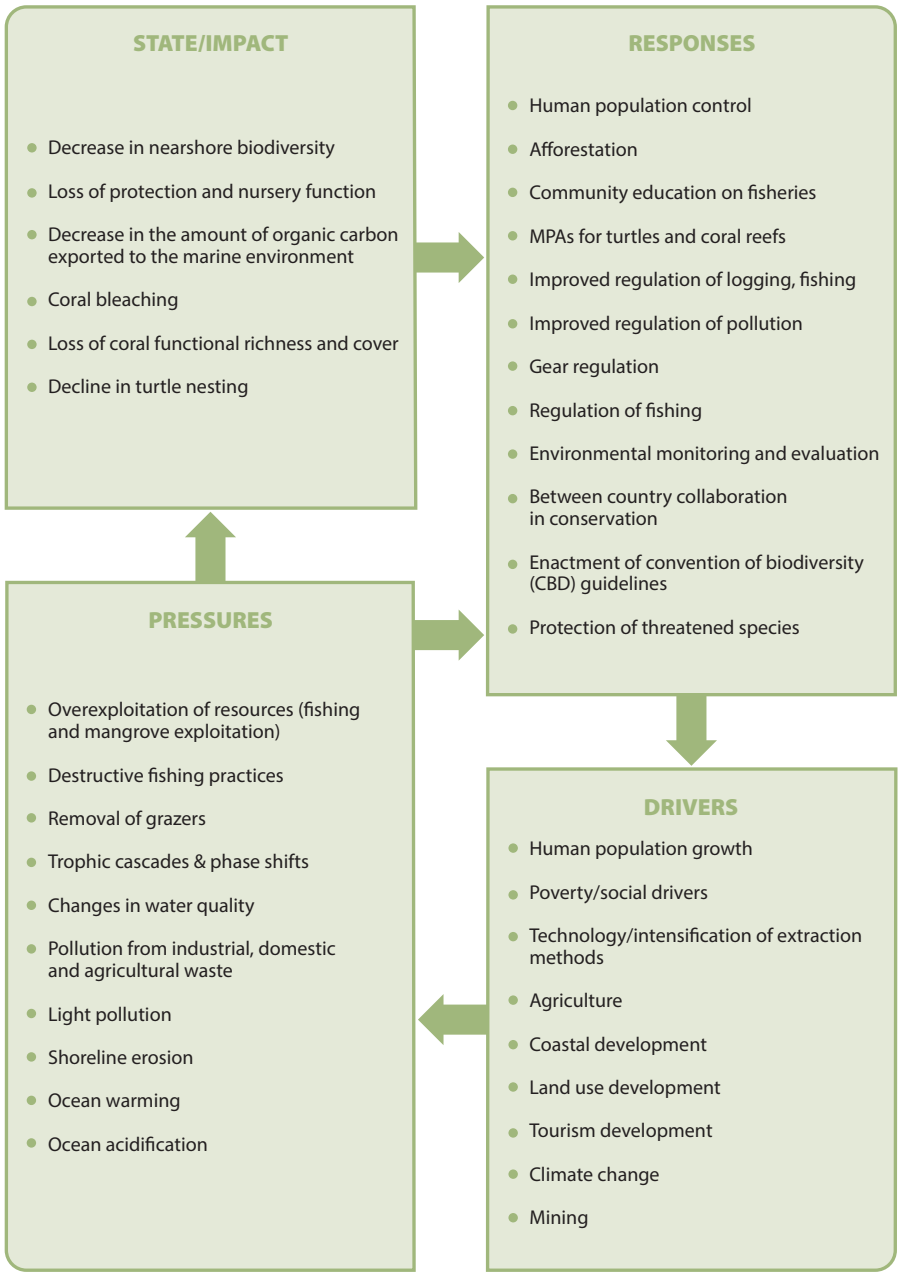


Figure 4.1. Summary of the Drivers-Pressures-Status-Impact- Response (DPSIR) for beaches and near-shore environments in the WIO.

change, continue to directly affect the hydrology of the land surface through alterations in evapotranspiration and groundwater levels, and the amount of sediment and freshwater discharged into marine coastal zones (Maina and others, 2012). A recent study on the effects of changes in temperature and precipitation on river flow and sediment discharge in Madagascar (Maina and others, 2013) revealed a general decline in river discharge. This study showed that these climate change-driven declines are outweighed by the impact of deforestation, which was shown to increase sedimentation.

HUMAN IMPACTS

An exponential increase in population, coupled with a high reliance on coastal and marine resources for sustenance and livelihood is one of the key pressures driving overexploitation and degradation of WIO nearshore ecosystems. Coastal cities and settlements are growing and developing at a rapid rate, contributing to coastal pollution from untreated sewage discharge. Industrial and agricultural activities in coastal watersheds and their residues are also contributing to eutrophication and sedimentation in the nearshore ecosystems. These human pressures reinforce

ongoing climate-mediated changes and, cumulatively, are leading to the retrogression of nearshore environments.

Mining and exploration activities are on the rise in the region, with many exploration and mining blocks located in coastal zones. Small-scale sand harvesting is currently practised in the nearshore environments of Tanzania and Mozambique (Masalu 2002), as well as in other areas. Heavy mineral sands (ie titanium, ilmenite and zircon) are currently mined in South Africa and Mozambique at an industrial scale, and such mining was recently commissioned in Kenya; exploration for these deposits still continues in Mozambique and elsewhere. In southern Kenya, the Kwale Project is located 10 km inland from the coast, and 50 km south of Mombasa, Kenya's principal port. Here, heavy mineral sand mining is being undertaken at unprecedented scales in watersheds in close proximity to the mangrove ecosystems of southern Kenya. The long-term effects of these activities possibly involve abandoned zones after mining and sedimentation of nearshore environments.

Trawl fishing is common in the region and has been found to have detrimental effects on benthic communities and non-targeted species, such as turtles. The nearshore environments of the Primeiras and Segundas Archipelago off the coast of Mozambique are heavily affected by this activity. A survey of commercial fishers, fishery observers and enforcers on the Sofala Bank and off the Primeiras and Segundas, revealed that at least 1 235-1 735 sea turtles are caught each fishing season by prawn trawlers, mainly green (*Chelonia mydas*, 48.4%) and loggerhead turtles (*Caretta caretta*, 25.8%), but catches also include olive ridley (*Lepidochelys olivacea*), hawksbill (*Eretmochelys imbricata*) and leatherback turtles (*Dermochelys coriacea*) (Brito 2012).

CONCLUDING REMARKS

Nearshore sub-tidal environments are valuable for services such as recreation and shoreline protection, and the provision of goods such as edible invertebrates and fish. Several anthropogenic pressures, including pollution, mining, overexploitation and climate change, are causing a decline in the integrity of these environments. Sub-tidal zones in the WIO are generally understudied and under-managed, with poor or no monitoring. Management of these environments should include, among others, a participatory approach in their management, awareness campaigns and education programmes. Moreover, the intertidal zone should be treated as a single organizational management entity within the larger framework of integrated coastal zone management (ICZM) (Nordlum and others, 2011).

References

Agulhas and Somali Current Large Marine Ecosystems Project (2012a). National marine ecosystem diagnostic analysis, *Tanzania*. Contribution to the Agulhas and Somali Current Large Marine Ecosystems Project (supported by the UNDP with GEF grant financing). ASCLME, 80 pp

Agulhas and Somali Current Large Marine Ecosystems Project (2012b). National marine ecosystem diagnostic analysis, *Somalia*. Contribution to the Agulhas and Somali Current Large Marine Ecosystems Project (supported by the UNDP with GEF grant financing). ASCLME, 30 pp

Agulhas and Somali Current Large Marine Ecosystems Project (2012c). *National marine ecosystem diagnostic analysis, South Africa*. Contribution to the Agulhas and Somali Current Large Marine Ecosystems Project (supported by the UNDP with GEF grant financing). ASCLME, 79 pp

Agulhas and Somali Current Large Marine Ecosystems Project (2012d). *National marine ecosystem diagnostic analysis, Seychelles*. Contribution to the Agulhas and Somali Current Large Marine Ecosystems Project (supported by the UNDP with GEF grant financing). ASCLME, 98 pp

BirdLife International (2008). *Threatened birds of the world 2008 (CD-ROM)*. BirdLife International, Cambridge, UK

Brito, A. (2012). An interview-based assessment of the incidental capture and mortality of sea turtles in Mozambique´s Sofala Bank commercial shrimp fishery

Brook, B.W. (2008). Synergies between climate change, extinctions and invasive vertebrates. *Wildlife Res*. 35, 249–252

Burke, L., Reytar, K., Spalding, M. and Perry, A. (2011).

Reefs at risk revisited. World Resources Institute, Washington, DC

DiBattista, J.D., Berumen, M.L., Gaither, M.R., Rocha, L.A., Eble, J.A., Eble, J.A., Choat, J.H., Craig, M.T., Skillings, D.J. and Bowe, B.W. (2013). After continents divide: comparative phylogeography of reef fishes from the Red Sea and Indian Ocean. *J. Biogeogr.* 40, 1170–1181

FAO-SWIOFC (2011). *South West Indian Ocean Fisheries Commission. Status of Resources*. Malé, Maldives

FAO-SWIOFC (2012). *Report of the fifth session of the Scientific Committee of the South West Indian Ocean Fisheries Commission*. Cape Town, South Africa, 27 February–1 March 2012. FAO Fisheries and Aquaculture Report/ FAO Rapport sur les pêches et l'aquaculture. Harare, FAO

Fennessy, S. (2012). *Retrospective analysis of existing data on shallow-water trawl fisheries for crustaceans in the South West Indian Ocean*. Specialist report prepared for the South West Indian Ocean Fisheries Project (SWIOFP). Oceanographic Research Institute, Durban, South Africa

Groeneveld, J.C., Cockcroft, A.C., Dias, N.M., Palha de Sousa, L., Mwakosya, C., Ulotu, E., Kimani, E., Munga, C. and Rafalimanana, T. (2009). *Regional Data Gap-Analysis for Component 2 (Crustaceans) for SWIOFP.* Proceedings of the Regional Workshop for Component 2 of SWIOFP 20th – 22nd April 2009. Oceanographic Research Institute, Durban, South Africa

Han, W., Meehl, G., Rajagopalan, B., Fasullo, J., Hu, A, Lin, J., Large, W, Wang, J-W, Quan, X.-W., Trenary, L., Wallcraft, A., Shinoda, T. and Yeager, S. (2010). Patterns of Indian Ocean sea-level change in a warming climate. *Nature Geosci.* 3, 546-550.

Hughes, G.R. (2010). Loggerheads and leatherbacks in the Western Indian Ocean. *Indian Ocean Turtle Newsletter* 11, 24-31

Hughes, G.R. (1974). *The sea turtles of southeast Africa* (Vol. 1). Oceanographic Research Institute.

Hughes, D.A., & Richard, J.D. (1974). The nesting of the Pacific ridley turtle Lepidochelys olivacea on Playa Nancite, Costa Rica. *Marine Biol*ogy, 24, 97-107.

Lubchenco, J. (1980). Algal Zonation in the New England Rocky Intertidal Community: An Experimental Analysis. *Ecology* 61, 333–344

Maina, J., de Moel, H., Vermaat, J. E., Bruggemann, J. H., Guillaume, M. M. M., Grove, C. A., Madin, J. S., Mertz-Kraus, R. and Zinke, J. (2012). Linking coral river runoff proxies with climate variability, hydrology and land-use in Madagascar catchments. *Mar. Pollut. Bull.* 64, 2047-2059

Maina, J., de Moel, H., Zinke, J., Madin, J., McClanahan, T., Vermaat, J. E. (2013). Human deforestation outweighs future climate change impacts of sedimentation on coral reefs. *Nat. Commun.* 4

Masalu, D.C. (2002). Coastal erosion and its social and environmental aspects in Tanzania: a case study in illegal sand mining. *Coast. Manag.* 30, 347-359

Márquez, M.R. (1990). Sea turtles of the world. An annotated and illustrated catalogue of sea turtle species known to date. *FAO Fish. Synops.* 11(125), 1-81

Mather, A.A. (2007) Linear and nonlinear sea level changes at Durban, South Africa. *Afr. J. Mar. Sci.* 103, 509–512

Mather, A.A., Garland, G.G. and Stretch, D.D. (2009). Southern African sea levels: Corrections, influences and trends. *Afr. J. Mar.Sci.* 31, 145–156

McClanahan, T.R. (1989). Kenyan coral reef-associated gastropod fauna: A comparison between protected and unprotected reefs. *Mar. Ecol. Prog. Ser.* 53, 11-20

McClanahan, T.R. (2002). The effects of time, habitat, and fisheries management on Kenyan coral-reef-associated gastropods. *Ecol. Appl.* 12, 1484-1495

Millennium Ecosystem Assessment (2005). *Ecosystem and Human Well-Being: Biodiversity Synthesis*. World Resources Institute.Washington, DC, USA

Munga, C., Ndegwa, S., Fulanda, B., Manyala, J., Kimani, E., Ohtomi, J. and Vanreusel, A. (2012). Bottom shrimp trawling impacts on species distribution and fishery dynamics; Ungwana Bay fishery Kenya before and after the 2006 trawl ban. *Fish. Sci.* 78, 209 – 219

Nordlund, L.M., de la Torre-Castro, M., Erlandsson, J., Conand, C., Muthiga, N., Jiddawi, N. and Gullström, M. (2013). Intertidal Zone Management in the Western Indian Ocean: Assessing Current Status and Future Possibilities Using Expert Opinions. *Ambio* 1-14

Ochiewo, J. (2004). Changing fisheries practices and their socioeconomic implications in South Coast Kenya. *Ocean Coast. Manag.* 47,389–408

Postaire, B., Bruggemann, J.H., Magalon, H. and Faure, B. (2014). Evolutionary Dynamics in the Southwest Indian Ocean Marine Biodiversity Hotspot: A Perspective from the Rocky Shore Gastropod Genus *Nerita*. *PLoS ONE* 9, e95040

Ratsimbazafy, R. (2003). Sea Turtles. In *The Natural History*

of Madagascar (eds. S.M. Goodman and J.P. Benstead) pp. 210-213

Seminoff, J.A. (2004). Sea turtles, red listing, and the need for regional assessments. *Marine Turtle Newsletter* 106, 4-6

van der Elst, R.P., Groeneveld, J.C., Baloi, A.P., Marsac, F., Katonda, K.I., Ruwa, R.K. and Lane, W.L. (2009). Nine nations, one ocean: A benchmark appraisal of the South Western Indian Ocean Fisheries Project (2008- 2012). *Ocean Coast. Manag.* 52, 258-267

WIOFish (2011). *Western Indian Ocean Fisheries Database: A catalogue of small-scale fisheries*. http://www.wiofish.org/



5
Mangroves, Salt Marshes and Seagrass Beds

Blandina Lugendo

Opposite page: Swamp mangrove near Quionga, North Mozambique. © José Paula.

Mangroves, salt marsh vegetation and seagrasses constitute true flowering plants in marine and estuarine habitats. While seagrass beds are found in temperate and tropical latitudes, saltmarshes are restricted to sub-tropical and temperate regions. Mangroves are a common feature of the coastlines of all the countries in the WIO region except Reunion (Figure 5.1). Saltmarshes are found almost entirely in South Africa due to its subtropical-temperate biogeographical location. It is common to find two or three habitats (mangroves, seagrass beds and salt marshes) co-occurring, however separation between these habitats is attributed to differences in salinity and depth preferences and or tolerances (Colloty and others, 2002). Mangroves, salt marshes and seagrass beds are ecologically and socio-economically important. They are easily impacted by human activities, resulting in habitat loss and a consequent reduction or total loss of the values associated with them.

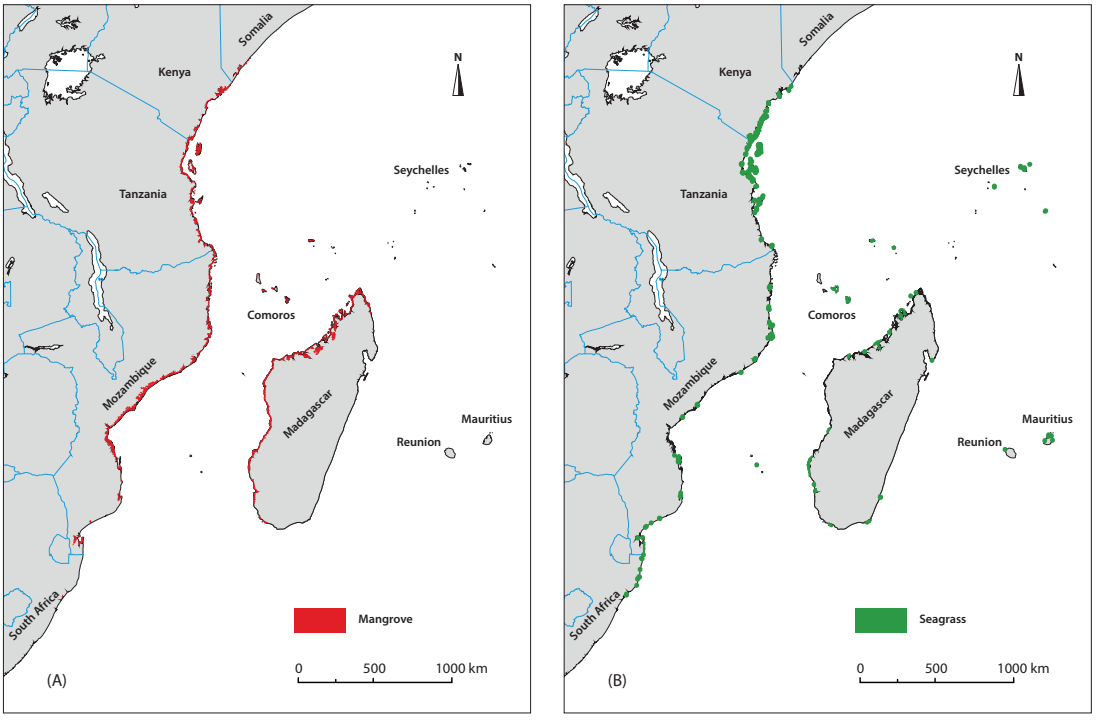


Figure 5.1. Map of mangrove and seagrass bed distribution in the WIO region. Source: http://data.unep-wcmc.org/datasets/10, accessed 16 August 2014.

BOX 5.1. MANGROVES AND THEIR IMPORTANCE



Mangrove forest in Ras Dege, Tanzania. © José Paula.

Mangroves are vascular plants that are capable of thriving in salt water and form a transition zone between land and sea. The term 'mangrove' includes trees, shrubs, palms or ground ferns generally exceeding half a metre in height, and which normally grow above mean sea level in the intertidal zone of marine coastal environments, or along estuarine margins (Duke, 2006). They are mainly found in estuaries, along riverbanks and in lagoons, and in gently sloping intertidal areas specially whenever there is freshwater seepage.

Mangroves provide breeding, spawning and nursery grounds for a variety of marine species including commercially important fish, shrimps and crabs, and are hence important for fisheries. Mangrove forests stabilize and protect shorelines, thereby reducing the impact of natural disasters such as tsunamis and cyclones. They form an important carbon sink (Donato and others, 2011).

Coastal communities use mangroves to supply local needs such as food, firewood, charcoal, timber, building materials and medicine. In Tanzania it is estimated that over 150 000 people in Rufiji make their living directly from mangrove resources (Taylor and others, 2003). Despite their socio-economic and ecological importance, mangroves constitute one of the most threatened tropical ecosystems (Valiela and others, 2001).

MANGROVES

Status And Trends

Coverage, distribution and composition

Their area in the WIO region is estimated at around 1 000 000 ha (Spalding and others, 1997). Over 90 per cent of these mangroves occur in the estuaries and deltas of four countries, viz. Mozambique, Madagascar, Tanzania and Kenya (Figure 5.2). Important mangrove forests occur in Boeny, Melaky and Diana (Madagascar), the Zambezi, Save to Púnguè and Limpopo Rivers (Mozambique), the Rufiji delta (Tanzania) and Lamu (Kenya). Ten species of

mangroves are found in the region (Table 5.1). This list excludes two species, namely *Pemphis acidula*, the inclusion of which in the mangrove group is under debate, and *Acrostichum aureum*, which is considered a mangrove associate. *Rhizophora mucronata*, *Avicennia marina* and *Ceriops tagal* are most common. One species (*Ceriops somalensis*) is

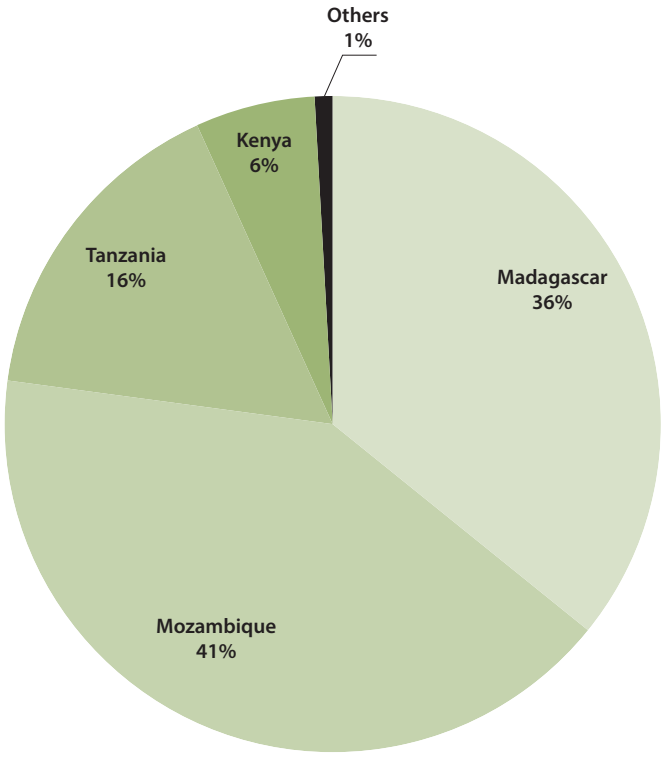


Figure 5.2. The relative extent of mangroves in the four countries with the greatest mangrove cover in the WIO region. (Source: FAO 2007, Giri and others, 2011).

Table 5.1. Mangrove species composition in different countries of the WIO region.

Species	*Avicennia marina*	*Bruguiera gymnorrhiza*	*Ceriops tagal*	*Ceriops somalensis*	*Heritiera littoralis*	*Lumnitzera racemosa*	*Rhizophora mucronata*	*Sonneratia alba*	*Xylocarpus granatum*	*Xylocarpus moluccensis*	**Total number of species**
Somalia	X	X	X	X		X	X	X	X		**8**
Kenya	X	X	X		X	X	X	X	X	X	**9**
Tanzania	X	X	X		X	X	X	X	X	X	**9**
Mozambique	X	X	X		X	X	X	X	X		**8**
South Africa	X	X	X			X	X		X		**7**
Madagascar	X	X	X		X	X	X	X	X		**8**
Seychelles	X	X	X			X	X	X	X		**7**
Mauritius		X					X				**2**
Comoros	X	X	X		X	X	X	X			**7**

endemic to Somalia. Details of the status of individual countries are provided in the following sections.

The Comoros harbour about 120 ha of mangroves (FAO 2007), with about 75 per cent of these occurring on the south coast of Moheli Island, especially in the region of Damou and Mapiachingo. Other mangrove areas include Grande Comore and Anjouan. Seven species occur in the Comoros (Table 5.1), the most abundant being *R. mucronata* and *A. marina*.

The total coverage of mangroves in Kenya is estimated to range between 46 000 and 54 000 ha (FAO 2007, Kirui and others, 2012). Eighteen mangrove formations are found in Kenya, the largest occurring in the Lamu area (33 500 ha) and at the River Tana delta (Kirui and others, 2012). Other important mangrove areas include Vanga-Funzi, Gazi, Mida Creek and the Mombasa creeks such as Mwache. Nine species occur in Kenya (Table 5.1), with *R. mucronata* and *A. marina* being the most abundant.

Recent estimates indicate that Madagascar harbours about 278 078 ha of mangroves (Giri and others, 2011). This figure is smaller than earlier estimates of 303 815 ha (FAO 2007). The majority (98 per cent) of mangroves occur on the west coast. Important mangroves occur in Mahajanga Bay, Nosy Be and Hahavavy. A total of eight species of mangroves occur in this country (Table 5.1).

In Mauritius, mangroves only cover between 120 and 145 ha (FAO 2007). They are present in Rodrigues and in the Agalega Islands. Two species of mangroves, viz. *R. mucronata* and *B. gymnorrhiza*, are reported to occur here, with *R. mucronata* being the most dominant species.

Mozambique harbours the largest mangrove area of all the countries in the WIO, estimated to range between 290 900 and 318 800 ha (Fatoyinbo and others, 2008, Giri and others, 2011). These recent estimates are lower than earlier estimates (396 080 ha by Barbosa and others, 2001, and 392 750 ha in FAO 2007). The largest mangroves are in the Save-Zambezi River complex in the Sofala and Zambezia Provinces, with a total area of 190 000 ha (Fatoyinbo and others, 2008). A total of eight mangrove species occur in Mozambique (Table 5.1) with *A. marina*, *R. mucronata* and *C. tagal* being most dominant.

In the Seychelles, mangroves occur mainly on the four larger granitic islands, which include Mahé, Praslin, Silhouette and La Digue. Mangroves cover about 2 900 ha (FAO 2007). More extensive mangrove forests occur in the Aldabra and Cosmoledo Atolls, with Aldabra alone having about two thirds of the combined mangrove area of the Seychelles and these atolls (Taylor and others, 2003). Seven species of mangrove are found in the Seychelles (Table 5.1).

Mangroves in Somalia occupy an area of about 1 000 ha (FAO 2007), mainly in the Juba/Shebele estuary, along the creeks of Istambul, Kudha and Burgavo, and on the sheltered side of the barrier islands (ASCLME/SWIOFP 2012b). Another large mangrove forest occurs in the Bojun Islands (FAO 2005). Eight species of mangrove occur in Somalia (Table 5.1), including *Ceriops somalensis* which is endemic to Somalia.

Mangroves in South Africa are limited to the eastern coastline from the border of Mozambique at Kosi Bay in KwaZulu-Natal to Nahoon Estuary in East London (Eastern Cape). Mangroves cover between 1 660 ha and 3 000 ha (Ward and Steinke 1982, FAO 2007, Adams and others, in prep.). Six mangrove species occur in South Africa (Table 5.1), the dominant species being *A. marina*. About 80 per cent of mangroves of South Africa occur in Mhlathuze estuary (Taylor and others, 2003, Rajkaran and others, 2004).

Mangrove cover in the United Republic of Tanzania is estimated to range between 127 200-133 500 ha (FAO 2007, Semesi 1992, MTNRE 1991, Griffith 1949, 1950), the latter figure being officially considered the total extent of mangroves in the country (115 500 ha on the Tanzania mainland, 18,000 ha on Zanzibar). The largest continuous and well-developed mangrove forests in Tanzania are found in the major estuaries of the Pangani, Wami, Ruvu, Rufiji and Ruvuma Rivers. The Rufiji Delta has the largest stand of mangroves (53 000 ha) on the entire East African coast (Semesi 1989). In Zanzibar, well-developed mangroves occur on Pemba Island. Nine mangrove species occur in Tanzania (Table 5.1) with *R. mucronata*, *C. tagal* and *A. marina* dominating.

Trends

Establishing trends in mangrove area coverage for most countries in the WIO is constrained by lack of consistent data. Differences in assessment methods in some countries render estimates from different years incompatible (FAO 2010). Mangrove area coverage in most countries is, however, on the decline (Figure 5.3).

In Kenya, the total mangrove area has decreased gradually and it is estimated that, over about 25 years (1985 – 2010), Kenya has lost about 18 per cent of its mangroves at an average rate of 0.7per cent yr^{-1} (Kirui and others,

2012). In the United Republic of Tanzania the available information indicates a similar decrease of 18 per cent over 25 years (1980 – 2005) at a similar rate of 0.7 per cent yr^{-1} (FAO 2007). If one considers the 1989 (115 500 ha) and 2003 (108 138 ha) estimates, the Tanzania mainland has lost about 6 per cent of its mangroves in 14 years (MTNRE 1991, Semesi 1992, Wang and others, 2003). Mangroves on Zanzibar also show a declining trend (refer estimates by Griffith 1949, 1950, Leskinen and Silima 1993, Leskinen and others, 1997).

Between 1990 and 1999-2002, the mangrove cover of Mozambique changed considerably, with a decrease of almost 27 per cent. The rate of mangrove deforestation was estimated at 1 821 ha yr^{-1}, and was highest in Maputo and Beira (Barbosa and others, 2001). The mangrove cover has been decreasing especially in Sofala, Zambezia and Nampula, with the largest changes occurring in Zambezia which has lost almost half of its mangroves (Fatoyinbo and others, 2008). Mangrove cover has, however, increased in Maputo (by 600 ha) and Inhambane (by 1 300 ha) but remained stable in Cabo Delgado (Fatoyinbo and others, 2008).

Due to a paucity of recent countrywide estimates, trends in mangrove cover in Somalia, South Africa and the island states (Madagascar, Seychelles, Comoros and Mauritius) were derived from data provided by the FAO (2007) for the 25-year period of 1980–2005. South Africa lost about 14 per cent of its mangroves at a rate of 0.6 ha yr^{-1}, while Somalia has lost about 23 per cent of its mangroves at a rate of 0.9 ha yr^{-1}. Madagascar has lost about 9 per cent of its mangroves at a rate of about 0.4 ha yr^{-1}, and the Comoros about 8 per cent at a rate of 0.3 ha yr^{-1}. In the Seychelles, mangrove cover has remained stable, while in Mauritius mangrove cover has increased by about 167 per cent, possibly due to mangrove restoration initiatives.

Threats

Threats to mangroves are uniform across the WIO with varying degrees of intensity. They include overharvesting for firewood, timber and charcoal; clearing and conversion to other land uses such as agriculture, aquaculture, urban development, tourism and salt production; pollution; sedimentation and changes in river flow. Natural factors that contribute to mangrove decline include pest infestation, El Niño events and climate change-associated factors such as sea level rise, excessive flooding and increased sedimentation. Details, with examples from various countries, are provided in the following sections.

Overharvesting of wood to be used as firewood, charcoal and timber is the most common threat to mangroves in the region, particularly in urban and peri-urban areas. In Tanzania, intensive mangrove harvesting has been reported in Rufiji (Wagner and Sallema-Mtui 2010), and in Chwaka Bay and Maruhubi on Zanzibar. In Kenya, overharvesting for fuel wood, timber and fish traps has resulted in fragmentation of many mangrove forests (Mohamed and others, 2009). In Mozambique, two islands (Xefina Pequena and Benguelene) have respectively lost about 25 per cent and 40 per cent of their mangrove cover (LeMarie and others, 2006). In Madagascar, overexploitation of mangroves has been reported in the regions of Mahajanga and Toliara (ASCLME 2012i); overharvesting has also occurred in South Africa, Mauritius and the Comoros (Spalding and others, 2010, Taylor and others, 2003). Mangrove wood is further exploited for commercial purposes in Tanzania, Madagascar and Somalia (LeMarie and others, 2006, Semesi 1992, Jones and others, 2014). Debarking of *Rhizophora mucronata* for tannin production has been reported in Zan-

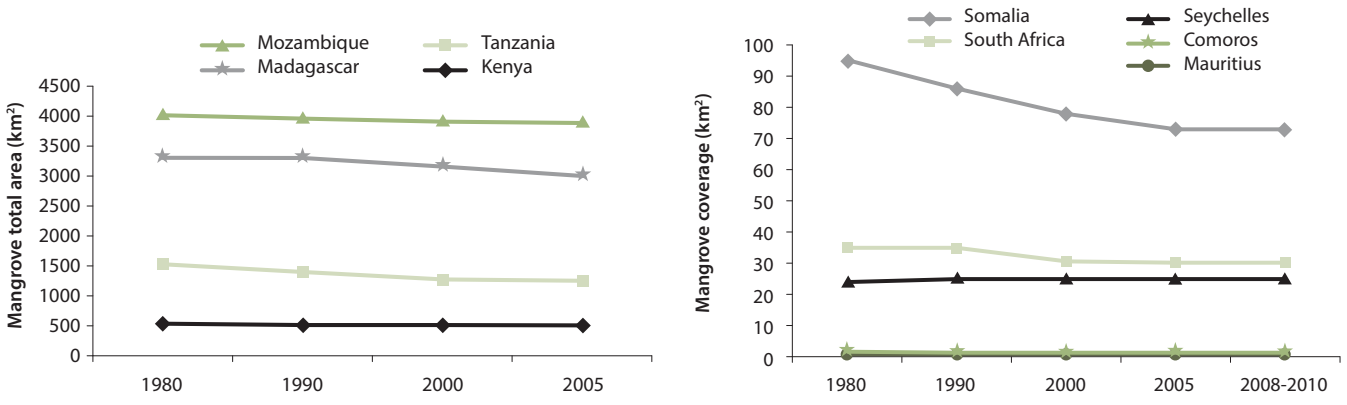


Figure 5.3. Trends in mangrove cover in WIO countries. (Data source: FAO 2007).

zibar (Wells and others, 2004).

Mangrove clearance for other land uses such as agriculture, solar salt production and coastal development is another important threat. Conversion for agriculture has been reported in Tanzania, Madagascar, Somalia, Mozambique and Seychelles (Semesi 1989, FAO 2005, Spalding and others, 2010, Taylor and others, 2003). Solar salt production has caused considerable mangrove loss in the region. For example, Kenya lost more than 500 ha of mangroves in Magarini District due to the construction of salt ponds (Ocholla and others, 2013). Solar salt production has also been reported in Somalia, Tanzania and Mozambique (ASCLME 2012a, ASCLME 2012c, ASCLME 2012d); however, the loss is rarely quantified.

Loss of mangroves due to coastal development is a common threat in the region. The problem is serious in the small island states due to their small size and that of their mangrove forests, the granitic nature of some islands and the constant need for land for human use. In the Seychelles, mangroves (eg on Mahé island) are cleared and sometimes drained (eg along the East Coast) for housing and hotels. Mauritius lost about 30 per cent of its mangroves between 1987 and 1994 (Turner and others, 2000), partly for tourism development (Spalding and others, 2010). Clearance for infrastructural development (eg at Iconi, Grande Comore and Anjouan Domoni) has resulted in considerable loss of mangroves in Comoros. This problem has also been reported in mainland states, including Tanzania, Mozambique and Somalia. Deforestation for shrimp ponds has also caused considerable mangrove deforestation in some countries such as Madagascar (Rasolofoharinoro and others, 1998).

Pollution from industries, agriculture and domestic runoff, and incidences of oil spills, are other important causes of mangrove loss in the region. About 200 ha of mangroves in Port Reitz Creek, Kenya, were totally destroyed by an accidental oil spill that occurred in 2005 (Kairo and others, 2005). In South Africa, oil pollution is prevalent in estuaries in large cities such as Richards Bay, Durban and East London, and in Somalia from tankers in shipping lanes along the Somali coast (ASCLME 2011). Oil pollution may be exacerbated by recent oil discoveries and the exploitation of new reserves in the region. Solid waste disposal is common in mangroves near urban areas. The use of DDT and other pesticides on rice farms also affects mangroves (Semesi and Mzava 1991).

Water abstraction has been reported to cause considerable mangrove loss in the region. In Mozambique, about 2 000 ha of mangroves were lost following the construction of the Cabora Bassa dam (Beilfuss and Brown 2006). This problem has been reported also in Tanzania (Semesi and Mzava 1991).

Sedimentation and coastal erosion is another major threat to mangroves. In Madagascar, between 40 and 50 million tonnes of sediments end up in mangroves every year, causing mangrove degradation (ASCLME 2012i). Sedimentation and coastal erosion also threaten mangrove ecosystems in Tanzania (Francis and others, 2001, Wagner and Sallema-Mtui 2010).

Other threats to mangroves recorded in the region include the El Niño incident of 1997/98, pest infestations and climate change-associated phenomena such as sea level rise, flooding and changes in hydrological regimes (Erftemeijer and Hamerlynck 2005, Diop and others, 2002). In Kenya the 1997/98 El Niño event caused a loss of at least 500 ha of mangroves, particularly in Mwache Creek. Predicted sea-level rise due to climate change is very likely to affect low-lying mangrove areas (FAO 2007, ASCLME 2012c).

SALT MARSHES

Status and trends

Coverage, distribution and composition

Saltmarshes occur almost exclusively in some estuaries and embayments along the coast of South Africa, particularly along the southeastern, southern and western coasts (a small saltmarsh is also reported to occur in Maputo Bay). They are distributed in the supratidal, intertidal and floodplain areas of the cool temperate, warm temperate and subtropical regions of the country. There is a temperate-subtropical gradient in the extent of the salt marshes; they are more extensive in the cool temperate region (52 per cent), followed by the warm temperate region (28 per cent) and last in the subtropical (WIO) region (20 per cent) (Adams and others, in prep).

Recent estimates (Adams and others, in prep) show that salt marshes in South Africa cover a total of 12 344 ha, with only about 2 517 ha (20 per cent) occurring in the WIO (subtropical) region. Here, extensive salt marsh communities occur in St. Lucia (2 222 ha). They also occur in Mhlathuze estuary (60 ha) and in Richards Bay (52 ha).

The species diversity in the saltmarshes is relatively low and often only a few species such as cordgrass *Spartina maritima*, the glasswort *Sarcocornia tegetaria* and the marsh

BOX 5.2. SALT MARSHES AND THEIR IMPORTANCE



A typical salt marsh ecosystem. © Janine Adams.

Salt marshes form an integral part of many estuarine and coastal ecosystems in South Africa (Bornman and others, 2002). These have been divided into intertidal marshes that occur from the mean neap high water mark to the mean spring high water mark, and supratidal marshes that occur above the spring high water mark. These two salt marsh types have different species composition (Adams and others, 1999). Salt marshes are reported to occur in the southern regions of Mozambique (adjacent to dwarf mangroves of Maputo Bay) but are poorly documented.

Salt marshes have a number of important functions, which include sediment stabilization and bank protection, filtration of sediment and pollution, and the provision of feeding areas and shelter for both marine and estuarine organisms. They serve as zones of nutrient capture and retention and are important inorganic and organic nutrient sources for estuarine ecosystems. Whilst some of the plant biomass trapped within these systems decays and enters the associated detritus food chain, much is retained as long-term carbon stores.

samphire *Salicornia meyeriana* are common (ASCLME 2012e). *Spartina maritima* commonly forms extensive monotypic stands in larger estuaries that are permanently open to the sea (Adams and Bate 1995). Three species, namely *Juncus kraussi*, *Sporobolus virginicus* and *Stenotaphrum secundata*, are widespread, occurring in more than half of the South African estuaries (Adams and others, in prep), probably due to their wide salinity tolerance.

The presence or absence of a particular species in a saltmarsh is related to patterns of tidal inundation and salinity. Each habitat supports a distinctive saltmarsh community consisting of one or a few species, resulting in clear zonation in some areas. The typical zonation of salt marshes along the intertidal gradient in South Africa is shown in Figure 5.4. The seagrass *Zostera capensis* Setchell occurs at the lower watermark, followed by cord grass (*S. maritima*). Above this zone, *Sarcocornia tegetaria* is replaced at higher levels by *Triglochin* spp., *Limonium scabrum* and *Bassia dif-*

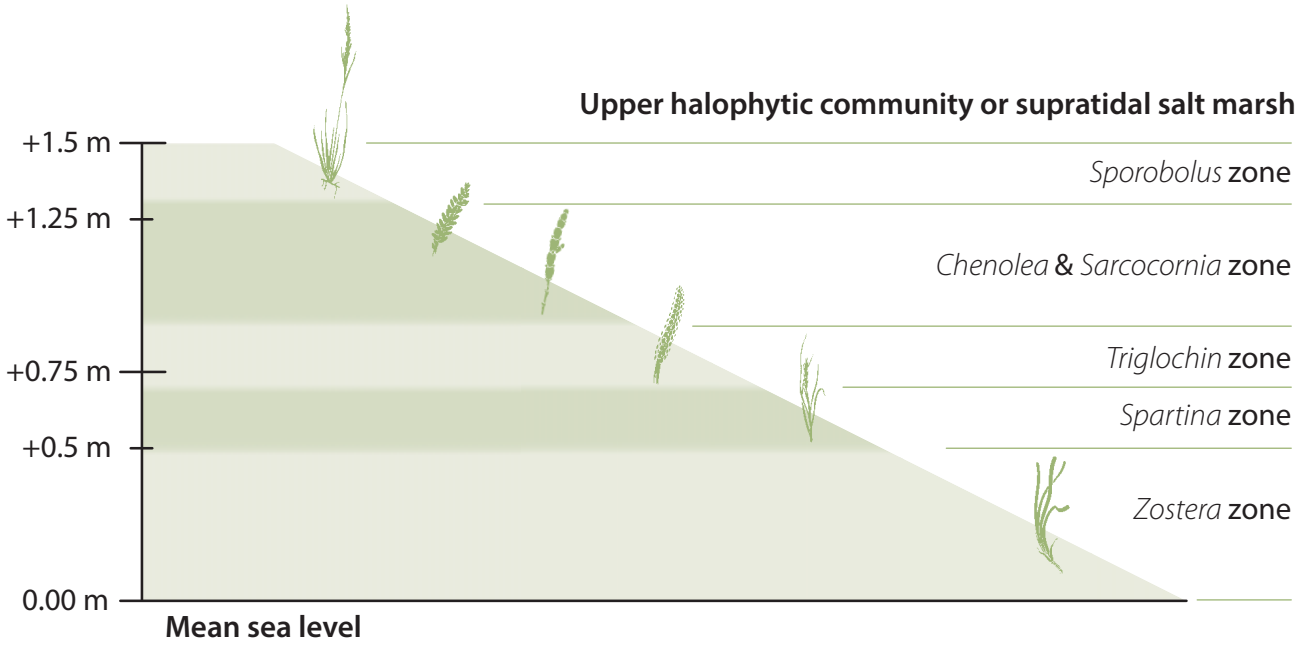


Figure 5.4. General zonation of salt marsh plants in South African estuaries. Adapted from: Adams and others, 1999.

fusa (Adams and Bate 1995).

The co-occurrence of salt marsh and mangrove habitats is common in some estuaries in the warm temperate and subtropical regions of South Africa. However, as one moves towards the subtropics, mangroves become more dominant. Examples of such 'transitional' estuaries include the St Lucia, Mlalazi, Richards Bay and Mhlathuze systems (Adams and others, in prep.). Outside the South African sub-tropical region, saltmarshes are poorly studied and understood in the WIO. However, there are anecdotal reports that they occur in several places between mangrove vegetation and marshland where they are dominated by succulent species such as *B. diffusa*, *Salicornia* sp., *Sesuvium portulacastrum* and *J. krausii*. Some of these species may occupy extensive areas between mangroves and terrestrial vegetation as observed in parts of Maputo Bay. Saltmarshes may also occur intermingled amongst mangroves depending on the extent of their degradation or the presence of extreme dwarf forms. Furthermore, coastal geomorphology may favour the occurrence of some saltmarsh species in north-eastern South Africa and subtropical southern Mozambique where there are numerous coastal lakes, almost all to some extent saline or brackish.

Threats

Saltmarshes in South Africa and elsewhere are threatened by both human and natural factors. Water abstraction, changes in hydrological flows and regimes, and the closure of river mouths are some of the main threats to saltmarshes in South Africa. Considerable water reduction from abstraction leads to massive dieback of salt marshes on floodplains. Other threats to salt marshes include urban and industrial developments, salt works, mining, boating, fishing, livestock grazing/trampling and siltation.

SEAGRASSES

Status and trends

Composition and coverage

Seagrasses are distributed throughout the WIO region; from north coast of Somalia to the north coast of South Africa, and in the island states (ASCLME 2012c). They are distributed from the intertidal zone down to about 40 m depending on water clarity, and often occur in close connection with coral reefs and mangroves. Twelve species belonging to three families, namely Zosteraceae, Hydrocharitaceae and Cymodoceaceae, occur commonly in the region, two species, *Halophila decipiens* and *Halophila beccarii*, being added recently (see Waycott and others, 2004, Bandeira 2011). This number excludes another two species: *Halodule wrightii*, which according to Ochieng and Erftermeijer (2003), Waycott and others (2004), and Bandeira (2011), does not occur in the region and is *Halodule uninervis* which was misidentified in the past, and *Halophila minor*, which is considered a member of the *Halophila ovalis* complex (Waycott and others, 2004). Kenya, Tanza-

BOX 5.3. SEAGRASSES AND THEIR IMPORTANCE




Dense mixed seagrass bed (left) and monospecific sparse stand of *Thalassia hemprichii* (right) at Inhaca Island, Mozambique. © José Paula and Salomão Bandeira, repectively.

Seagrasses are one of the most productive aquatic ecosystems on earth, and are widely distributed in both tropical and temperate coastal waters. They serve as critical nurseries and foraging grounds for numerous fishes and invertebrates. In the WIO region, seagrass habitats are known to support populations of two endangered species, the green sea turtle (*Chelonia mydas*) and dugong (*Dugong dugon*) (ASCLME/SWIOFP 2012b).

nia and Mozambique support the highest diversity of seagrasses (UNEP/ Nairobi convention secretariat 2009). Details of each country in the WIO are provided in the following sections.

Comoros: Eight seagrass species are found in the Comoros (Table 5.2). Extensive seagrass beds are found in the Mohéli Marine Park, which harbours almost 90 per cent of the seagrasses in the country (ASCLME 2012f). The remaining area is made up of seagrass beds located at Mitsamiouli, Malé and Ouroveni in Grande Comoro and at Bimbini and Ouani in Anjouan.

Kenya: Ten species of seagrasses are reported to occur in Kenya (Table 5.2), with *Thalassodendron ciliatum*, a species that usually forms monospecific stands, being dominant (Richmond 2011, Ochieng and Erftemeijer 2003). Seagrass beds in Kenya are estimated to cover an area of 3 400 ha (ASCLME 2012b, ASCLME/SWIOFP 2012b). Important seagrass beds in Kenya include Kiunga, Malindi, Mombasa, Diani-Challe, Gazi Bay and Mida Creek (Dahdouh-Guebas and others, 1999, ASCLME 2012b).

Madagascar: Madagascar harbours seven seagrass species (Table 5.2). Most seagrass beds are dominated by *T. ciliatum* and *Thalassia hemprichii* (Bandeira and Gell 2003); however, information on the seagrasses of Madagascar is limited.

Mauritius: Six seagrass species are known to occur in the Republic of Mauritius (Table 5.2). Rodrigues, in particular, has only two *Halophila* species (ASCLME 2012g). Seagrass beds cover an estimated area of 55 ha and 649 ha in Mauritius and Rodrigues, respectively (Turner and Klaus 2005).

Mozambique: Ten species of seagrasses are found in Mozambique (Table 5.2). Seagrass beds in this country are estimated to cover a total surface area of 43 900 ha (Bandeira and Gell 2003), with 2 500 ha at Inhassoro and Bazaruto Island, 3 000 ha at Mecufi-Pemba and 4 500 ha in the southern Quirimbas Archipelago (Green and Short 2003). Seagrasses were reported to cover half of the intertidal area around Inhaca Island (Bandeira 2002).

Reunion: In Reunion, monospecific stands of the seagrass *Syringodium isoetifolium* are dominant. They are mainly found in reefal lagoons (ASCLME/SWIOFP 2012a).

Seychelles: Seychelles is endowed with nine seagrass species (Table 5.2) (ASCLME 2012h). The total area covered is unknown, but *Cymodocea serrulata*, *S. isoetifolium*

Table 5.2. Seagrass distribution in different countries in the WIO region.

Families	Species	Somalia	Kenya	Tanzania	Mozambique	South Africa	Madagascar	Mauritius	Seychelles	Comoros	Reunion
Cymodoceaceae	***Cymodocea rotundata*** Ehrenberg & Hemprich ex Ascherson	X	X	X	X	X	X		X	X	
Cymodoceaceae	***Cymodocea serrulata*** (R. Brown) Ascherson	X	X	X	X	X	X	X	X	X	
Cymodoceaceae	***Halodule uninervis*** (Forsskal) Ascherson	X	X	X	X		X	X	X	X	
Cymodoceaceae	***Syringodium isoetifolium*** (Ascherson) Dandy	X	X	X	X			X	X	X	X
Cymodoceaceae	***Thalassodendron ciliatum*** (Forsskal) den Hartog		X	X	X		X	X	X	X	
Hydrocheritaceae	***Enhalus acoroides*** (L.f) Royle		X	X	X				X		
Hydrocheritaceae	***Halophila ovalis*** (R. Brown) Hooker f.	X	X	X	X	X	X	X	X	X	
Hydrocheritaceae	***Halophila stipulacea*** (Forsskal) Ascherson	X	X	X	X		X	X		X	
Hydrocheritaceae	****Halophila decipiens*** Ostenfeld, 1902										
Hydrocheritaceae	****Halophila beccarii*** Ascherson, 1871										
Hydrocheritaceae	***Thalassia hemprichii*** (Ehrenberg) Ascherson	X	X	X	X	X	X		X	X	
Zosteraceae	***Zostera capensis*** Setchell		X	X	X	X					
	Total number of species	**7**	**10**	**10**	**10**	**5**	**7**	**6**	**8**	**8**	**1**

*Recent documentation – exact location may be dependent of subtidal observation (Waycott and others, 2004, Bandeira 2011).

and *T. hemprichii* are generally dominant (Bandeira and Gell 2003). Seychelles possesses the deepest seagrass stands in the WIO as *T. ciliatum* was observed at 33 m (Titlyanov and others, 1995).

Somalia: Seven species of seagrasses have been identified in Somalia (Table 5.2), with *T. ciliatum* being abundant in most areas (UNEP/ Nairobi convention secretariat 2009, ASCLME 2012c). Seagrasses are limited in distribution from Adale to Ras Chiamboni and there are a few beds along the north coast (ASCLME 2012c).

South Africa: Seagrass beds in South Africa are limited to the sheltered waters of estuaries (ASCLME 2012e). South Africa hosts five seagrass species (Table 5.2). *Zostera capensis* is dominant in sheltered east coast estuaries with muddy bottoms, while *T. ciliatum* is dominant on the rocky shorelines. Information on the total area covered by seagrasses in the country is not available for most species, although that of the most common seagrass species (*Zostera capensis*) is estimated at 700 ha (Bandeira and Gell 2003).

Tanzania: Ten species of seagrasses (Table 5.2) occur in Tanzania. Dominant seagrasses include *T. hemprichii*, *S. isoetifolium* and *T. ciliatum* (ASCLME 2012a). One other species, *Z. capensis*, has also been reported to be present in the country (Bandeira and Gell 2003), although this has not been independently verified. The most extensive seagrass beds occur along the Tanga coast, in the deltas of the Ruvu, Wami and Rufiji Rivers, on Mafia Island, in the Songo Songo Archipelago and around Kilwa and Chwaka Bay (UNEP/Nairobi Convention Secretariat 2009, ASCLME 2012a). The area of the seagrass beds and the relative species densities are yet to be established in Tanzania. However in one area, Chwaka Bay, seagrasses are estimated to cover 10 000 ha (UNEP/Nairobi Convention Secretariat 2009).

Threats

Damage to seagrass beds in the WIO is rarely documented. As a result, the extent and severity of damage on most seagrass beds are difficult to estimate in the region given the lack of data. Threats to seagrass beds in the different countries are more or less similar and are mainly attributable to human activities, although natural factors also play an important role. Some examples are summarised in the following section.

Comoros seagrasses have been affected by sedimentation and climate change. For example, *T. ciliatum* beds in Mohéli Marine Park were destroyed by high sediment influx into the lagoon from upland deforestation, coupled

with high rainfall, which took place between 1993 and 1998 (ASCLME 2012f). Some re-colonization has been reported. In Kenya, increased sedimentation (from some 58 000 tonnes per annum in 1960 to up 7-14 million tonnes per annum in Sabaki catchment) has significantly affected Kenyan seagrass beds (Katwijk and others, 1993). Beach seining in most intertidal seagrass beds and shallow water trawling are among the major threats to seagrass beds in Tanzania (Green and Short 2003). In Mozambique, *Z. capensis* has disappeared from the bay in front of Inhaca's main village due to trampling and the heavy concentration of fishing and tourist activities (ASCLME/SWIOFP 2012a). Moreover, digging in *Z. capensis* and related seagrass beds to collect bivalves, together with flooding, has dramatically depleted the seagrass cover at Bairro dos Pescadores near Maputo (Bandeira and Gell 2003). Mozambican seagrasses are also threatened by oil pollution (Munga 1993). Seagrass area loss in Mozambique is estimated at 2 755 ha (Bandeira and Gell 2003).

Natural threats to seagrasses include grazing by sea urchin as observed in Mombasa lagoon in Kenya (Alcoverro and Mariani 2002), and shoreline dynamics that cause sand deposition and removal.

DRIVING FORCES

The driving forces behind mangrove degradation and loss include rapid demographic growth, poverty, inadequate education and environmental awareness, inadequate law enforcement, economic growth and global market forces, and climate change (UNEP/Nairobi Convention Secretariat 2009, Wagner 2007).

On a decision-making level, a low level of knowledge and awareness of the real value of the goods and services provided by mangroves has contributed to poor decision-making, especially when choices between conservation and development have to be made (Lal 2002). A worst-case scenario occurred in Tanzania when, in 1998, the Government approved a shrimp farm project which, if not halted by the joint efforts of stakeholders, would have resulted in the clearance of about 19 000 ha of mangroves in the Rufiji delta (Bryceson 1998). Mangrove clearance in favour of tourism has occurred in many countries in the WIO and, if left to continue, could lead to severe consequences, including the complete elimination of mangroves, especially in the Small Island Developing States. Low levels of knowledge and awareness also contribute to weak enforcement of existing legislation, resulting in uncontrolled destructive practices (eg forest encroachment and waste disposal). For example, mangrove clearance for urban expansion has been one of the main threats to mangroves. Poverty translates into overdependence on natural resources by poor communities due to limited alternative sources of livelihood. For example, demand for firewood and charcoal as cheap alternative sources of energy has caused massive mangrove loss across the WIO region. Poverty underlies similar destructive drivers in salt marshes and seagrass ecosystems, which tend to be incidentally damaged during extraction of related resources such as fish.

IMPACTS

The greatest impact of the decline of these habitats is a loss of their nursery function with an associated reduction in fish catches. Other negative effects include a decrease in estuarine biodiversity, shoreline protection and the amount of organic carbon exported to the marine environment (Rajkaran 2011). Impacts on human well-being associated with the loss of these ecosystem goods and services include food insecurity and the loss of livelihoods.

RESPONSES

Mangroves

Background information on mangrove management in most WIO countries is provided by de Lacerda (2001). Basically, there is no legislation specific to mangrove management in almost all countries in the WIO. Mangrove management is instead included in other legislation and often more than one instrument and/or institution is involved.

In Kenya, Tanzania, Mozambique, South Africa and Madagascar, the management of mangroves is included in the management of terrestrial forests. In Kenya, the Forest Act of 2005 oversees the management of mangroves, while the Forest Act of 2002 (on the Tanzanian mainland) and the Forest Resources Management and Conservation Act of 1996 (on Zanzibar) are responsible for the management of mangroves in Tanzania. In Mozambique, a range of legislation governs mangrove management, including the Law of Forests and Wildlife of 1999, Land Law of 1997, Environmental Law and Tourism Law. In South Africa, the National Forests Act (No 84 of 1998), which

controls the management of forestry in the country, also covers the management of mangroves. In addition, the Marine Living Resource Act (18 of 1998) covers the management of mangrove forests and associated biota (Rajkaran 2011). In Madagascar, the management of coastal plant resources is the responsibility of the Ministry of Environment and Forests, and the Ministry of Fisheries and Marine Resources (Andriamalala 2007).

In Seychelles, mangrove management is covered by the Environment Protection Act, EPA 1994, which deals with water bodies in general. The Seychelles National Wetland Policy also contributes to mangrove management. In Mauritius mangrove management is catered for by the Fisheries and Marine Resources Act of 1998 as well as the National Environment Policy (NEP) 2007. In the Comoros, an Environmental Action Plan governs the management of mangroves. Coastal and marine environmental governance in Somalia is generally very weak due to the absence of a strong central government. Specific policies and legislation to address environmental issues are generally lacking (ASCLME 2012c).

A mangrove management plan is vital for the successful conservation of mangroves. Most countries in the region (except Tanzania) do not have mangrove management plans. A mangrove management plan for Zanzibar was prepared in 2008-2009. The one for the Tanzania mainland was developed in 1991 and, although it was the first mangrove management plan within the region, the plan is now outdated and requires revision to include new and emerging issues in the sector.

While, in some countries (eg Kenya and Tanzania), mangroves have been declared forest reserves since the colonial era, mangrove forests are also included in protected areas in many countries within the WIO. The total mangrove area in these protected areas is, however, often small. The designation of areas containing mangroves as Ramsar Sites eg Port Launay in Seychelles (Taylor and others, 2003) and Rufiji-Mafia-Kilwa in Tanzania has also contributed to mangrove protection in the WIO region.

Mangrove restoration is a common management initiative in all countries within the region. The significant increase in mangrove area coverage in Mauritius (about 167%), due to restoration provides an example of a successful initiative. Community participation is a key to the successful management of mangroves. NGOs and CBOs in the region are active and most take part in the management of mangroves, including mangrove restoration initiatives.

Saltmarshes

Most saltmarshes occur in estuaries and are consequently included in the management plans of estuaries required by the Integrated Coastal Management Act in South Africa. The South African National Water Act (Act 36 of 1998) necessitates the determination of the ecological reserve for estuaries before abstraction of freshwater. This is the amount of water required by an estuary to maintain its structure and function within a particular health class (Adams and others, 1992).

Seagrasses

There is no legislation in place within the WIO region to protect seagrass beds. However, seagrass beds are covered under legislation that protects fishery resources. Seagrasses are also protected in marine protected areas (MPAs), although no MPA has been designed solely for this purpose. Even within MPAs that incorporate seagrass beds they do not receive special attention; as a result only a small fraction of seagrass beds are included in MPAs (Green and Short 2003). An accelerating decline in the extent of seagrass beds in the WIO region calls for more research to generate information needed for their sustainable management in the WIO (Gullström and others, 2002).

POLICY OPTIONS

Mangrove and salt marsh degradation in the WIO continues despite present management initiatives. The situation is worse for seagrasses, which lack a clear management framework. The following policy options are therefore proposed:

- A mangrove management plan for each country.
- Habitat mapping that would involve the use of old and new techniques to establish the compatibility of resource use of these resources.
- Ecosystem monitoring.
- Habitat restoration and rehabilitation, if possible supported by restoration guidelines or manuals,
- Integrated coastal zone management to control pollution and sedimentation from catchment areas.
- Raised awareness regarding the importance of mangroves, salt marshes and seagrasses.
- Enforcement of laws and regulations pertaining to the conservation of these habitats.
- A full economic valuation of mangroves, salt marshes and seagrasses, incorporating the full range of their ecosys-

tem services to allow their appropriate inclusion in coastal development planning.

References

Adams, J.B., Veldkornet, D. and Tabot, P. (in prep.). Distribution of macrophyte species and habitats in South African estuaries: implications for conservation and management

Adams, J.B. Bate, G.C. and M. O'Callaghan. (1999). Estuarine Primary Producers. In Estuaries of South Africa (eds. Allanson, B.R. and Baird, D.) pp. 91-118

Adams, J.B. and Bate, G.C. (1995). Ecological implications of tolerance of salinity and inundation by *Spartina maritima*. *Aquatic Botany* 52, 183–191

Adams, J.B., W.T. Knoop and Bate, G.C. (1992). The distribution of estuarine macrophytes in relation to freshwater. *Bot. Mar*. 35, 215-226

Alcoverro, T. and Mariani, S. 2002. Effects of sea urchin grazing on seagrass (*Thalassodendron ciliatum*) beds of a Kenyan lagoon. *Mar. Ecol. Prog. Ser.* 226, 255–263

Andriamalala, A. (2007). *Etude* écologique *pour la gestion des mangroves à Madagascar: Comparaison d'une mangrove littorale et d'estuaire à l'aide de la télédétection*. Thèse de doctorat. Université de Basel

ASCLME (2011). *Marine Pollution in the Agulhas & Somali Currents Large Marine Ecosystem*. *Copenhagen*, *Denmark*

ASCLME (2012a). *National Marine Ecosystem Diagnostic Analysis. Tanzania*. Contribution to the Agulhas and Somali Current Large Marine Ecosystems Project (supported by UNDP with GEF grant financing)

ASCLME (2012b). *National Marine Ecosystem Diagnostic Analysis. Kenya*. Contribution to the Agulhas and Somali Current Large Marine Ecosystems Project (supported by UNDP with GEF grant financing)

ASCLME (2012c). *National Marine Ecosystem Diagnostic Analysis. Somalia*. Contribution to the Agulhas and Somali Current Large Marine Ecosystems Project (supported by UNDP with GEF grant financing)

ASCLME (2012d). *National Marine Ecosystem Diagnostic Analysis. Mozambique*. Contribution to the Agulhas and Somali Current Large Marine Ecosystems Project (supported by UNDP with GEF grant financing)

ASCLME (2012e). *National Marine Ecosystem Diagnostic Analysis. South Africa*. Contribution to the Agulhas and Somali Current Large Marine Ecosystems Project (supported by UNDP with GEF grant financing)

ASCLME (2012f). *National Marine Ecosystem Diagnostic Analysis. Comoros*. Contribution to the Agulhas and Somali Current Large Marine Ecosystems Project (supported by UNDP with GEF grant financing)

ASCLME (2012g). *National Marine Ecosystem Diagnostic Analysis. Mauritius*. Contribution to the Agulhas and Somali Current Large Marine Ecosystems Project (supported by UNDP with GEF grant financing)

ASCLME (2012h). *National Marine Ecosystem Diagnostic Analysis. Seychelles*. Contribution to the Agulhas and Somali Current Large Marine Ecosystems Project (supported by UNDP with GEF grant financing)

ASCLME (2012i). *National Marine Ecosystem Diagnostic Analysis. Madagascar*. Contribution to the Agulhas and Somali Current Large Marine Ecosystems Project (supported by UNDP with GEF grant financing)

ASCLME/SWIOFP (2012a). *Transboundary Diagnostic Analysis for the western Indian Ocean*. vol. 1: Baseline. South Africa

ASCLME/SWIOFP (2012b). *Transboundary Diagnostic Analysis for the western Indian Ocean*. vol. 2: Diagnostic Analysis. South Africa

Bandeira, S.O. (2002). Diversity and distribution of seagrasses around Inhaca Island, southern Mozambique. *S. Afr. J. Bot*. 68, 191–198

Bandeira, S.O. and Gell, F. (2003). The seagrasses of Mozambique and Southeastern Africa. In *World Atlas of Seagrasses (*eds. Green, E.P. and Short, F.T.) pp. 93-100. University of California press, Berkeley, Los Angeles, London

Bandeira S.O. (2011). Seagrasses. In *A Field Guide to the Seashores of Eastern Africa and the Western Indian Ocean Island* (ed. Richmond, M.D.) 3rd Edition, pp. 74-77

Barbosa, F.M.A., Cuambe, C.C. and Bandeira, S.O. (2001). Status and distribution of mangroves in Mozambique. *S. Afr. J. Bot*. 67, 393-398

Beilfuss, R. and Brown, C. (2006). A*ssessing environmental flow requirements for the Marromeu Complex of the Zambezi Delta: Application of the DRIFT Model (Downstream Response to Imposed Flow Transformations)*. Museum of

Natural History-University of Eduardo Mondlane, Maputo, Mozambique.

Bornman, T.G., Adams, J.B. and Bate, G.C. (2002). Freshwater Requirements of a Semi-arid Supratidal and Floodplain Salt Marsh. *Estuaries* 25, 1394–140

Bryceson, I. (1998). *Public plea to the Tanzanian government to reject Rufiji prawn project*.

Colloty, B.M., Adams, J.B. and Bate, G.C. (2002). Classification of estuaries in the Ciskei and Transkei regions based on physical and botanical characteristics. *S. Afr. J. Bot*. 68, 312–321

Dahdouh-Guebas, F., Coppejans, E., and Van Speybroeck, D. (1999). Remote sensing and zonation of seagrasses and algae along the Kenyan coast. Kluwer Academic Publishers, Netherlands. *Hydrobiologia* 400, 63–73

de Lacerda, D.L. (2001). *Mangrove Ecosystems: Function and Management*. Springer

Diop. E.S., Gordon, C., Semesi, A.K., Soumare, A., Diallo, A., Guisse, A., Diouf, M. and Ayivor, J.S. (2002) Mangroves of Africa. In *Mangrove Ecosystems: Function and Management* (ed. de Larceda, L.D.) pp. 61-121. Springer-Verlag, Berlin

Donato, D.C., Kauffman, J. B., Murdiyarso, D., Kurnianto, S., Stidham, M. and Kanninen, M. (2011). Mangroves among the most carbon-rich forests in the tropics. *Nature Geosci*, 4, 293-297

Duke, N. (2006). *Australia's Mangroves. The Authoritative Guide to Australia's Mangrove Plants*. University of Queensland

Erftemeijer, P. and Hamerlynck, O. (2005). Die-back of the mangrove *Heritiera littoralis* in the Rufiji Delta (Tanzania) following El Nino floods. *J. Coast. Res*. 42, 228-235

FAO (2005). *Global forest resources assessment 2005*. Thematic study on mangroves-Somalia Country profile. FAO. Rome

FAO (2007). *The world's mangroves 1980-2005*. A thematic study prepared in the framework of the Global Forest Resources Assessment 2005 FAO. Rome

FAO (2010). Global Forest resources assessment 2010. Main report. Rome

Fatoyinbo, T., Simard, M., Washington-Allen, L. and Shugart, H. (2008). Landscape extent, height, biomass, and carbon estimation of Mozambique's mangrove forests with Landsat ETM+ and Shuttle Radar Topography Mission Elevation Data. *J. Geophys. Res*. 113, G02S06

Francis, J., Wagner, G.M., Mvungi, A., Ngwale, J.J. and Salema, R. (2001). *Tanzania National Report: Integrated Problem Analysis*. A report prepared for ACOPS, IOC/UNESCO and UNEP as part of implementation of the GEF MSP Sub-Saharan Africa Project (GF/6010-0016): Development and Protection of the Coastal and Marine Environment in Sub-Saharan Africa

Giri, C., Ochieng, E., Tieszen, L.L, Zhu, Z., Singh, A. and Loveland, T. (2011). Status and distribution of mangrove forests of the world using earth observation satellite data. *Global Ecol. Biogeogr*. 20, 154–159

Green, E.P. and Short, F.T. (eds.) (2003). *World Atlas of Seagrasses*. UNEP World Conservation Monitoring Centre. University of California Press. Berkeley, USA

Griffith, A.L. (1949). *Reconnaissance report on the forest problems of the Zanzibar Protectorate*. The Government Printer, Zanzibar

Griffith, A.L. (1950). *Working scheme for the mangroves of the Zanzibar Protectorate*. The Government Printer, Zanzibar

Gullström, M., Castro, M., Bandeira, S.O., Björk, M., Dahlberg, M., Kautsky, N., Rönnbäck, P. and Öhman, M.C. (2002). *Seagrass Ecosystems in the Western Indian Ocean*. Royal Swedish Academy of Sciences. *Ambio* 31, 7-8

Jones, T.G., Ratsimba, H.R., Ravaoarinorotsihoarana, L., Cripps, G. and Bey, A. (2014). Ecological Variability and Carbon Stock Estimates of Mangrove Ecosystems in Northwestern Madagascar. *Forests* 5, 177-205

Kairo, J.G., Bosire, J.O. and Omar, M. (2005). *Assessment of the effects of oil spill on the mangrove forest of Port Reitz*, Mombasa

Katwijk, M.M., Meier, N.F., van Loon, R., van Hove, E.M., Giesen, W.B.J.T, van der Velde, G. and den Hartog, C. (1993). Sabaki River sediment load and coral stress: correlation between sediments and condition of the Malindi-Watamu reefs in Kenya (Indian Ocean). *Mar. Biol*. 117, 675-683

Kirui, K. B., Kairo, J. G., Bosire, J., Viergever, K. M., Rudra, S., Huxham, M. and Briers, R. A. (2012). Mapping of mangrove forest land cover change along the Kenya coastline using Landsat imagery. *Ocean Coast. Manage*. 83, 19-24

Lal, P. N. (2002). Integrated and Adaptive Mangrove Management Framework - An Action Oriented Option for the New Millenium, *In Mangrove Ecosystems: Function and Management* (ed. de Lacerda, L.D.). pp. 235-256

LeMarie, M., Van Der Zaag, P., Menting, G., Baquete, E. and Schotanus, D. (2006). The use of remote sensing

for monitoring environmental indicators: the case of the Incomati estuary, Mozambique. *Phys. Chem. Earth*. 31, 857–863.

Leskinen, J., Pohjonen, V.M. and Mbarouk, S.A. (1997). *Woody Biomass Inventory of Zanzibar Islands*. Zanzibar Forestry Development Project Technical Paper No. 40. Commission for Natural Resources, Zanzibar and Forest and Park Services, Helsink

Leskinen, J. and Silima, P.A. (1993). *Unguja and Pemba coral rag forest inventory*. Zanzibar Forestry Development Project Technical Paper No. 10. Commission for Natural Resources, Zanzibar and Forest and Park Services, Helsinki

Mohamed, M., Neukermans, G., Kairo, J., Dahdouh-Guebas, F. and Koedam, N. (2009). Mangrove forests in a peri-urban setting: the case of Mombasa (Kenya). *Wetl. Ecol. Manag*. 17, 243-255

MTNRE (1991). *Management plan for the mangrove ecosystem of mainland Tanzania*. vol. 1-10. Ministry of Tourism, Natural Resources and Environment, Forest and Beekeeping Division, Catchment Forest Project, Dar es Salaam

Munga, D. (1993). *The impact of pollution on the mangrove ecosystem in Kenya*. National Workshop for improved management and conservation of the Kenyan mangroves. August 1993. pp. 255 - 272

Ochieng, C.A. and Erftemeijer, P.L.A. (2003). Seagrasses of Kenya and Tanzania. In *World Atlas of Seagrasses (*eds. Green, E.P. and Short, F.T.) pp. 82-92. University of California press, Berkeley, Los Angeles, London

Ocholla, G.O., Bunyasi, M.M., Asoka, G.W., Pacha, O., Mbugua, H.K., Mbuthi, P., Mbiti, S., Wendo, H.K. and Kamau P.K. (2013). Environmental Issues and Socio-economic Problems Emanating from Salt Mining in Kenya; A Case Study of Magarini District. *Int. J. Human. Soc. Sci. Res.* 3, 3

Rajkaran, A. (2011). *A status assessment of mangrove forests in South Africa and the utilization of mangroves at Mngazana Estuary*. PhD Thesis. Faculty of Science at Nelson Mandela Metropolitan University

Rajkaran, A., Adams, J.B. and du Preez, D.R. (2004). The use of GIS to monitor the extent of mangrove harvesting in the Mngazana estuary, Eastern Cape, South Africa. *Afr. J. Aquat. Sci.* 29(1), 57–65

Rasolofoharinoro, M., Blasco, F., Bellan, M.F., Aizpuru, M., Guaquelin, T. and Denis, J. (1998). A remote sensing based methodology for mangrove studies in Madagascar. *Int. J. Remote. Sens.* 19, 1873-1886

Richmond, M.D. (2011). *A Field Guide to the Seashores of Eastern Africa and the Western Indian Ocean Island*. 3rd Edition. pp. 74-77

Semesi, A.K. (1989). *The mangrove resources of the Rufiji Delta, Tanzania*. Paper presented at a workshop on Marine Sciences in East Africa. Institute of Marine Sciences, University of Oar es Salaam

Semesi, A.K. (1992). Developing management plans for the mangrove forest reserves of mainland Tanzania. *Hydrobiologia* 247, 1-10

Semesi, A.K. and Mzava, E.M. (1991). *Management plans for mangrove ecosystem of mainland Tanzania*. vol 1-10. Ministry of Tourism Natural Resources and Environment, Forestry and beekeeping Division, Mangrove Management Project, Dar es Salaam, Tanzania

Spalding, M., Kainuma, M. and Collins, L. (2010). *World Atlas of Mangroves*. The International Society for Mangrove Ecosystems, Okinawa, Japan

Spalding, M.D., Blasco, F. and Field, C.D. (eds.) (1997). *World Mangrove Atlas*. The International Society for Mangrove Ecosystems, Okinawa, Japan

Taylor, M., Ravilious, C. and Green, E.P. (2003). *Mangroves of East Africa*. UNEP-WCMC Biodiversity Series 13. Cambridge

Titlyanov E., Cherbadgy I. and Kolmakov P. (1995). Daily variations of primary production and dependence of photosynthesis on irradiance in seaweeds and seagrass *Thalassodendron ciliatum* of the Seychelles Islands. *Photosynthetica* 31, 101-115

Turner, J.R. and Klaus, R. (2005). Coral Reefs of the Mascarenes, Western Indian Ocean. *Philosophical Transactions of the Royal Society* 363, 1-22

Turner, J, Jago, C. Daby D. and Klaus, R. (2000). In *Seas at the Millennium: An environmental evaluation*. (ed. Sheppard, C.) The Mascarene Region, pp. 253-268, Elsevier Science Ltd.

UNEP/Nairobi Convention Secretariat, 2009. *Transboundary Diagnostic Analysis of Land-based Sources and Activities Affecting the Western Indian Ocean Coastal and Marine Environment*. Nairobi, Kenya

Kaschner, K., Rius-Barile, J., Kesner-Reyes, K., Garilao, C., Kullander, S.O., Rees, T. and Froese, R. (2013). *AquaMaps: Predicted range maps for aquatic species*. World wide web electronic publication: www.aquamaps.org, Version August 2013. http://data.unep-wcmc.org/datasets/10

Valiela, I., Bowen, J.L. and York, J.K. (2001). Mangrove Forests: One of the World's Threatened Major Tropical Environments. *Bioscience* 5, 807-815

Wagner, G.M. (2007). The Dar es Salaam Seascape: A Case Study of an Environmental Management 'Hotspot'. *Western Indian Ocean Journal of Marine Science*. 6, 85–109

Wagner, G.M. and Sallema-Mtui, R. (2010). *Change Analysis of Rufiji-Mafia-Kilwa Mangroves (Tanzania) In Relation To Climate Change Factors and Anthropogenic Pressures*. WWF: Dar es Salaam, Tanzania

Wang, Y., Bonynge, G., Nugranad, J., Traber, M., Ngusaru, A., Tobey, J., Hale, L., Bowen, R. and Makota, V. (2003). Remote sensing of mangrove change along the Tanzania coast. *Mar. Geod.* 26, 1–14

Ward, C.J. and Steinke, T.D. (1982). A note on the distribution and approximate areas of mangroves in South Africa. *S. Afr. J. Bot.* 1, 51-53

Waycott, M., McMahon, K., Mellors, J., Calladine, A. and Kleine, D. (2004). *A guide to tropical seagrasses of the Indo-West Pacific*. James Cook University, Townsville

Wells, S., Juma, S., Muhando, C., Makota, V. and Agardy, T. (2004). *Study on the ecological basis for establishing a system of marine management areas in the United Republic of Tanzania: Options for an MPA/MMA network*. Report prepared for the World Bank, Tanzania Office, Dar es Salaam



6
Coral and Biogenic Reef Habitats

David Obura

Opposite page: A soft coral of the genus *Scleronephthya*, found occasionally under ledges and overhangs on reefs in the WIO. © Michael H. Schleyer.

INTRODUCTION

Coral reefs are among the best-known marine habitats in the WIO. They are found throughout the region where rocky substrata occur between about 0 and 50 m depth, and water clarity and quality are adequate to give them a competitive edge through their symbiosis with zooxanthellae living within their tissues. The distribution of coral reefs in the WIO is relatively well known, comprising four main classes of reef: fringing reefs are found around all the islands and along the East African coast; barrier reefs are most strongly developed at Tulear (Madagascar) and around Mayotte (which also has a second/inner barrier within its lagoon); atolls are found in the Seychelles (eg Aldabra, Cosmoledo, Farquhar, Alphonse) and Mozambique Channel (Europa, Bassas da India and the submerged atolls of Zélée and Geyser); and numerous coral banks, such as those along the continental coastline (eg at Malindi, Kenya; Leven and Castor, NW Madagascar; Africa Bank, Mozambique), and the very large oceanic banks of the Mascarene Plateau (Cargados Cajaros, Nazareth and Saya de Malha), and the North Seychelles Bank.

The precise area of reef habitat in the WIO is not yet determined accurately. The most commonly used area estimates (Table 6.1) include many 'coral reef-associated' habitats, such as deeper rubble beds and channels between reefs. The Millennium Coral Reef Mapping Project, which has completed the most comprehensive global mapping of coral reefs has validated maps for the islands, giving higher reef areas in many cases than previously thought (see Table 6.1), but the mainland reefs have not been validated. Because the fringing reef systems of the mainland coast are generally narrow and have high levels of terrestrial input, light penetration is generally low, introducing significant errors in analysis of satellite images.

Non-coral biogenic reefs are limited in distribution in the WIO, though many facies of coral reef environments are dominated by other biota that build reef frameworks (as mentioned above), including coralline algae, seagrasses, foraminifera, pelycepods and others. In temperate waters, bivalve reefs become more common, particularly in South Africa in intertidal and shallow subtidal zones (Beck and others, 2011); further work will probably reveal some in the southern temperate waters of Madagascar as well (Bouchet 2012).

Because coral reefs are among the most biodiverse and productive ecosystems, and are found in benign environments along the coast, they support many human activities, and are among the most valuable of ecosystems for the services they provide. Thus, they are of great importance for both intrinsic and utilitarian reasons. They have been exhaustively covered in prior regional syntheses, for example the national level Marine Ecosystem Diagnostic Analyses (MEDA) and regional Trans-boundary Diagnostic Analyses (TDA) conducted by the TRANSMAP, WIO-LAB, ASCLME and SWIOFP GEF projects (see TRANSMAP 2008, UNEP/Nairobi Convention Secretariat 2009, ASCLME/SWIOFP 2012a, ASCLME/SWIOFP 2012b).

Table 6.1. Summary of coral reef statistics for countries and major reef areas in the WIO. Adapted from Obura and others (2012).

	Reefs at risk[a] %	Reef area km^2 [b]	Coral diversity [c]	MPAs with coral reefs [d]
Comoros	99	430/305	314/223	1 (1)
Iles Eparses	na	na/121		1
Kenya	91	630	237/240	10
Madagascar	87	2 230/5 076	315/293	13
Mauritius	81	870/2693	215/185	21
Mayotte (Iles Eparses)	100/na	570/413 (121)	216/274 (40/209)	2 (6)
Mozambique	76	1 860	314/297	6[c]
Reunion	100	<50	168/205	1
Seychelles	17	1 690/5 443	310/217	14
Somalia	95	710	308/na	0
South Africa	na	50	na/91	2
Tanzania	99	3 580	314/280	11

Notes:

a- Reefs at Risk country estimates reported in Spalding and others, 2001. Country estimates were not given in Reefs at Risk revisited, in 2011.
b- Reef areas were obtained from the World Atlas of Coral reefs, and for the islands (to the right of the '/') from the Millennium Reef Mapping project. Differences in these numbers reflect different methodologies and assumptions about reef habitats and structure.
c- The first numbers are from two sources: mainland sites- Spalding and others, 2001 (World Atlas of Coral Reefs) based on Veron (2000) estimates of predicted numbers of species; island sites - based on field surveys and literature for RAMP-COI. The second number is the predicted species richness based on field surveys (Obura 2012) and are probably underestimates of true diversity. Discrepancies between these numbers are based on differences in methods and sources of information.
d- Numbers of marine protected areas with coral reefs in Madagascar and Mozambique have increased greatly since the source report was published, these numbers incorporate estimated increases. Mayotte/Iles Éparses : two EEZ MPAs and, in Mayotte, six restricted-use MPAs.

SCALE OF BIOLOGICAL DIVERSITY (MAIN GRADIENTS OF DIVERSITY FOR SPECIES AND COMMUNITIES)

The Western Indian Ocean is recognised as a distinct biogeographic region (Longhurst 1998). In the Marine Ecoregions of the World (MEOW) classification (Spalding and others, 2007), it is placed in the West Indo-Pacific Realm that stretches from the Andaman Sea westwards over the entire Indian Ocean. On the basis of hard coral species, Obura (2012) proposed adjustments to the MEOW classification to more closely match the Regional Seas definition of the WIO (including the whole coast of Somalia up to the Horn of Africa), but also adding the Chagos Archipelago, reflecting its role as a stepping stone in east-west connectivity across the Indian Ocean (see Sheppard and others, 2012).

Though a number of major global initiatives have surveyed species diversity in the Indian Ocean, eg the Challenger expedition, the International Indian Ocean Expedition in 1950-60 and, most recently, in the Census of Marine Life, it is recognised that the WIO has been poorly sampled compared to other regions, with large gaps in the numbers of species reported in even major taxa (Griffiths 2005, Wafar and others, 2011). Overall, some 2000 species of reef fish and just under 400 hard coral species have been reported for the WIO (Veron 2000, IUCN 2013, Obura 2012). Historically, species diversity across the Indo-Pacific region has been seen as one of linear decline in all directions from the high-diversity centre in the south-east Asian region, or Coral Triangle (Veron and others, 2009, Roberts and others, 2002). This paradigm showed decreasing diversity of reef taxa as far as the African coast with, in some cases, a peak of diversity in the Red Sea and/or the Seychelles islands (Sheppard 1987), attributed to endemism.

However, this is being re-evaluated as recent studies show an increase in diversity of reef taxa westwards from the Indian Ocean islands to the African coast, peaking in the northern part of the Mozambique Channel (Reaka 2008, Tittensor and others, 2010, Obura 2012). Drivers for this pattern include tectonic/paleo-oceanographic drivers over the course of the Cenozoic (Obura 2015), as well as Quarternary influence of the South Equatorial Current (SEC) and Mozambique Channel eddies accumulating and maintaining species in the northern Mozambique Channel (Tsang and others, 2012, Obura 2012). Consequently, the northern Mozambique Channel may be a second peak of shallow marine biodiversity in the world, after the Coral Triangle.

From here, there is decreasing diversity north and south as currents flow out of the northern Mozambique Channel, with transitions towards the north and south due to mixing with other water masses and climatic regions. In northern Kenya, Somalia and the northern Seychelles islands, there is a faunistic transition to species characteristic of the extreme environments and habitats of the Gulf of Aden and Persian Gulf, and endemism already noted for the Red Sea (Randall 1998). In southern Madagascar and southern Mozambique, there is a transition to the temperate systems of the Madagascar Plateau, South Africa and the southern Indian Ocean, resulting in high levels of endemism in southern Madagascar in fish and invertebrates (Bouchet 2012), and shared species between southern Madagascar and South Africa.

Endemism in the Mascarene Islands (Mauritius, Reunion and Rodrigues) is high, being isolated from the more biodiverse areas, being south of the main flow of the SEC. The level of endemism of reef fish in the Mascarene Islands is fifth highest globally, comparable to levels reported for the remote island groups of the east part of the Pacific, such as the Hawaiian Islands, the Galapagos and Easter/Pitcairn Islands (Randall 1998). There are 37 species endemic to these islands out of a total of 819 species associated with them. Endemism in the northern Seychelles islands is somewhat lower, due to exchanges with northern parts of the Indian Ocean. In corals, ten per cent of the species found in the WIO are endemic to the W & N Indian Ocean (ie From Sri Lanka and S India westwards), with the balance (90 per cent) being widespread in the broader Indo-Pacific (Obura 2012), a proportion also reflected in the fish.

An increasing number of genetic studies are now being conducted in the WIO, with a bias towards fish due to their commercial importance. Results from fish emphasize the uniqueness of the Mascarene Island fauna due to high endemicity in the remote islands (Hoareau and others, 2013, Postaire and others, 2014), and genetic exchange between the Indian and Atlantic oceans with fluctuating currents around the coast of South Africa (Teske and others, 2011). Based on phylogenetic origins of coral species, the WIO is hypothesised to be a 'museum' for species that originated in the Tethys Sea some 30-50 mya and have not dispersed west to the Central Indo-Pacific (Obura 2015). This is in contrast to the majority of species, most of which have more recent origins in the Southeast Asian region and have dispersed into the WIO in ocean currents.

PROPORTION OF MAJOR GROUPS OF SPECIES THAT ARE ASSESSED ON A SYSTEMATIC BASIS FOR STATUS

Coral reefs have been a strong focus of research, with better representation of major coral reef taxonomic groups (eg hard corals, reef fish, epibenthic molluscs, echinoderms and others) in faunal inventories compared to, for example, soft substrata or deep sea habitats (Griffiths 2005, Wafar and others, 2011). Even so, problems in taxonomic assessments remain even in well-studied groups such as corals and fish. Reef fish and hard coral (Sheppard 1987, Obura 2012) diversity have been assessed comprehensively at the regional level, building on multiple national or sub-regional studies (eg, for corals: Rosen 1971, Pichon 1978, Schleyer and Celliers 2003, Riegl 1996). Other groups have been assessed on sub-regional scales, eg hydroids (Gravier-Bonnet and Bourmaud 2006), and others, with a focus on commercial species, eg sea cucumbers (Conand and Muthiga 2011). Taxonomic information on hard and soft corals, mangroves, seagrasses, holothurians and crabs is compiled in a six-volume CD set produced in the early 2000s.

Marine megafauna that range widely beyond coral reefs are often recorded on them, partly due to the presence of scientists/observers in reef systems: eg turtles, seabirds (Birdlife International 2012, Le Corre and Jaquemet 2005), marine mammals (Ridoux and others, 2010), and whale sharks (Rowat 2007) (and see Chapter 9 on deep sea and offshore habitats, and summaries in Obura and others, 2012). Broad public interest in these groups enables citizen observation networks to provide useful biogeographic and status information on the species, eg marine mammal sighting networks in a number of countries, the Indian Ocean-South East Asian (IOSEA) network for sea turtles, Birdlife International for seabirds, etc. The lack of biodiversity data for the WIO region in global databases (eg the Ocean Biogeograhic Information System (OBIS) and Global Biodiversity Information Facility (GBIF)) is notable and far more severe than for other regions, resulting in inaccurate comparative results.

WIO countries need to invest in biodiversity assessments and data archiving to fill the above gaps, but it is essential that adequate standards are maintained to provide input to global resources such as OBIS/GBIF, as well as regional ones, such as the Africa Marine Atlas (ODINAFRICA). There even are problems with the hard coral and fish datasets which have insufficient location data and poor

identifications from one study to another. A further problem is that corals are presently undergoing major taxonomic revision; traditional taxonomy has proven to be a poor match to true phylogenetic relationships, as corals have undergone considerable convergence in their macroscopic characters which are used in traditional taxonomy. This is only now being revealed by new genetic and microstructural techniques (see Budd and Stolarski 2011). As a result, much of the historical genus-level work, which is adequate for ecological purposes, will need to be completely revised for any conclusions on biodiversity and biogeographic patterns.

The application of molecular techniques such as genetic barcoding is therefore urgently needed. While this may be technically challenging and expensive, it does enable studies in the region to 'leap-frog' to faster data capture using new methods. Genetic techniques also assist in aligning regional work with global taxonomic references and standards. Finally, high levels of diversity in microbial and invertebrate communities are undescribed (Mora and others, 2011), and genetic and genomic techniques could yield significant advances in marine science if applied in the WIO.

As an ecosystem, coral reefs have thus been broadly assessed in the WIO, capacity having been developed for national monitoring systems in the late 1990s and early 2000s under the umbrellas of the Global Coral Reef Monitoring Network (GCRMN), the Nairobi Convention and the Indian Ocean Commission, as well as in numerous national and bilateral programmes. Information from the region has been compiled in global (Wilkinson 2000) and regional reports (CORDIO 2011), as well as analytical assessments of reef status and drivers (McClanahan and others, 2007; Maina and others, 2008; Ateweberhan and others, 2011).

TRENDS AND THREATS

Drivers

Coral reefs are valued for their ecosystem services, and are thus subjected to significant use and threats throughout the WIO. The exploitation of marine resources (particularly fisheries), urban pollution, terrigenous sedimentation, coastal development and tourism are among the main anthropogenic pressures that cause degradation of coral reef ecosystems in the region. These are strongly driven by population growth and economic development where regulation of impacts is weak (UNEP/Nairobi Convention Secretariat , 2009, ASCLME/SWIOFP 2012a, ASCLME/SWIOFP 2012b).

Pressures, state and impacts

Fishing pressure is increasing globally with population growth, and globalization of fisheries is resulting in mounting pressures on even remote mid-ocean reefs and banks. Destructive fishing with small-mesh seine nets, poison and dynamite are pervasive where national governance mechanisms fail to keep them under control. Migrant fishing is increasing in intensity, driven by degradation of local systems, causing fishers to travel farther afield.

Threats from pollution are less severe in the WIO than elsewhere, reflecting the low levels of industrialization and maritime trade by world standards, though these are increasing. One third of all global oil tanker traffic passes through the Mozambique Channel (GEF-WIOMHD 2012), prompting efforts to establish a marine highway and contain pollution risks, though regulations have not yet been approved. Coral diseases are on the rise globally with the increase in the human footprint and are of concern in the WIO, though levels are apparently low except at localities subjected to high anthropogenic influence.

Similarly, pests such as crown of thorns starfish (*Acanthaster planci*) occur in small 'outbreak' populations, mainly in mainland countries and Madagascar, generally on limited and isolated patch reefs a few kilometres in extent. These go through 5-10 year cycles from outbreak to recovery, often close to freshwater and terrestrial influence that may promote their boom and bust cycles. One hundred and four introduced or alien species and 45 cryptogenic species have been identified in multiple marine habitats within the region, but only five are considered to be invasive. Perhaps the most damaging is the blue mussel, *Crassostrea gigas*, which is invasive in bays and harbours in temperate and sub-tropical climes in South Africa. Surveys for invasive species on coral reefs have not yielded significant threats.

Climate change is now recognized as one of the greatest threats to coral reefs worldwide, particularly from rising sea surface temperatures and ocean acidification. Coral bleaching has led to substantial damage to coral reefs on a global scale (16 per cent of reefs suffered lasting damage in 1998 alone: Wilkinson 2000), with some parts of the western Indian Ocean losing 50-90 per cent of their coral cover (eg Kenya, Tanzania, Seychelles, Mayotte) in the major

bleaching event of 1998, associated with an El Niño and Indian Ocean Dipole event. Since then, minor bleaching events have been reported in numerous localities, particularly in 2005 and 2010, but none as extensive as the 1998 event. Regional studies of coral bleaching have revealed different histories of bleaching, indicating high- and low-vulnerability regions to potential future climate change (McClanahan and others, 2014). Reefs in hot stable temperature regimes in the east of the Mozambique Channel and the Seychelles, and in cooler but more variable regions in Kenya, have apparently suffered greater bleaching, but reporting is scanty from many representative sites. Reefs in cooler conditions at the southern edge of the WIO distribution of corals have not suffered from coral bleaching, with hard coral cover increasing slightly over the last 15 years (Schleyer and Celliers 2003), perhaps benefiting from warming conditions. For the Indian Ocean as a whole, 65 per cent of reefs are at risk from local and global threats, rising to >85 per cent by 2030 (Burke and others, 2011). The threat of ocean acidification to coral reefs in the WIO is currently unknown, though researchers in South Africa and Reunion are beginning to tackle this issue.

The growing global energy demand has led to increased exploration for oil and gas within the WIO (Kenya, Tanzania, Mozambique, Madagascar and Seychelles). Tanzania has been a natural gas producer for many years, from the Songosongo and Mtwara regions, and recent natural gas finds in Cabo Delgado, northern Mozambique, are the largest global finds in 20 years, constituting some 30-65 Tcf (trillion cubic feet) of recoverable gas resources. There is a high likelihood of similar finds elsewhere, particularly in the Mozambique Channel, which will probably transform the economies of these East African coastal states. Whether this occurs in a framework of sustainability with minimised damage to the environment, or with no regard for environmental standards, will determine the future of the region profoundly. Over and above continuously increasing local threats (eg fishing) and threats from climate change, extraction of fossil fuel reserves may pose the most significant threat to reefs and other nearshore ecosystems by virtue of the transformation and growth it will cause in all economic sectors.

A vivid example of the combined effects of these stresses is the Grand Récif at Tulear – the largest barrier reef in the Indian Ocean, and earlier recognized as an exceptional reef system for its diversity, complexity and size. However, in the last 40 years, combined pressures from local threats (small scale commercial fishing, urban pollution and massive sedimentation), compounded by climate drivers, have resulted in widespread degradation of the reef system (Bruggemann and others, 2012), with the loss not only of ecosystem function, but also of many species, including reef-building corals.

The emergence of remote sensing techniques and information technology for amassing and managing large and global datasets have enabled the development of integrated threat assessments for coral reefs (Halpern and others, 2009, Burke and others, 2011) that will aid future management of coral reefs. However, the indices vary in their estimate of threat levels, eg Reefs at Risk predicts high risks for most of the coral reef coastlines on the African mainland and Madagascar (Figure 6.1, left), but Maina and others (2011) anticipate medium threats for most of these locations (Figure 6.1, right).

Responses

Coral reefs have been the focus of marine management in the WIO region due to their high biodiversity, and initially for their importance for tourism. In the past, as fishing was considered the greatest threat, protection of reefs was prioritised to shelter some locations from fishing pressure for their conservation. However, with mounting evidence of the importance of protected zones to maintain and replenish fisheries (Partnership for Interdisciplinary Studies of Coastal Oceans 2007), reef management is now recognized as a key tool in fisheries management.

Among the main tools for reef management, area-based tools such as Marine Protected Areas (MPAs) include a range of protection levels, involving the partial or full protection of certain resources from use or extraction in no-take zones. The WIO has been a leader in marine conservation, having some of the first marine protected areas globally (Inhaca Island in Mozambique, and Malindi and Watamu Marine Parks in Kenya, in the 1960s) and two World Heritage marine sites, Aldabara and iSimangaliso, making coral reefs among the best-represented habitats on the World Heritage list and in the WIO (Obura and others, 2012).

Other tools for management include temporal tools, such as area closures during certain seasons or critical events (such as spawning events), and effort and extraction controls such as on numbers of fishers and types/methods of fishing allowed. Historically, coral reef management in the WIO was driven by central government agencies. Fish-

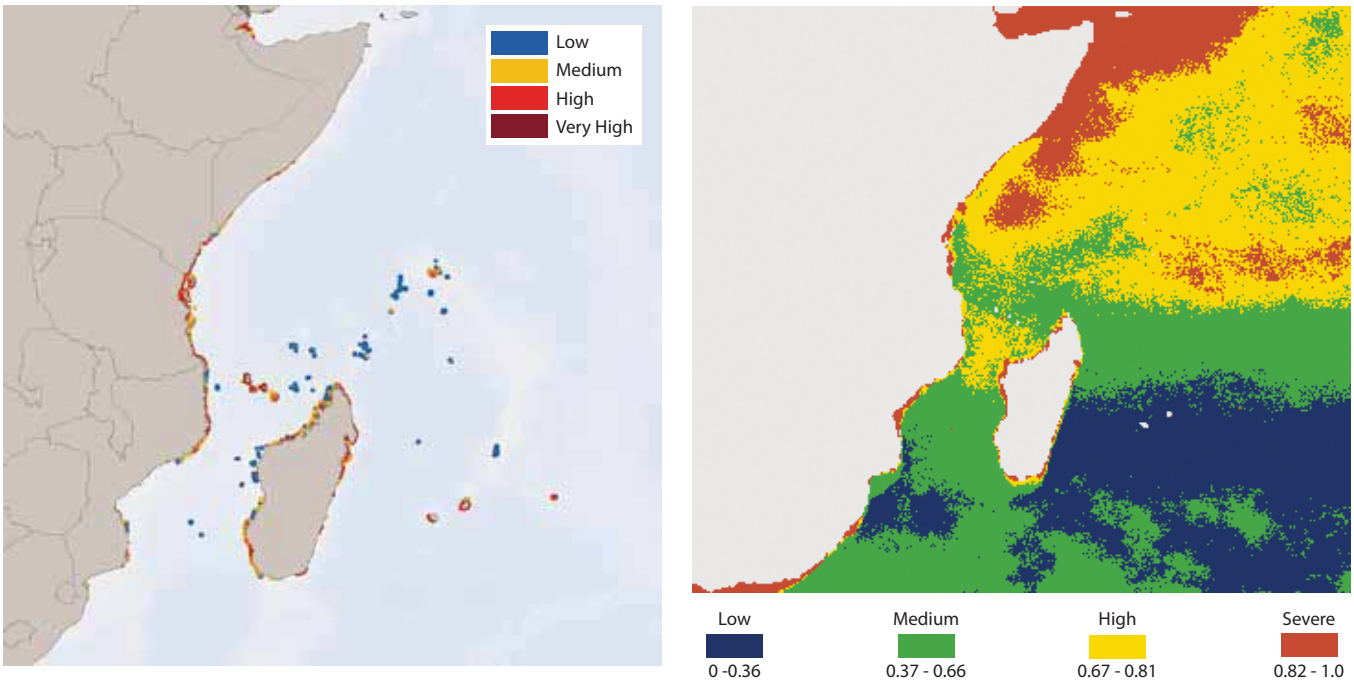


Figure 6.1. Maps of integrated threats to WIO reefs, from left: Reefs at Risk (Burke and others, 2011), and right: Maina and others, (2011).

ing communities are now increasingly realising the value of taking on the responsibility and authority to limit access to reefs on which they depend, in Locally Managed Marine Areas (LMMAs) (Rocliffe and others, 2014). These initiatives are typically undertaken in co-management arrangements with central government, usually under the authority of Fisheries rather than Conservation legislation.

Restoration of degraded reef communities has not yet reached a level where action can be taken at ecological scales (Edwards 2010), though successful piloting of reef restoration through coral nursery and transplantation are being undertaken at Cousin Island, Seychelles, and in Tanzania. Restoring the conditions that promote natural recovery – adequate herbivore and consumer populations, a clean environment and connectivity corridors – can be accomplished in well-planned MPAs or through fisheries and coastal management at a larger scale than can be achieved by attempts to manipulate local reefs through replanting of corals.

Three broad areas of intervention are possible to manage coral reefs sustainably (Table 6.2). These are particularly important in WIO countries where large sectors of the coastal populations are poor, and rely directly on the ecosystem goods and services from reefs for their economic security. While biodiversity conservation is an essential tool to maintain ecosystem services, the broader goals of societal sustainability and welfare are needed in the WIO to justify allocation of resources to coral reef management. A holistic and broad-based approach will be needed to manage the entire seascape or EEZs of WIO countries (Sale and others, 2014) to ensure sustainable coastal ecosystems into the future.

At the regional level, a Coral Reef Task Force has the role of coordinating work under the Nairobi Convention,



Figure 6.2. Distribution of Marine Protected Areas and Locally Managed Marine Areas in the Western Indian Ocean (from Rocliffe and others, 2014).

including reporting to the GCRMN, while the Indian Ocean Commission has developed a database/information system to support coral reef monitoring throughout the WIO region through its various projects (most recently the ISLANDS project, and in 2014-2017 under the 'Biodiversity Project') (ISLANDS 2013).

WIO countries have all signed the Convention on Biological Diversity, and have thus adopted Targets set under the Convention to effectively manage ten per cent of their marine zones by 2020. Currently, MPAs are estimated to cover some 130 000 km^2 in the region (Rocliffe and others, 2014), representing some two per cent of the EEZs in these countries within the Western Indian Ocean province; a sizeable gap remains before the Aichi Target 11 is attained by 2020. The French islands, with their low human population density and dependence on the marine environment

Table 6.2. Classes of action that can be taken to manage coral reefs. Source: Sale and others (2014).

Build resilience to enable recovery following impacts		
Natural threat	i. Catastrophic geologic: earthquake, tsunami, volcano, meteors	The WIO has very low risk from these, being a tectonically passive region.
	ii. Meteorological and climatic: tropical storms, floods, droughts.	Severe storms smash coral reefs or bury them under sediment. The Mascarene Islands, Madagascar and Mozambique are vulnerable to cyclones.
	iii. Extreme low tides	Not a threat in the WIO due to macro-tidal range.
Global change threats	i. Elevated sea surface temperatures	Coral bleaching in corals may be temporary or lethal; it stimulates algal blooms on reefs, increases disease.
	ii. Increased storms, wider climatic fluctuations	Stronger storms will smash or bury coral reefs; increased rain increases sediment fluxes.
	iii. Rising CO_2 dissolved in seawater with increasing ocean acidification	Decreases calcification in corals and other organisms; higher CO_2 may increase algal productivity.
	iv. Diseases, plagues and invasive species	Intensity and frequency correlated with environmental change.
Direct conservation measures possible using area-based, temporal and other tools		
Direct human pressures	i. Exploitation: over-fishing, dynamite fishing and trawler damage (exacerbated by population growth, global markets)	Harvesting of fishes and invertebrates beyond sustainable yields, includes damaging fishing practices (dynamite, cyanide fishing); boat scour and anchor damage to reefs.
	ii. Sedimentation increase: farming, logging, development	Excess sediment on coral reefs caused by poor land use, deforestation and dredging; reduces photosynthesis; associated with disease.
	iii. Nutrient and chemical pollution.	From untreated sewage, agriculture, animal husbandry and industry wastes; includes complex organic substances, heavy metals, inorganic chemicals. Eutrophication reduces light penetration, promotes growth of competing algae on corals. Chemicals kill various species associated with coral reefs.
	iv. Development of coastal areas	Removal or burial of coral reefs for urban, industrial, transport and tourism development; mining reef rock and sand beyond sustainable limits; coastal hardening results in erosion.
	v. Hydrocarbon extraction and spills, maritime pollution	Localized impacts from extraction and shipping infrastructure; increased risk of oil spills and other chemical pollution.
Improved policy and legislation reduce impacts and enable conservation measures		
Governance, awareness, will	i. Rising poverty, increasing populations, alienation from land	Impoverished, dispossessed people increase extraction of reef resources for subsistence and habitation; tragedy of the commons.
	ii. Poor management capacity and lack of resources	Few trained personnel for coastal management, raised awareness, enforcement and monitoring needed; lack of funds and logistics for management.
	iii. Poor political will, low priority for oceans governance	Political ignorance, indifference, inertia; corruption and low transparency in governance at national and regional levels impede decision-making and reduce resources.
	iv. Uncoordinated global and regional conservation arrangements	Poor coordination among Multilateral Environmental Agreements and international donors results in overlapping meetings and reporting requirements, exhausts capacity in smaller countries.

(except Mayotte, which is densely populated) have recently designated their entire EEZs as MPAs, contributing greatly to the total (Mayotte: 70 000 km^2 and Glorieuses 48 000 km^2). Seychelles has committed to conservation-based management of 30 per cent of its EEZ under a 'debt for climate adaptation' swap within a Trust Fund that it is establishing.

Most of the other countries have very high levels of subsistence dependence on coral reefs, low government resources for protection and management, and high pressures for development. The rate at which they can better manage their coral reefs and other marine habitats will probably be slow. However, a number of regional initiatives will contribute to the required targets, including upscaling the LMMAs in all countries under a regional network. Both Madagascar and the Comoros made Presidential commitments to expand their marine protected areas in number and coverage at the World Parks Congress in November 2014 in Sydney Australia, providing significant impetus to up-scale efforts in the coming decades.

Monitoring data suitable to assess the performance of countries in meeting their obligations to multiple Millennium Ecosystem Assessments is essential (Pereira and others, 2013), and coral reefs are among the few marine ecosystems for which this should be possible - they are one of the ten environments for which globally-consistent sources of marine data are available (IODE workshop, Townsville November 2013). Innovative assessment tools such as global threat assessments (Halpern and others, 2009, Burke and others, 2011) and the Ocean Health Index (Halpern and others, 2012) could also assist countries in meeting these reporting requirements.

Greater recognition of the ecosystem services contributed by coral reefs (to communities, global tourism, economies and trade) would provide impetus to secure resources to monitor the ecosystem processes and indicators that underpin these goods and services, incentivizing monitoring and assessment to manage them for future benefit. The IPBES and the Sustainable Development Goals should, in parallel with the CBD, generate increased justification to upscale coral reef assessments globally.

CONCLUSION

Coral reefs are among the Western Indian Ocean's most biodiverse and valuable ecosystems, and are probably the most vulnerable and threatened. The principal drivers of impacts – population growth, demographic migration to coasts, urban and coastal development, and climate change – all deleteriously affect reefs. WIO countries have a track record of reef research and management and conservation of their reefs but, with ongoing growth in all drivers within the region, as well as at global levels (Secretariat of the Convention on Biological Diversity 2014), a paradigm shift in commitment to limit impacts will be needed. The justification for such increased commitment is high, given the economic and social value of coral reefs and the irreplaceability of some of their ecosystem services. The recent commitment by the Comoros and Madagascar to increase protection of their marine environment shows what is possible. This will require the involvement of state and non-state, thereby assuring the survival of coral reefs into the future for the well-being of those who depend on them.

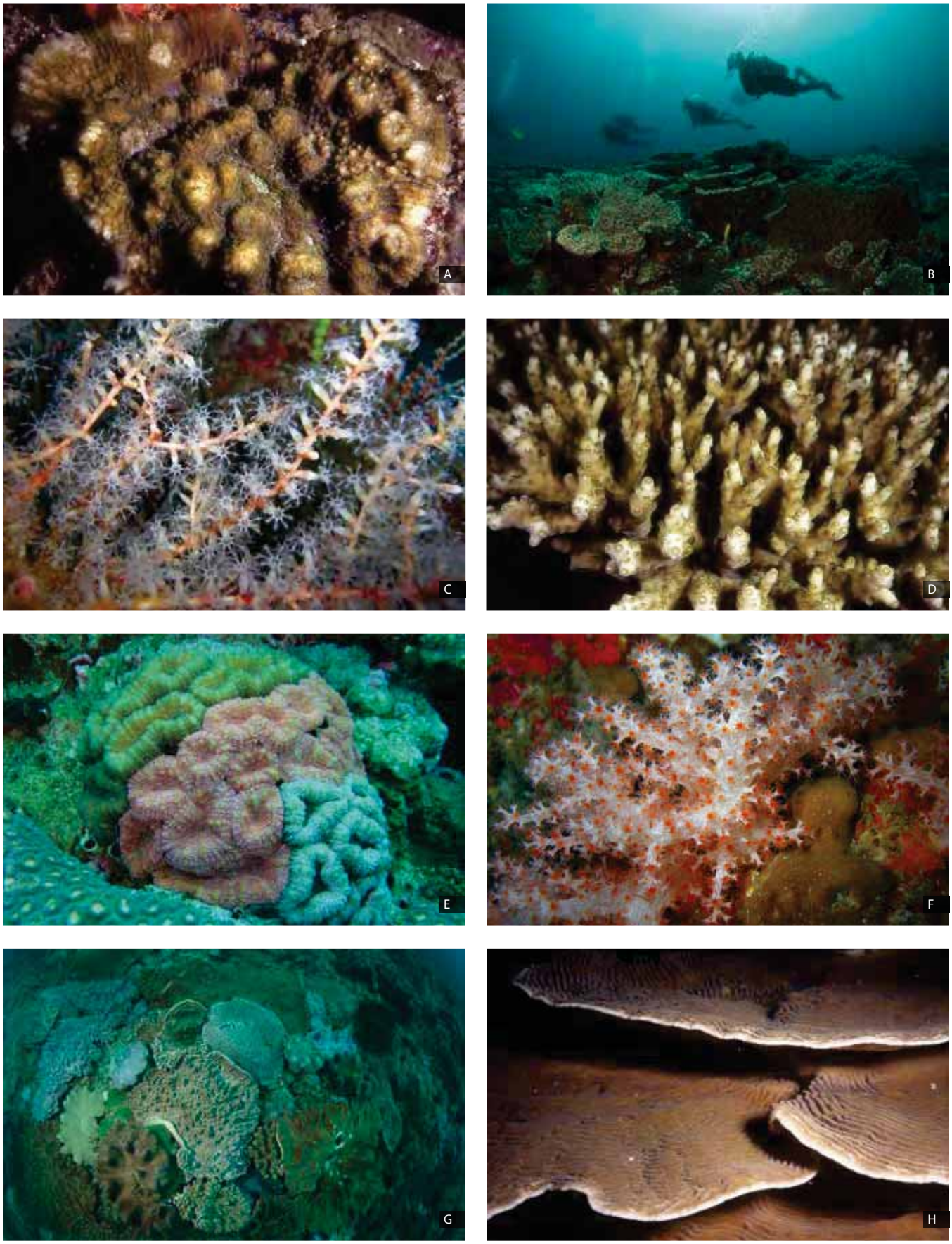


Figure 6.3. Corals are extremely variable: An encrusting hard coral (*Echinopora*) **(a)**; divers moving over a reef vista **(b)**; a branching soft coral (*Carijoa*) **(c)**; a digitate staghorn (*Acropora*) coral **(d)**; a lobate coral (*Lobophyllia*) **(e)**; a spiny soft coral (*Stereonephthya*) **(f)**; mixed hard and soft corals **(g)**; and a plate coral (*Pachyseris*) **(h).** © J Tamelander (b, g) and Michael H. Schleyer (a, c-f, h).

References

ASCLME/SWIOFP (2012a). *Transboundary Diagnostic Analysis for the western Indian Ocean*. vol. 1: Baseline. South Africa

ASCLME/SWIOFP (2012b). *Transboundary Diagnostic Analysis for the western Indian Ocean*. vol. 2: Diagnostic Analysis. South Africa

Ateweberhan, M., McClanahan, T.R., Graham, N.A.J. and Sheppard, C.R.C. (2011). Episodic heterogeneous decline and recovery of coral cover in the Indian Ocean. *Coral Reefs* 30, 739–752

Beck, M.W., Brumbaugh, R.D., Airoldi, L., Carranza, A., Coen, L.D., Crawford, C., Defeo, O., Edgar, G.J., Hancock, B., Kay M.C., Lenihan, H.S., Luckenbach, M.W., Toropova, C.L., Ahang, G. and Guo, A.X. (2011). Oyster Reefs at Risk and Recommendations for Conservation, Restoration, and Management. *BioScience* 61, 107–116

BirdLife International (2012). *Marine Protected Areas and Regional Synthesis Report on Birds as Indicators of Ecosystem Health*. The Seventh Conference of the Parties to the Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Western Indian Ocean (Nairobi Convention). UNEP-DEPI-EAF-CP

Bouchet, P. (2012). The "Atimo Vatae" Expedition. Museum of National History of Paris. http://www.laplaneterevisitee.org/fr/87/accueil

Bruggemann, J.H., Rodier, M., Guillaume, M.M.M., Andréfouët, S., Arfi, R., Cinner, J.E., Pichon, M., Ramahatratra, F., Rasoamanendrika, F., Zinke, J. and McClanahan, T.R. (2012). Wicked Social-Ecological Problems Forcing Unprecedented Change on the Latitudinal Margins of Coral Reefs: the Case of Southwest Madagascar. *Ecology and Society* 17 (4), 1-17

Budd, A.F. and Stolarski, J. (2011). Corallite Wall and Septal Microstructure in Scleractinian Reef Corals: Comparison of Molecular Clades Within the Family Faviidae. *J. Morphol.* 272, 66–88

Burke, L., Reytar, K., Spalding, M. and. Perry, A. (2011). Reefs at Risk Revisited. *World Resources Institute Washington, DC*

Conand, C. and Muthiga, N. (2011). Strengthening capacity for the sustainable management of the sea cucumber fisheries of the western Indian Ocean: perspectives and main results from the regional MASMA project. *7th Western Indian Ocean Marine Science Association Symposium*, Kenya

CORDIO (2011). *CORDIO Annual Reports*. CORDIO East Africa. www.cordioea.net/

Edwards, A.J. (ed.) (2010). *Reef Rehabilitation Manual*. Coral Reef Targeted Research & Capacity Building for Management Program: St Lucia, Australia

Secretariat of the Convention on Biological Diversity (2014) Global Biodiversity Outlook 4. Montréal. www.cbd.int/GBO4

GEF-WIOMHD (2012). GEF-Western Indian Ocean marine highway development and coastal and marine contamination prevention project, GEF-WIOMHD. Environmental Components B & C. Post completion Report

Gravier-Bonnet, N., and Bourmaud, C.A-F. (2006). Hydroids (Cnidaria, Hydrozoa) of coral reefs: preliminary results on community structure, species distribution and reproductive biology in Juan de Nova Island (Southwest Indian Ocean). *Western Indian Ocean J. Mar. Sci.* 5(2), 123-132 .

Griffiths, C. (2005). Coral marine biodiversity in East Africa. *Indian J Mar Sci,* 34, 35–41

Halpern, B.S., Longo, C., Hardy, D., McLeod, K.L., Samhouri, J.F., Katona, S.K., Kleisner, K., Lester, S.E., O'Leary, J., Ranelletti, M., Rosenberg, A.A., Scarborough, C., Selig, E.R., Best, B.D., Brumbaugh, D.R., Chapin, F.S., Crowder, L.B., Daly, K.L., Doney, S.C., Elfes, C., Fogarty, M.J., Gaines, S.D., Jacobsen, K.I., Karrer, L.B., Leslie, H.M., Neeley, E., Pauly, D., Polasky, S., Ris, B., Martin, K.St., Stone, G.S., Sumaila, U.R. and Zeller, D. (2012). An index to assess the health and benefits of the global ocean. (2012). *Nature* 488, 615–620

Halpern B.S., Kappel, C.V., Selkoe, K.A., Micheli F., Ebert, C.M., Kontgis, C., Crain C.M., Martone R.G., Shearer C. and Teck, S.J. (2009). Mapping cumulative human impacts to California Current marine ecosystems. *Conserv. Lett.* 2, 138–148

Hoareau, T.B., Boissin, E., Paulay, G. and Bruggemann, J.H. (2013). The Southwestern Indian Ocean as a potential marine evolutionary hotspot: perspectives from comparative phylogeography of reef brittle-stars. *J. Biogeogr.* 40, 2167–2179

ISLANDS (2013). *Coral Reef Monitoring In The Southwest Indian Ocean*. Indian Ocean Commission

IUCN (2013). IUCN Red List of Species. http://www.iucnredlist.org

Le Corre, M. and Jaquemet, S. (2005). Assessment of the seabird community of the Mozambique Channel and its potential use as an indicator of tuna abundance. *Estuar. Coast. Mar. Sci.* vol. 63, 421–428

Longhurst, A. (1998). *Ecological Geography of the Sea*. Academic Press, San Diego, CA

Maina, J., McClanahan, T.R., Venus, V., Ateweberhan, M. and Madin, J. (2011). Global gradients of coral exposure to environmental stresses and implications for local management. *PLoS ONE* 6, e23064

Maina, J., Venus, V., McClanahan, T.R. and Ateweberhan, M. (2008) Modelling susceptibility of coral reefs to environmental stress using remote sensing data and GIS models. *Ecol. Model.* 212, 180–199

McClanahan, T.R., Ateweberhan, M., Muhando, C.A., Maina, J. and Mohammed, M.S. (2007). Effects of climate and seawater temperature variation on coral bleaching and mortality. *Ecol. Monogr.*, 77, 503–525

McClanahan, T.R., Ateweberhan, M., Darling, E.S., Graham, N.A.J. and Muthiga, N.A. (2014). Biogeography and Change among Regional Coral Communities across the Western Indian Ocean. *PLoS ONE* 9(4), e93385

Mora, C., Tittensor, D.P., Adl, S., Simpson, A.G.B. and Worm, B. (2011). How Many Species Are There on Earth and in the Ocean? *PLoS Biol.* 9, e1001127

Obura, D.O. (2012). The Diversity and Biogeography of Western Indian Ocean Reef-Building Corals. *PLoS ONE* 7, e45013

Obura, D.O. (2015/final review) Phylogeography of corals in the western and northern Indian Ocean during the Cenozoic. *J. Biogeogr.*

Obura, D.O., Church, J.E. and Gabrié, C. (2012). *Assessing Marine World Heritage from an Ecosystem Perspective: The Western Indian Ocean*. World Heritage Centre, United Nations Education, Science and Cultural Organization (UNESCO)

Pereira, H.M., Ferrier, S., Walters, M., Geller, G.N., Jongman, R.H.G., Scholes, R.J., Bruford, M.W., Brummitt, N., Butchart, S.H.M., Cardoso, A.C., Coops, N.C., Dulloo, E., Faith, D.P., Freyhof, J., Gregory, R.D., Heip, C., Höft, R., Hurtt, G., Jetz, W., Karp, D.S., McGeoch, M.A., Obura, D.O., Onoda, Y., Pettorelli, N., Reyers, B., Sayre, R., Scharlemann, J.P.W., Stuart, S.N., Turak E., Walpole, M. and Wegmann, M. (2013). Ecology. Essential biodiversity variables. *Science* 339, 277–278

Pichon, M. (1978). Recherches sur les peuplements a dominance d'anthozoaires dans les recifs coralliens de Tulear (Madagascar). *Atoll Research Bulletin* 222, 1–490

Partnership for Interdisciplinary Studies of Coastal Oceans (2007). The Science of Marine Reserves (2nd Edition, International Version). www.piscoweb.org

Postaire B., Bruggemann J.H., Magalon H. and Faure B. (2014). Evolutionary dynamics in the Southwest Indian Ocean marine biodiversity hotspot: a perspective from the rocky shore gastropod genus *Nerita*. *PLoS ONE* 9, e95040

Randall, J.E. (1998). Zoogeography of shore fishes of the Indo-Pacific region. *Zoo. Stud.* 37, 227–268

Reaka M.L., Rodgers P.J., and Kudla, A.U. (2008). Patterns of biodiversity and endemism on Indo-West Pacific coral reefs. *Proc. Natl. Acad. Sci. U.S.A.* 105, 11474–11481

Ridoux, V., Certain, G., Doremus, G., Laran S., Van Canneyt O. and Watremez, P. (2010). *Mapping diversity and relative density of cetaceans and other pelagic megafauna across the tropics: general design and progress of the REMMOA aerial surveys conducted in the French EEZ and adjacent waters*. French MPA Agency (AAMP), SC/62/E14

Riegl, B.M. (1996). Hermatypic coral fauna of subtropical Southeast Africa: a checklist. *Pac. Sci.* 50, 404–414

Roberts C.M., McClean C.J., Veron J.E.N., Hawkins J.P., Allen G.R., McAllister D.E., Mittermeier C.G., Schueler F.W., SPALDING M., Wells F., Vynne C. and Werner T.B. (2002). Marine biodiversity hotspots and conservation priorities for tropical reefs. *Science* 295, 1280-1284

Rocliffe, S., Peabody, S., Samoilys, M. and Hawkins, J.P. (2014). Towards A Network of Locally Managed Marine Areas (LMMAs) in the Western Indian Ocean. *PLoS ONE* 9(7), e103000

Rosen, B.R. (1971). The distribution of reef coral genera in the Indian Ocean. *Symp. Zool. Soc. London* 28, 263–300

Rowat, D. (2007). Occurrence of whale shark (*Rhincodon typus*) in the Indian Ocean: A case for regional conservation. *Fis. Res.* 84, 96–101

Sale, P.F., Agardy, T., Ainsworth, C.H., Feist, B.E., Bell, J.D., Christie, P., Hoegh-Guldberg, O., Mumby, P.J., Feary, D.A., Saunders, M.I., Daw, T.M., Foale, S.J., Levin P.S., Lindeman, K.C., Lorenzen, K., Pomeroy, R.S., Allison, E.H., Bradbury, R.H., Corrin J., Edwards, A.J., Obura, D.O., de Mitcheson, Y.J.S., Samoilys, M.A.

and Sheppard, C.R.C. (2014). *Mar. Pollut. Bull.* 1–16

Schleyer, M.H. and Celliers, L. (2003). Biodiversity on the marginal coral reefs of South Africa: What does the future hold? *Zool. Verh. Leiden* 345

Sheppard, C.R.C. (1987). Coral species of the Indian Ocean and adjacent seas a synonymized compilatoin and some regional distributional patterns. *Atoll Research Bulletin* 307, 1– 33

Sheppard, C.R.C., Ateweberhan, M., Bowen, B.W., Carr, P., Chen, C.A., Clubbe, C., Craig, M.T., Ebinghaus, R., Eble, J., Fitzsimmons, N., Gaither, M. R., Gan, C-H., Gollock, M., Guzman, N., Graham, N.A.J., Harris, A., Jones, R., Keshavmurthy, S., Koldewey, H., Lundin, C.G., Mortimer, J.A., Obura, D., Pfeiffer, M., Price, A.R.G., Purkis, S., Raines, P., Readman, J.W., Riegl, B., Roger, A., Schleyer, M., Seaward, M.R.D, Sheppard, A.L.S., Tamelander, J., Turner, J.R., Visram, S., Vogler, C., Vogt, S., Wolschke, H., Yang, J.M-C., Yang, S-Y. and Yesson, C. (2012). Reefs and islands of the Chagos Archipelago, Indian Ocean: why it is the world's largest no-take marine protected area. *Aquatic Conservation: Marine and Freshwater Ecosystems* 22, 232-261

Spalding, M.D., Fox H.E., Allen, G.R., Davidson, N., Ferdana, Z.A., Finlayson, M., Halpern, B.S., Jorge, M.A., Lombana, A.L. and Lourie, S.A. (2007). Marine ecoregions of the world: a bioregionalization of coastal and shelf areas. *BioScience* 57, 573–583

Teske, P.R., Heyden, von der S., McQuaid, C.D. and Barker, N.P. (2011). A review of marine phylogeography in southern Africa. *S. Afr. J. Sci.* 107, 43–53

Tittensor, D.P., Mora, C., Jetz, W., Lotze, H.K., Ricard, D., Berghe, E.V. and Worm, B. (2010). Global patterns and predictors of marine biodiversity across taxa. *Nature* 466, 1098–1101

Transmap (2008). *Transboundary networks of marine protected areas for conservation and sustainable development: biophysical, socioeconomic and governance assessment in eastern Africa*. Final Report, Project INCO-CT2004-510862, European Commission.

Tsang, L.M., Achituv, Y., Chu, K.H. and Chan, B.K.K. (2012). Zoogeography of Intertidal Communities in the West Indian Ocean as Determined by Ocean Circulation Systems: Patterns from the *Tetraclita* Barnacles. *PLoS ONE* 7(9), e45120

UNEP/Nairobi Convention Secretariat (2009). Strategic Action Programme for the Protection of the Coastal and Marine Environment of the Western Indian Ocean from Land-based Sources and Activities, Nairobi, Kenya

Veron, J., DeVantier, L.M., Turak, E., Green, A.L., Kininmonth, S., Stafford-Smith, M. and Peterson, N. (2009). Delineating the coral triangle. *Galaxea, Journal of Coral Reef Studies*, 11, 91–100

Veron, J.E.N. (2000). Corals of the World. Volumes 1-3. *Australian Institute of Marine Science, Townsville, Australia*.

Wafar, M., Venkataraman, K., Ingole, B., Khan, S.A. and LokaBharathi, P. (2011). State of Knowledge of Coastal and Marine Biodiversity of Indian Ocean Countries. *PLoS ONE* 6(1)

Wilkinson, C. (2000). Status of Coral Reefs of the World: 2000. Townsville, Australia: Australian Institute of Marine Science



7
Intertidal and Nearshore Rocky Reefs

Daudi J. Msangameno

Opposite page: Zoanthids at the rocky shore of Ponta Mazondúe, Inhaca Island, Mozambique. © José Paula.

INTRODUCTION

Rocky reefs: general overview and formation

Rocky shores and nearshore rocky reefs form extensive habitats along several coastlines, being an important marine biotope with considerable socio-ecological significance (Raffaelli and Hawkins 1996). They arise as a result of marine erosion of the over-burden and bedrock due to a combination of sea level rise and wave action in areas where there is low sediment supply (Ruwa 1996). These natural habitats may be extended by a plethora of man-made structures such as jetties, breakwaters, docks, groynes, dykes and seawalls, which essentially function as artificial rocky reefs (Crowe and others, 2000, Moschella and others, 2005). The nature and properties of rocky shores and reefs are primarily related to the mode of their formation (Yorath and Nasmith 2001), with most being comprised of limestone, basalt and granite. Their physical properties such hardness and porosity vary, with limestone and basaltic rocks being more porous than granite. This, in turn, determines the patterns of settlement and establishment of marine epibenthic organisms on them (UNEP/Nairobi Convention Secretariat 2009). In many tropical regions where such reefs are mostly formed from raised fossilised coral, the rock may be pitted, cracked and/or creviced. This creates heterogeneous environments with numerous rock pools, overhangs, gullies and caves. However, in the arctic and cold temperate regions, such reefs are often formed from glacial action and, hence, are mostly dominated by boulders with deep interstitial spaces. In spite of some uniformity within similar latitudinal settings, rocky reefs are highly variable and, depending on local geology, they can range from steep overhanging cliffs to wide, gently-shelving platforms, and from smooth, uniform slopes to highly dissected, irregular masses or even extensive boulder beaches (Steffani 2000). Rocky reefs are, therefore, rarely smooth slabs of rock, but are instead complex environments which abound with cracks, crevices, gullies and pools, creating special habitats with their own sets of advantages and limitations (Raffaelli and Hawkins 1996).

Like other intertidal ecosystems, rocky reefs generally occur at the interface of the land and sea, thus their physical and biological dynamics are influenced by both marine and land-based processes (Underwood 2000). Intertidal rocky reefs are open ecosystems, subjected to steep environmental gradients (Thompson and others, 2002). Such openness and their steep environmental variability create multiple ranges of micro-habitats that support highly-adapted and diverse assemblages of animal and plant life (Menge and others, 1986, Raffaelli and Hawkins 1996, Terlizzi and others, 2002, Johnson and others, 2003). As in most intertidal habitats, physical factors (eg substratum type, temperature, irradiance and wave action) and biological processes (eg settlement, recruitment, predation and competition) as well as their interactions determine the spatial and temporal patterns of biological resources on rocky reefs (Terlizzi and others, 2002).

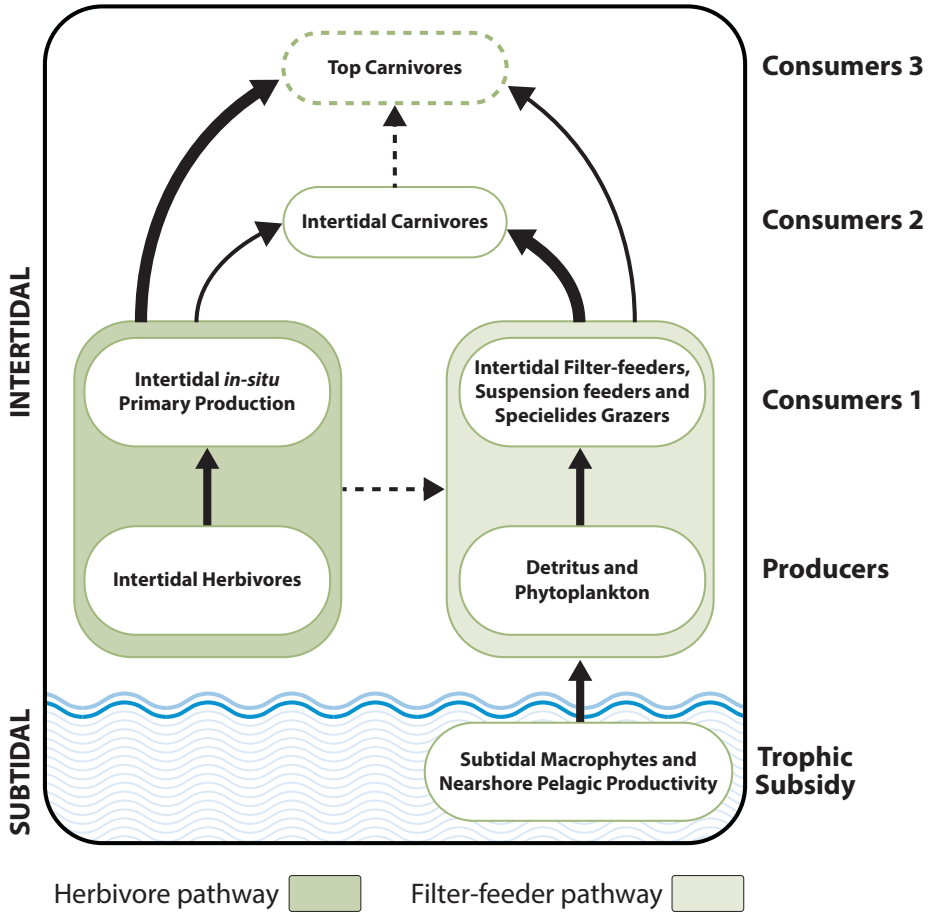


Figure 7.1. Schematic representation of the main pathways of energy-biomass transfer in a typical rocky reef food web. NB: Arrow thickness and pattern indicate the relative importance of the transfer between the different trophic compartments. Source: Steffani 2000.

Biological structures and patterns of resource distribution in rocky reef habitats

The integrity of any marine ecosystem is a function of the interactions between its various biological components relative to their trophic interdependencies. A proper understanding of such interactions is vital to predict future trends in the health of an ecosystem (eg Griffin and others, 2008) and, hence, its ability to offer vital ecological goods and services. In describing the trophic structure of intertidal rocky reef biota, species can be divided into functional groups relative to their role in energy-biomass flows or their order of ecological succession within the habitat. For instance, Menge and Sutherland (1987) and Bruno and others (2003) identify two such groups. They include primary and secondary space-holders. The former refer to primary producers (macrophytes, benthic microalgae and cyanophytes) and filter-feeding epifauna, while the latter comprise mobile consumers (grazers). It is worth noting that certain secondary space-holders are also primary producers or filter-feeders (Scrosati and others, 2011). However, in a more classical categorization, benthic organisms can simply be grouped into autotrophs, grazing herbivores, filter-feeders or predators (Paine 1980). These functional groups form trophic levels within the rocky reef food webs, connected by energy-biomass transfer linkages whose strengths are regulated by biophysical factors such as degree of wave exposure, larval supply and nearshore ocean circulations (Steffani 2000). Simple models describing trophic relationships between groups within rocky reef ecosystems are based on few trophic levels, with primary producers and filter-feeders occupying the base, herbivores the middle and predators the top (Paine 1980, Menge and Sutherland 1987). However, some authors have described such patterns of energy-biomass transfer by emphasizing the division of transfer according to the main pathways of energy entry into the secondary compartments. Bustamante (1994), for instance, describes two such entries that include the 'herbivore' and 'filter-feeder' pathways (Figure 7.1). It is obvious from the model that, while the herbivores depend directly on intertidal primary producers as a source of energy, filter-feeders use

energy imported from the adjacent pelagic and subtidal ecosystems (Bustamante 1994, Menge and others, 1997). Such importation reflects the importance of the interconnectivity between the marine biotopes in maintaining the ecological functioning of the seascape.

Organisms on rocky reefs exhibit unique distribution patterns in response to a range of factors operating at different spatial scales (Menge and Sutherland 1987). Variations in mesoscale factors such as large current systems and large-scale temperature regimes may explain disparities at a biogeographical level (Bustamante and Branch 1996). However, a suite of site-specific factors determine patterns of species distributions in the local setting. Environmental stress related to physical attributes, such as wave exposure, insolation, temperature, aspect, substratum type, as well as a range of biotic factors often lead to the development of characteristic species zonation on most rocky reefs (Stephenson and Stephenson 1972). The adaptive ability of organisms to withstand prolonged atmospheric exposure during low tide largely determines their relative position along the shore height axis (Underwood 1981, Thompson and others, 2002). The following broad zones can therefore be distinguished on a typical intertidal rocky reef: the supra-littoral zone (littoral fringe), upper eulittoral zone and the lower eulittoral (sublittoral zone) (Lewis 1964), with the mid-shore generally having the greatest species diversity, whilst the lower shore those most prolific. Although physical parameters are the primary determinants in establishing communities on an intertidal rocky reef, biological processes such as facilitation, competition, predation and grazing play an important role in shaping the final species assemblages (Petraitis 1990, Steffani 2000, Bruno and others, 2003, Coleman and others, 2006). For instance, while the bottom-up effect of physical factors has long been known to directly set the upper limits of species distribution on the upper shores, such limits are mainly determined by top-down biotic processes such as grazing on lower shores (Underwood and Jernakoff 1984, Boaventura and others, 2002) and competition (Hawkins and Hartnoll 1985). Jonsson and others (2006) have also described the interaction of wave exposure and biological processes (grazing) in determining the horizontal patterns of species distribution on intertidal rocky shores.

The regulatory role of physical and biological factors in biological zonation and the vertical limits of species distribution on intertidal rocky reefs may be rendered more complex by the presence of rock pools. These conspicuous components of many intertidal rocky reefs exhibit biological characteristics that vary significantly from those found on the surrounding emergent rock (Metaxas and Scheibling 1993). These include a significant enhancement of species abundance and richness on intertidal rocky reefs (eg Firth and others, 2013). Although the physical environment on the rocky reefs is generally regulated by tidal cycles, fluctuations in physical factors such as temperature are generally less severe in pools than on the emergent rock. In turn, this enables extension of the upper limits of many species, making the biological zonation less pronounced (Metaxas and Scheibling 1993, Steffani 2000).

While a range of physical and biological factors have been widely demonstrated to determine vertical patterns (zonation) in species distribution on most intertidal rocky reefs, their horizontal patterns have been largely linked to the degree of wave exposure. Wave action plays a major role in determining the nature and pattern of energy flows within these habitats in terms of physical stress, as well as in moderating the biotic interactions within communities (McQuaid and Branch 1984, 1985, McQuaid and others, 1985, Menge and Olson 1990, Emanuel and others, 1992) and, consequently, the relative abundances of the various functional groups within this ecosystem (McQuaid and Branch, 1985).

Rocky reefs in the WIO region

Rocky shores cover an area of about 3000 km^2 in the Indian Ocean (excluding the western Australian coast) (Wafar 2001). In spite of their seemingly limited extent, rocky reefs form one of the most interesting coastal habitats in the region. Such habitats are characterized by strong environmental gradients at very small spatial and temporal scales, thus exerting strong selective pressures which in turn enhance species diversity and adaptation (Lubchenco 1980). Numerous forms of rocky reefs occur in the WIO region, with the most common being limestone, sandstone and granite (Ruwa 1996, UNEP/Nairobi Convention Secretariat 2009). Pleistocene limestone outcrops are the main rock formations in the region, being dominant in Madagascar, northern Mozambique, Tanzania and Kenya, with aeolianite dominating the northeastern and southern coasts of South Africa and Mozambique respectively (eg Kalk 1995, Ramsay and Mason 1990, Ramsay 1996). To a minor extent, some rocky reefs on oceanic islands in the WIO are either granitic or basaltic. A notable example of the former are those found at Mahe in the Seychelles (eg Hill and Currie 2007). Basaltic rocky reefs are mostly found in Mauritius and the Comoros. Some islands comprise atolls formed

Table 7.1. Examples of rocky reef formations at selected locations in the WIO region.

Location	Type of substrata
Dar es Salaam (Tanzania)	Limestone (Hartnoll 1976)
Inhaca (Mozambique)	Sandstone (Kalk 1995)
Maputaland (South Africa)	Sandstone (Ramsay 1996, Ramsay and Mason 1990)
Durban (South Africa)	Sandstone (Martin and Flemming 1988)
Seychelles	Coral rock, granite (Ngusaru 1997)
Mauritius	Basalt, limestone (Hartnoll 1976)
Kenya	Limestone (Ngusaru 1997)
Tulear (Madagascar)	Limestone (Hartnoll 1976)
Comoros	Basalt (Ngusaru 1997)
Northern Mombasa (Kenya)	Limestone (Ngusaru 1997)

Source: UNEP/Nairobi Convention Secretariat (2009).

from coral (eg Aldabra Atoll Seychelles) and have limestone cliffs interglacial in origin (Ruwa 1996). Figures 7.2-7.4 show some of the typical rocky reefs in the WIO region.

IMPORTANCE OF ROCKY REEF ECOSYSTEMS IN THE WIO REGION

Intertidal rocky reefs have considerable ecological, socio-economic and conservation value in the WIO region. Together with other contiguous biotopes, they play a significant role in sustaining coastal livelihoods and maintaining the ecological integrity of the WIO seascape.

Ecological value

WIO rocky reef habitats abound with flora and fauna. Macroalgae are one of the common features in such habitats, especially on the lower shores and in rock pools. These highly productive macrophytes provide a major source of organic matter for other forms of marine life (Worm and Lotze 2006). Together with seagrasses, macroalgae account for up to 40 per cent of primary productivity in the coastal zone (Charpy-Roubaud and Sournia 1990) and contribute significantly to the global marine plant biomass (Smith 1981). They also fulfil crucial ecological functions such as carbon storage and nutrient cycling (Borg and others, 1997, Worm and others, 2000). The benthic-pelagic coupling between such reefs and other nearshore ecosystems ensures a constant interchange of biomass and energy (Menge and others, 1997). For instance, sessile invertebrates, which characteristically inhabit most rocky reefs, release large numbers of eggs and larvae. These, in turn, form an important food source for juvenile fish and other pelagic animal species, enhancing the productivity of nearshore ecosystems by ensuring a constant supply of energy up the food chain (Raffaelli and Hawkins 1996). Conversely, most filter-feeding invertebrates typical of exposed rocky reefs play a major role in energy importation from nearby ecosystems. Rocky reefs also form extensive feeding, resting, spawning and nursery areas for marine and terrestrial animals (Thompson and others, 2000). During low tide, numerous species of coastal birds and mammals forage on benthic molluscs and crustaceans as well as fish, while during high tide, certain species of visiting fauna (mostly fish) feed on invertebrates while herbivorous fish graze on the plants (Borg and others, 1997, Worm and others, 2000).

Socio-economic value

Intertidal rocky reefs are subject to varying degrees of subsistence, commercial and recreational fishing in the WIO. Seaweed collection is a common activity for many people. Several species of macroalgae are collected for their economic value, as they are used for the industrial production of agar and carrageenan (Williams and Phillip 2000). Subsistence and artisanal gleaning for invertebrates is also a common activity (Kyle and others, 1997, Msangameno pers. obs.), with different species of whelks, limpets, abalones, crabs, octopuses, mussels, chitons, sea urchins, barnacles and rock oysters being collected for food as well as income (Denny and Gaines 2007) (Figure 7.6). Spearfishing is also common in rock pools and shallow intertidal lagoons (Msangameno pers.obs.). Collection of certain sponges, echinoderms and molluscs for medicinal and magical treatment has also been reported (eg Kyle and others, 1997). Although there are limited options in the region for in situ farming, rocky reef species have become the mainstay of profitable mariculture ventures elsewhere. For instance, the

culture of mytilid mussels is practised in over 40 countries (Denny and Gaines 2007) and could be introduced to the WIO. Farming of stalked barnacles, abalone and oyster species is also a common commercial practice in certain parts of the region, namely on the south coast of South Africa at the limit of the WIO region (eg Troelli and others, 2006).

Conservation value

Besides their ecological and socio-economic importance, intertidal rocky reefs have considerable conservation value. For instance, they are so rich in invertebrate fauna that almost all phyla are represented in such habitats (Deepananda and Macusi 2012). Their biodiversity and endemic organisms, as well as ecological connectivity with other coastal and marine ecosystems, make these highly complex habitats worth conserving. Two case studies are presented to illustrate the conservation potential of the intertidal rocky reef habitats in the region (Boxes).

BOX 7.1. MACROBENTHIC ABUNDANCE AND DIVERSITY ON ROCKY REEFS IN TWO TRANS-BOUNDARY AREAS IN THE WIO REGION





Gastropod feeding on zoanthid (left) and mixed zoanthid, sponge and algae (right) at Inhaca Island, Mozambique. © José Paula.

A nested approach was used to assess the abundance and species composition of intertidal rocky reef flora and fauna in two trans-boundary areas on the East African coast as part of a biophysical assessment of key marine habitats in the Trans-boundary Networks of Marine Protected Areas for Integrated Conservation and Sustainable Development (TRANSMAP 2011) project. These areas included the tropical northern trans-boundary section (hereafter, NTA) of Tanzania and Mozambique and the subtropical southern trans-boundary area (hereafter, STA) of northern KwaZulu-Natal, South Africa, and southern Mozambique. A photographic record was used for community analysis of the macroalgae, macrobenthos and macrofauna associated with the rocky reefs at these localities.

General community composition

High macrobenthic abundances and diversity were encountered in the trans-boundary areas. Overall, the average cover of sessile organisms was 30.6 per cent, with the STA having a higher cover (53.4 per cent) than the NTA (7.6 per cent). The average abundance of motile species was 183.7 individuals m^{-2} in the STA and 373.2 individuals m^{-2} in the NTA. In both trans-boundary areas, highly diverse macrobenthic communities were found on the intertidal rocky reefs. In the NTA, a total of 47 macrobenthic species were identified, including 17 sessile and 30 mobile species belonging to a total of 25 families, the majority of which (51 per cent) were molluscs. In the STA, 17 species of mobile organisms were identified within diverse taxonomic groups.

Macroalgal associations

An abundance and diversity of macrofauna were associated with the algal communities in the two trans-boundary areas, with the STA having a higher average abundance of 262.2 individuals m^{-2} compared to 156.0 in the NTA. This difference was attributable to the higher algal cover and diversity in the STA compared to the NTA. Such higher algal abundances tend to enhance substratum heterogeneity, which in turn creates micro-habitats which harbor diverse faunal assemblages.

BOX 7.2. PATTERNS OF MACROBENTHIC ASSEMBLAGE WITHIN THE INTERTIDAL ROCKY REEFS ON ZANZIBAR ISLAND, TANZANIA



Turbinaria and *Ulva* at Zanzibar southern shores. © José Paula.

A multivariate approach was used to analyse the species composition of three intertidal rocky reefs on the island of Zanzibar (Msangameno 2013). This included a general macrobenthic community analysis and an assessment of the benthic epifauna associated with five macroalgal communities dominant on the Island (dominated by *Gracilaria*, *Chondrophycus*, *Ulva*, *Halimeda* or *Turbinaria*).

General community analysis

In total, 102 macrobenthic species were recorded on the intertidal rocky reefs on the island, belonging to 49 families. Of these, two thirds were sessile and one third motile. The breakdown by major groups was as follows: Chlorophyta (14 species, 6 families), Phaeophyta (7 species, 2 families), Rhodophyta (22 species, 11 families), Sea grasses (9 species, 2 families), Arthropoda (2 species, 2 families), Cnidaria (6 species, 3 families), Mollusca (30 species, 17 families), Porifera (3 species, 1 family), Echinodermata (9 species, 5 families). The benthic cover of sessile organisms (macrophytes and sedentary macrofauna) was high across the reefs, averaging 25.8 per cent, and the abundance of motile macrofauna averaged 26.4 individuals m^{-2}.

Macroalgal associations

A total of 130 species of macrofauna were found to be associated with the dominant algal communities on the intertidal rocky reefs on the island. These belonged to 65 families of most of the major macrofaunal groups: Mollusca (68 species, 37 families), Arthropoda (28 species, 8 families), Echinodermata (20 species, 9 families), Annelida (3 species, 2 families), Cnidaria (3 species, 3 families), Pisces (1 species, 1 family), Platyhelminthes (2 species, 1 family), Porifera (1 species, 1 family) and Sipuncula (4 species, 3 families). The average of these was 1013 individuals m^{-2} (range: 16 to 68 800). Differences in both faunal abundance and diversity were evident among the dominant macroalgal communities, with highest abundance being recorded in *Ulva*-dominated communities and lowest in those dominated by *Halimeda*. The Shannon diversity (Shannon) was highest in *Turbinaria*-dominated communities and lowest in *Halimeda*-dominated communities.

THREATS TO THE INTERTIDAL ROCKY REEF ECOSYSTEMS IN THE WIO

The provision of ecological goods and services by rocky reef habitats is constantly threatened by natural and anthropogenic pressures at different scales. Since rocky reefs comprise one of the harshest marine environments (Crowe and others, 2000), the biological communities in their habitats are, therefore, able to withstand significant levels of natural stress. This capacity is nonetheless compromised when large increases in human-induced disturbances are superimposed on the natural stress (Addessi 1994, Lindberg and others, 1998). The following are some of the important threats to the integrity of rocky reef ecosystems in the region.

Resource overexploitation

Their relatively rich resources, easy accessibility and the typically low cost fisheries they attract (Peschak 2006), make such habitats extremely vulnerable to resource overexploitation. A number of examples have been reported in the region on the impact of over-exploitation resulting in reduced resource abundance on rocky reefs (eg Newton and others, 1993). Overharvesting of these resources may also have a profound impact on the functioning and integrity of the rocky reef ecosystems, not only in terms of the direct effects on populations of the targeted species but also in terms of habitat destruction and recruitment failure, leading to a cascade of impacts on the associated ecosystems. Large-scale modifications of the community composition due to selective species overexploitation have been widely reported worldwide (eg Siegfried 1994, Denny and Gaines 2007). A notable example in the region was recorded in South Africa (Siegfried 1994) in which over-exploitation of intertidal invertebrates by subsistence collectors transformed a filter-feeding community into a stable coralline algal community. The impact of resources overharvesting on rocky reef ecosystems becomes more pronounced when keystone species are involved (Little and Kitching 1996). These comprise top predators with multi-level trophic interactions, whose impact on the prey community structure is disproportionately large relative to their biomass (Navarrete and Menge 1996). Since they play a major role in preventing species dominance, and thus enhance coexistence and diversity, their depletion leads to negative changes within benthic biological communities (Lindberg and others, 1998), threatening the ability of rocky reef ecosystems to offer crucial ecosystem goods and services on which coastal livelihoods are based.

Trampling

Human visits to rocky reefs negatively affect the biological resources. Besides resource exploitation and pollution, habitat disturbance due to human trampling may lead to localised changes in species composition (Casu and others, 2006). For instance, a loss of abundance of several benthic taxa due to such disturbance has been demonstrated, including bivalves (Smith 2002), polychaetes (Brown and Taylor 1999), macroalgae (Schiel and Taylor 1999), limpets (Pombo and Escofet 1996, Dye 1998, Roy and others, 2003), sea stars and octopuses (Ghazanshahi and others, 1983), snails (Roy and others, 2003), crabs (Murray and others, 1999) and barnacles (Brosnan and Crumrine 1994). The impact of trampling can be direct or indirect, the former referring to the effect of physical damage resulting in dislodgement, mortality or general structural deformation (Denny 1987) which increases the vulnerability of rocky reef communities to natural stresses such as desiccation and wave force, or to predation and competition (Brosnan and Crumrine 1994, Brown and Taylor 1999). The indirect effects of trampling include a loss of physiological efficiency, such as reduced reproductive potential in certain species (Denis 2003), or the competitive ability of other species (Schiel and Taylor 1999). The most serious impact occurs when trampling leads to a loss of habitat-providing organisms. These are the sessile macrobenthos with which other organisms are associated, and whose loss consequently leads to the loss of the associated species (Gibbons 1991, Casu and others, 2006).

Pollution

Since, intertidal rocky reefs occur at the sea-land interface, they are subjected to various forms of pollution within a range of spatial and temporal scales, invariably impacting their benthic resources. The impact of various forms of pollution on rocky reefs has been documented by a number of authors. Crowe and others (2000), for instance, have extensively reviewed the effects of various types of pollution. These include eutrophication, oil pollution, siltation, heavy metal pollution, pesticide pollution, antifouling paints and thermal pollution. Table 7.2 summarizes the potential impact of various types of pollution on the rocky reef ecosystems in the WIO region.

Table 7.2. Summary of the impact of pollution on rocky reef ecosystems.

Pollution type	Source of pollutant	Impact on habitat and resources
Eutrophication	Natural sources e.g. animal droppings (Bosman and Hockey 1988); sewage outfalls and agricultural run-off (Raffaelli and Hawkins, 1996, Clark and others, 1997)	Temporal and spatial changes in patterns in macrobenthic abundance, biomass and diversity (Pearson and Rosenberg 1978); transformation of stable benthic communities, e.g. replacement of perennial macroalgae by blooms of ephemeral algae, diatoms and cyanobacteria (Schramm 1996); increased frequency of 'red tide' algal blooms (Hallegraeff 1993)
Oil Pollution	Oil spills (Watt and others, 1993)	Complete or partial loss of macrobenthic diversity (Pople and others, 1990, Jones and others, 1996)
Siltation	River discharge, shore erosion, sediment re-suspension, atmospheric transport (Airoldi 2003); intertidal and pelagic detrital matter (Fornos and others, 1992, Airoldi 2003); industrial and domestic discharges (Eagle and others, 1979, Kim and others, 1998); mining (Hyslop and others, 1997); construction (MacDonald and others, 1997); dredging (Eagle and others, 1979) and aquaculture (Holmer and others, 2001).	Reduced species abundance (Littler and others, 1983, Saiz-Salinas and Urdangarin 1994); transformation of certain rocky shores assemblages (Branch and others, 1990); effects on larval settlement, recruitment, growth and survival (Airoldi 2003).
Thermal pollution	Thermal effluent from power plants (Airoldi 2000).	Decline in algal biomass and diversity (e.g. Vadas and others, 1978).
Heavy metal pollution	Denudation of ore-containing rocks and volcanism (Clark and others, 1997); sewage discharge (Anderlini 1992); industrial discharge and urban run-off (Clark and others, 1997)	Effects on growth of benthos such as mussels and fucoid algae (Munda and Hudnik 1986), effects on larval development (Fichet and others, 1998).
Biocides	Agricultural runoff and use of antifouling paints (Airoldi 2000)	Effects on certain benthic species (e.g. Sarojini and others, 1989, Lundebye and others, 1997).
Microbial contamination	Municipal wastewater disposal, contaminated surface and sub-surface runoff, contaminated agricultural runoff, industrial effluent (Mong and others, 2009, UNEP/Nairobi Convention Secretariat 2009).	Health risks to sea food (Fernandes 1996)

Introduced species

Rocky reefs, like other benthic marine habitats, are prone to the effects of introduced alien organisms. This occurs either through accidental transportation of propagules or adult organisms as fouling on ships or in their ballast water (Raffaelli and Hawkins 1996). Species may also be introduced intentionally for aquaculture (Raffaelli and Hawkins 1996, Crowe and others, 2000, Haupt 2010). In most cases, such introductions have not led to significant changes in the original biological composition. However, their potential negative effects on benthic rocky reef communities remain a reality (eg Haupt 2010). For instance, pathogens introduced with alien species may find new hosts with no natural resistance, with potentially permanent adverse impacts (Crowe and others, 2000).

Climate change

Human exacerbation of the greenhouse effect has been predicted to lead to a rise in atmospheric and ocean temperatures and ultimately to changes in atmospheric and oceanic dynamics. This global change is likely to have enormous impacts on ecosystems (IPCC 1996), driving shifts in the composition and structure of their natural assemblages (Little and Kitching 1996, Sagarin and others, 1999, Helmuth and others, 2006, Hawkins and others, 2009). Recent climatic events are already affecting the survival, development, phenology, physiology and ecology of a wide range of species within marine ecosystems (Walther and others, 2002). The probable impact of global climate change on intertidal rocky reef ecosystems can be modelled around potential environmental alterations induced by global warming and increased radiation (Steffani 2000), resulting in sea level rise and changes in patterns in atmospheric and ocean mass circulation. Table 7.3 summarizes the potential impact of various aspects of global climate change on the ecological integrity of intertidal rocky reef ecosystems in the WIO.

Coastal development

Sixty per cent of the global population is estimated to dwell along the coastline (Lindeboom 2002). The coastal zone is also one of the most economically active areas, plac-

Table 7.3. Possible impact of global climate change on rocky reef ecosystems in the WIO.

Phenomena	Impact on habitat and resources
Air and sea temperature rise	Changes in biological composition in favour of more heat-resistant organisms (Barry and others, 1995, Steffani 2000) ; effects on trophic interactions within benthic biological communities (Sanford 1999); genetic range shifts in some species towards higher latitudes (Hijmans and Graham 2006, Ling and others, 2009), local extinction of certain species (Helmuth and others, 2002, Hobday 2006).
Sea level rise	Submergence and eventual loss of biological assemblages, especially on flat reefs and wave-cut platforms (Shackleton and others, 1996, Steffani 2000); upward displacement of benthic organisms on gentle sloping rocky reefs (Shackleton and others, 1996, Kendall and others, 2004, Jackson and McIlvenny 2011).
Increased intensity and frequency of storms	Prevention of natural succession or recovery in benthic communities; reduction of habitat heterogeneity and thus reduced species diversity (Sousa 1985); community transformation e.g. reduced abundance of perennial species in favour of short-lived, fast-growing ephemerals (Steffani 2000).
Changes in ocean circulation or nearshore current systems	Changes in rates of settlement and recruitment of benthic organisms; changes in biotic interactions such as predation, herbivory and competition (Menge and Sutherland 1987); reduced productivity due to changes in patterns of nutrient and plankton supply (Menge and others, 1997).
Changes in sediment dynamics	Loss of sand-intolerant species; increased dominance by sand-tolerant species; reduced diversity within benthic communities (Littler and others, 1983).
Ocean acidification	Reduced rate of calcification in calcareous benthos e.g. certain species of crustaceans, molluscs, echinoderms and coralline algae ; impairment of physiological and developmental processes in many benthic species, especially in the early life history stages (Havenhand and others, 2008, Gaylord and others, 2011); shift in the structure, dynamics and productivity of biological communities.
Increased precipitation	Habitat degradation due to increased runoff, sedimentation and eutrophication (e.g. Justić and others, 1996, Airoldi 2003).

ing enormous pressure on marine and coastal environments. This has been compounded by uncoordinated and poorly managed coastal zone development (Fraschetti and others, 2011). Activities such as coastal construction have been shown to adversely affect biological resources in many intertidal habitats, including rocky shores. For instance, the construction of certain structures for sea defences interferes with key oceanographic and biological processes essential to maintenance of the integrity of such ecosystems (Miller and Sternberg 1988, Bertasi and others, 2009). These include the interruption of the supply of recruits, nutrients and planktonic food. Increased urbanization, which is a key feature of coastal development, may also increase the rate of pollution (Terlizzi and others, 2005), which may in turn increase habitat degradation or loss, biological instability and alterations in connectivity. Although the construction of sea defences associated with major coastal development may provide additional habitat for rocky shore species (Moschella and others, 2005), the diversity on such artificial substrata is usually lower than on natural reefs (Firth and others, 2013)

CONCLUSION AND IDENTIFICATION OF GAPS

Rocky reefs provide significant ecological goods and services in the WIO region. Their role in supporting the eco-

Table 7.4. Possible underlying causes for the degradation of rocky reef ecosystems in the WIO, the perceived current status of their resources, possible socio-ecological impacts of ecosystem change, and potential or desirable responses to these changes.

Drivers of habitat change and resource degradation	Current state of resources	Impact on ecosystems and livelihoods	Potential/desirable responses
• Globalization • Population growth • Climate change • Inadequate governance • Poverty and inequality • Changes in land use • Migration • Tourism development • Pollution • Natural disasters • Inadequate education and lack of awareness • Invasive species • Resource overexploitation	• Generally these ecosystems still support exploitation of their resources (albeit on reduced biomasses), but current trends in habitat degradation threaten this capacity	• Habitat degradation • Transformation of benthic biological communities • Loss of biodiversity and species extinction • Health hazards • Reduced life expectancy	• Global conventions and agreements • National policies and legislation • Education and awareness programmes • Establishment of MPAs and no-take zones • Economic empowerment and livelihood diversification • Effective coastal zone management • Hotspot identification through increased research effort • Sustained observation and long-term monitoring



Figure 7.2. Some aspects of rocky shore and their exploitation at the WIO. **(a)** Mission Rocks, Kwa-Zulu Natal, South Africa, **(b)** highly exposed and wave beaten rocky cliffs in Black Rock, Kwa-Zulu Natal, South Africa, **(c)** Ponta Mazondúe, Inhaca Island, Mozambique, **(d)** sand-inundated rocky shores in Mtwara, Southern Tanzania, **(e)** southern shores of Zanzibar Island, Tanzania, **(f)** northern shores of Mauritius, **(g)** collecting ascideans at Inhaca, and **(h)** octopus in Cabo Delgado, Mozambique. © David Glassom (a-b), José Paula (c, f-h), Daudi Msangameno (d-e).

logical productivity of other nearshore marine habitats with which they are interconnected is even more important. There are real and emerging threats to the integrity of rocky reef ecosystems in the region, emanating mostly from the impact of anthropogenic activity. If these threats continue unabated, they may significantly compromise the ability of such systems to support both coastal livelihoods and the ecological functioning of the WIO seascape at a range of scales. Holistic attempts to address key aspects of the management of intertidal and nearshore marine habitats in the region have been initiated and implemented to some extent at various levels. However, significant challenges remain. One of the most obvious shortcomings in the current approach to seascape management lies in an inadequate understanding of the various drivers of change within marine ecosystems, including the intertidal rocky reefs. There has been a paucity of research on the ecological and anthropogenic processes that govern biological resources in these habitats. With the exception of the South African rocky shores which have been studied extensively, and some early work along the Somali coast, rocky shores in other parts of the region have received little attention. This is especially so on the tropical shores of East Africa. In addition to this, certain thematic gaps also need attention. These include efforts to elucidate responses of such ecosystems to human-derived stresses; their interaction with other intertidal and nearshore ecosystems; and the role of keystone and habitat-forming taxa in regulating the ecological dynamics on rocky reefs. This information will be vital to formulate responses to management challenges and pressures on this resource base. Apart from rapid assessments of the current status of the biological resources, long-term and broad-scale studies are needed, as well as long-term monitoring of change. This will enable the adoption of appropriate mitigation measures to prevent and/or minimise further impacts on rocky reef ecosystems and, consequently, local livelihoods.

References

Addessi, L. (1994). Human disturbance and long-term changes on a rocky intertidal community. *Ecol. Appl.* 4, 786-797

Airoldi, L. (2000). Responses of algae with different life histories to temporal and spatial variability of disturbance in subtidal reefs. *Mar. Ecol. Prog. Ser.* 195, 81-92

Airoldi, L. (2003). The effects of sedimentation on rocky coast assemblages. In *Oceanography and Marine Biology: an Annual Review* (eds. R.N. Gibson and Atkinson, R.J.A.) vol. 41 pp. 161-236

Anderlini, V.C. (1992). The effect of sewage on trace metal concentrations and scope for growth in *Mytilus edulis aoteanus* and *Perna canaliculus* from Wellington Harbour, New Zealand. *Sci. Total. Environ.* 125, 263-288

Barry, J.P., Baxter, C.H., Sagarin, R.D. and Gilman, S.E. (1995). Climate-related, long-term faunal changes in a California rocky intertidal community. *Science* 267, 672-675

Bertasi, F., Colangelo, M.A., Colosio, F., Gregorio, G., Abbiati, M. and Ceccherelli, V.U. (2009). Comparing efficacy of different taxonomic resolutions and surrogates in detecting changes in soft bottom assemblages due to coastal defence structures. *Mar. Pollut. Bull.* 58, 686-694

Boaventura, D., Alexander, M., Santina, P.D., Smith, N.D., Ré, P., da Fonseca, L.C. and Hawkins, S.J. (2002). The effect of grazing on the distribution and composition of low shore algal communities on the central coast of Portugal and on the southern coast of Britain. *J. Exp. Mar. Biol. Ecol.* 267, 185-206

Borg, A., Pihl, L. and Wennhage, H. (1997). Habitat choice by juvenile cod (*Gadus morhua* L.) on sandy soft bottoms with different vegetation types. *Helgoland Meeresunters* 51, 197-212

Bosman, A.L. and Hockey, P.A.R. (1988). The influence of seabird guano on the biological structure of rocky intertidal communities on islands off the west coast of Southern Africa. *S. Afr. J. Mar. Sci.* 7, 61-68.

Branch, G. M., Eekhout, S. and Bosman, A. L. (1990). Short-term effects of the 1988 Orange River floods on the intertidal rocky-shore communities of the open coast. *T. Roy. Soc. S. Afr.* 47, 331-354

Brosnan, D.M. and Crumrine, L.L. (1994). Effects of human trampling on marine rocky shore communities. *J. Exp. Mar. Biol. Ecol.* 177, 79-97.

Brown, P.J. and Taylor, R.B. (1999). Effects of trampling by

humans on animals inhabiting coralline algal turf in the rocky intertidal. *J. Exp. Mar. Biol. Ecol.* 235, 45-53

Bruno, J. F., Stachowicz, J.J. and Bertness, M.D. (2003). Inclusion of facilitation into ecological theory. *Trends Ecol. Evol.* 18, 119-125

Bustamante, R.H. (1994). *Patterns and causes of intertidal community structure around the coast of South Africa*. PhD thesis. University of Cape Town, South Africa

Bustamante R.H. and Branch G.M. (1996). Large scale patterns and trophic structure of southern African rocky shores: the roles of geographic variation and wave action. *J. Biogeogr.* 23, 339-351

Casu, D., Ceccherelli, G., Curini-galletti, M. and Castelli, A. (2006). Short-term effects of experimental trampling on polychaetes of a rocky intertidal substratum (Asinara Island MPA, NW Mediterranean. In *Scientific Advances In Polychaete Research* (eds. R. Sarda, G. San Martin, E. Lopez and D. George). Institut de Ciències del Mar

Charpy-Roubaud, C. and Sournia, A. (1990). The comparative estimation of phytoplanktonic, microphytobenthic and macro-phytobenthic primary production in the oceans. *Marine Microbial Food Webs* 4, 31-57

Clark, R.B., Frid, C. and Attrill, M. (1997). *Marine Pollution*. (4th ed.). Clarendon Press, Oxford

Coleman, R.A., Underwood, A.J., Benedetti-Cecchi, L., Åberg, P., Arenas, F., Arrontes, J., Castro, J., Hartnoll, R.G., Jenkins, S.R., Paula, J., Della-Santina, P. and Hawkins, S.J. (2006). A continental scale evaluation of the role of limpet grazing on rocky shores. *Oecologia* 147, 556-564

Crowe, T.P., Thompson, R.C., Bray, S. and Hawkins, S.J. (2000). Impacts of anthropogenic stress on rocky intertidal communities. *J. Aquat. Ecosyst. Stress Recovery* 7, 273-297

Deepananda, K.H.M.A and Macusi, E.D. (2012). Human disturbance on tropical rocky shore assemblages and the role of marine protected areas in reducing its impact. *Philipp. Agric. Sci.* 95 (1), 87-98

Denis, T.G. (2003). *Effects of human foot traffic on the standing stock, reproduction, and the size structure of populations of the intertidal rockweed Silvetia compressa (O. Fucales)*. MSc. dissertation, California State University, Fullerton, CA, USA.

Denny, M. (1987). Lift as a mechanism of patch initiation in mussel beds. *J. Exp. Mar. Biol. Ecol.* 113, 231-245

Denny, M.W. and Gaines, S.D. (2007). *Encyclopedia of Tide Pools and Rocky Shores*. University of California Press-Dye, A. H. (1998). Dynamics of rocky intertidal communities: analyses of long time series from South African shores. *Estuar. Coast. Shelf S.* 46, 287-305

Eagle, R.A., Hardiman, P.A., Norton, M.G., Nunny, R.S. and Rolfe, M.S. (1979). *Field assessment of effects of dumping wastes at sea: 5.The disposal of solid wastes off the north-east coast of England*. Lowestoft: MAFF Fisheries Research Technical Report. No. 51

Emanuel, B.P., Bustamante, R.H., Branch, G.M., Eekhout, S. and Odendaal, F.J. (1992). A geographic and functional approach to the selection of marine reserves on the west coast of South Africa. *S. Afr. J. Mar. Sci.* 12, 341-354.

Fernandes, A. (1996). *Poluição: Factos e figuras*. Proceedings from the Workshop on the Role of Research in Coastal Zone Management, Maputo, 24-25 April, 1996. Departamento de Ciencias Biologicas, Universidade Eduardo Mondlane

Fichet, D., Radenac, G. and Miramand, P. (1998). Experimental studies of impacts of harbour sediments re-suspension to marine invertebrates larvae: Bioavailability of Cd, Cu, Pb and Zn and toxicity. *Mar. Pollut. Bull.*36, 7-12

Firth, L.B., Thompson, R.C., White, F.J., Schofield, M., Skov, M.W., G. Hoggart, S.P.G. and Jackson, J., Knights, A.M. and Hawkins, S.J. (2013). The importance of water-retaining features for biodiversity on artificial intertidal coastal defence structures. *Divers. Distrib.* 19 (10), 1275-1283

Fornos, J. J., Forteza, V., Jaume, C. and Martinez-Taberner, A. (1992). Present-day *Halimeda* carbonate sediments in temperate Mediterranean embayments: Fornels, Balearic Islands. *Sediment.Geol.* 75,283-293

Fraschetti, S., Terlizzi, A., Guarnieri, G., Pizzolante, F., D'Ambrosio, P., Maiorano, P., Beqiraj, S. and Boero, F. (2011). Effects of unplanned development on marine biodiversity: A lesson from Albania (Central Mediterranean Sea). *J. Coastal Res.* 58, 106-115

Gaylord, B., Hill, T.M., Sanford, E., Lenz, E.A., Jacobs, L.A., Sato, K.N., Russell, A.D. and Hettinger, A. (2011). Functional impacts of ocean acidification in an ecologically critical foundation species. *J. Exp.l Biol.* 214 (15), 2586-94

Ghazanshahi, J., Huchel, T.D. and Devinny, J.S. (1983). Alteration of southern California rocky shore ecosystems by public recreational use. *J. Environ.Manage.* 16,

379-394

Gibbons, M.J. (1991). Rocky shore meiofauna: a brief overview. *T. Roy. Soc. S. Afr.* 47, 595-603

Griffin, John N., De La Haye, K.L., Hawkins, S.J. and Thompson, R.C. (2008). Predator diversity and ecosystem functioning: density modifies the effect of resource partitioning. *Ecology* 89(2), 298-305

Hallegraeff, G.M. (1993). A review of harmful algal blooms and their apparent global increase. *Phycologia* 32, 79-99

Hartnoll, R.G. (1976). The Ecology of some rocky shores in tropical East Africa. *Estuar. Coast. Mar. Sci.* 4 (1), 1-10

Haupt, T.M. Griffiths C.L., Robinson, T.B. and Tonin, A.F.G. (2010). Oysters as vectors of marine aliens, with notes on four introduced species associated with oyster farming in South Africa. *Afr. Zool.* 45(1), 52-62

Havenhand, J.N., Buttler, F.R., Thorndyke, M.C. and Williamson, J.E. (2008). Near-future levels of ocean acidification reduce fertilization success in a sea urchin. *Curr. Biol.* 18, 651-652

Hawkins, S.J., Sugden, H.E., Mieszkowska, N., Moore, P.J., Poloczanska, E., Leaper, R., Herbert, R. J.H., Genner, M.J., Moschella, P.S., Thompson, R.C., Jenkins, S.R., Southward, A.J. and Burrows, M.T. (2009). Consequences of climate-driven biodiversity changes for ecosystem functioning of North European rocky shores. *Mar. Ecol. Prog. Ser.* 396, 245-259.

Hawkins, S.J. and Hartnoll, R.G. (1985). Factors determining the upper limits of intertidal canopy-forming algae. *Mar. Ecol. Prog. Ser.* 20, 265-271

Helmuth, B., Harley, C.D.G., Halpin, P.M., O'Donnell, M., Hofmann, G.E. and Blanchette C.A. (2002). Climate change and latitudinal patterns of intertidal thermal stress. *Science* 298, 1015-1017

Helmuth, B., Mieszkowska, N., Moore, P. and Hawkins, S.J. (2006). Living on the edge of two changing worlds: forecasting the responses of rocky intertidal ecosystems to climate change. *Annu. Rev. Ecol. Evol. Syst.* 373-404

Hijmans, R.J. and Graham, C.H. (2006). The ability of climate envelope models to predict the effect of climate change on species distributions. *Glob. Change Biol.* 12, 2272-2281

Hill, M. and Currie, D. (2007). *Wildlife of Seychelles*. HarperCollins Publishers Ltd., LondonHobday, A.J. (2006). Impacts of climate change on pelagic fishes. In *Impacts of Climate Change on Australian Marine Life: Part C. Literature Revie*w (eds. A.J. Hobday, Okey, T.A., Poloczanska, E.S., Kunz, T.J. and Richardson, A.J.) pp. 94-101. Report to the Australian Greenhouse Office, Canberra, Australia

Holmer, M., Lassus, P., Stewart, J. E. and Wildish, D. J. (2001). ICES symposium on environmental effects of mariculture. Introduction. *ICES Journal of Marine Science* 58, 363-368

Hyslop, B.T., Davies, M.S., Arthur, W., Gazey, N.J. and Holroyd, S. (1997). Effects of colliery waste on littoral communities in north-east England. *Environ. Pollut.* 96, 383-400

IPCC (1996). Climate change 1995-The science of Climate Change: Contribution of Working Group 1 to the Second Assessment report of the Intergovernmental Panel on Climate Change. Houghton, J. T. Meira Filho, L.G. Callander, B.A. Harris, N. Kattenberg, A and Maskell, K. (Eds.). Cambridge University Press, Cambridge

Jackson, A.C. and McIlvenny, J. (2011). Coastal squeeze on rocky shores in northern Scotland and some possible ecological impacts. *J. Exp. Mar. Biol. Ecol.* 400, 314-321

Johnson, M.P., Frost, N.J., Mosley, M.W.J., Roberts, M.F. and Hawkins S.J. (2003). The area-independent effects of habitat complexity on biodiversity vary between regions. *Ecol. Lett.* 6 (2), 126-132

Jones, D.A., Watt, I., Plaza, J. and Woodhouse, T.D. (1996). Natural recovery of the intertidal biota within the proposed marine habitat and wildlife sanctuary for the Gulf (Saudi Arabia) after the 1991 Gulf War oil spill. In *A Marine Wildlife Sanctuary for the Arabian Gulf. Environmental Research and Conservation Following the 1991 Gulf War Oil Spill* (eds. F. Krupp, Abuzinada, H. and Nader, I.A.). pp. 138-158. NCWCD, Riyadh and Senckenberg Research Institute, Frankfurt, Germany

Jonsson P.R., Granhag, L., Moschella, P.S., Aberg, P., Hawkins, S.J. and Thompson, R.C. (2006). Interactions between wave action and grazing control the distribution of intertidal macroalgae. *Ecology* 87(5), 1169-1178.

Justic, D., Rabalais, N.N. and Turner, R.E. (1996). Effects of climate change on hypoxia in coastal waters: A double CO_2 scenario for the northern Gulf of Mexico. *Limnol. Oceanogr.* 41, 992-1003

Kalk, M. (1995). *A Natural History of Inhaca Island, Mozambique*. Witwatersrand University Press, South AfricaKendall, M.A., Burrows, M.T., Southward, A.J. and Hawkins, S.J. (2004). Predicting the effects of marine climate change on the invertebrate prey of the birds of rocky shores. *Ibis* 146, 40-47

Kim, K.Y., Choi, T.S., Huh, S.H. and Garbary, D.J. (1998). Seasonality and community structure of subtidal benthic algae from Daedo Island, Southern Korea. *Bot. Mar.*41, 357-365

Kyle, R., Pearson, B., Fielding, P. J., Robertson W. D. and Birnie, S.L. (1997). Subsistence Shellfish Harvesting In The Maputaland Marine Reserve In Northern Kwa-Zulu-Natal, South Africa: Rocky Shore Organisms. *Biol.Conserv.* 82, 183-192

Kyle, R., Robertson, W. D. and Birnie, S. L. (1997). Subsistence shellfish harvesting in the Maputaland Marine Reserve in northern KwaZulu-Natal, South Africa: sandy beach organisms. *Biol. Conserv.* 82, 173-182

Lewis, J.R. (1964). *The Ecology of Rocky Shores*. English Universities Press

Lindberg D.R., Estes, J.A. and Warheit, K.I. (1998). Human influences on trophic cascades along rocky shores. *Ecol. Appl.* 8, 880-890

Lindeboom, H. (2002). The coastal zone: an ecosystem under pressure. In *Oceans 2020: Science, Trends and the Challenge of Sustainability* (eds. J.G. Field, Hampel, G. and Summerhayes, C.). pp. 49-84 Island Press, Washington, DC

Ling, S.D., Johnson, C.R., Ridgway, K., Hobday, A.J. and Haddon, M. (2009). Climate-driven range extension of a sea urchin: inferring future trends by analysis of recent population dynamics. *Glob. Chang. Biol.* 15, 719-731

Little, C. and Kitching, J.A. (1996). *The Biology of Rocky Shores*. Oxford University Press

Littler, M.M., Martz, D.R. and Littler, D.S. (1983). Effects of recurrent sand deposition on rocky intertidal organisms: importance of substrate heterogeneity in a fluctuating environment. *Mar. Ecol. Prog. Ser.* 11, 129-139

Lubchenco, J. (1980). Algal zonation in the New England rocky intertidal community: an experimental analysis. *Ecology* 61, 333-344

Lundebye, A.K., Curtis, T. M. Braven, C.J. and Depledge, M.H. (1997). Effects of the organophosphorous pesticide, dimethoate, on cardiac and acetylcholinesterase (AChE) activity in the shore crab *Carcinus maenas*. *Aquatic Toxicology* 40, 23-36

MacDonald, L.H., Anderson, D.M. and Dietrich, W.E. (1997). Paradise threatened: land use and erosion on St. John, US Virgin Islands. *Environmental Management* 21, 851-863

Martin, A.K. and Flemming, B.W. (1988). Physiography, structure and geological evolution of the Natal continental shelf. In *Coastal Ocean studies off Natal, South Africa* (ed. E.H. Schumann). pp. 11-46. Springer-Verlag, New York

McQuaid, C.D. and Branch, G.M. (1984). Influence of sea temperature, substratum and wave exposure on rocky intertidal communities: an analysis of faunal and floral biomass. *Mar. Ecol. Prog. Ser.* 19,145-151

McQuaid, C.D. and Branch, G.M. (1985). Trophic structure of rocky intertidal communities response to wave action and implications for energy-flow. *Mar. Ecol. Prog. Ser. 22*, 153-161

McQuaid, C.D., Branch, G.M. and Crowe, A.A. (1985). Biotic and abiotic influences on rocky intertidal biomass and richness in the southern Benguela region. South *African Journal of Zoology* 20,115-122

Menge, B. A., Daley, B. A., Wheeler, P. A., Dahlhoff, E., Sanford, E. and Strub, P. T. (1997). Benthic-pelagic links and rocky intertidal communities: Bottom-up effects on top-down control? *Proceedings of the National Academy of Sciences USA* 94, 14530-14535

Menge, B.A., Lubchenco, J., Ashkenas, L.R. and Ramsey, F.L. (1986). Experimental separation of effects of consumers on sessile prey on a rocky shore on the Bay of Panama: direct and indirect consequences of food web complexity. *J. Exp. Mar. Biol. Ecol.* 100, 225-269

Menge, B.A. and Olson, A.M. (1990). Role of scale and environmental factors in regulation of community structure. *Trends Ecol. Evol.* 5, 52-57

Menge, B.A. and Sutherland, J.P. (1987). Community regulation: variation in disturbance, competition, and predation in relation to environmental stress and recruitment. *The American Naturalist* 130, 730-757

Metaxas, A. and Scheibling, R.E. (1993). Community structure and organization of tidepools. *Mar. Ecol. Prog. Ser.* 98, 187-198

Miller, D.C. and Sternberg, R.W. (1988). Field measurements of the fluid and sediment-dynamic environment of a benthic deposit feeder. *J. Mar. Res.* 46, 771-796

Mong, Y., Rejo, R., Randriamanarivo, R., Ranaivoson, J., Rakotorinjanahary, H., Ralaimaro, J. and Manera, J.Y. (2009). *Rapport national sur les activites terrestres, les sources de pollution et niveaux de pollution des eaux et des sediments: Madagascar*. Unpublished Report submitted to UNEP/WIO-LaB Project/Nairobi Convention Secretariat, Nairobi, Kenya

Moschella, P.S., Abbiati, M., Åberg, P., Airoldi, L., Ander-

son, J.M., Bacchiocchi, F., Bulleri, F., Dinesen, G.E., Frost, M., Gacia, E., Granhag, L., Jonsson, P.R., Satta, M.P., Sundelöf, A., Thompson, R.C. and Hawkins, S.J. (2005). Low-crested coastal defence structures as artificial habitats for marine life: Using ecological criteria in design. *Coast.Eng.* 52, 1053-1071

Msangameno, D.J. (2013). *Patterns and processes of benthic biological communities on the intertidal rocky shores of Unguja Island, Tanzania*. PhD Thesis. University of Dar es salaam

Munda, I. M. and Hudnik, V. (1986). Growth response of *Fucus vesiculosus* to heavy metals, singly and in dual combinations, as related to accumulation. *Botanica Marina* 29, 410-412

Murray, S.N., Denis, T.G., Kido, J.S. and Smith, J.R. (1999). *Human visitation and the frequency and potential effects of collecting on rocky intertidal populations in southern California marine reserves*. CalCOFI Report. 40, pp.100-106. Fullerton, California

Navarrete, S.A., and Menge, B.A. (1996). Keystone predation: interactive effects of two predators on their main prey. *Ecol.Monogr.* 66, 409-429

Newton, L.N., Parkes, E.V.H. and Thompson, R.C. (1993). The effects of shell collecting on the abundance of gastropods on Tanzanian shores. *Biol. Conserv.* 63, 241-245

Ngusaru, A. (1997). Geological history. In *A field guide to seashores of Eastern Africa and the Western Indian Ocean Islands* (ed. M.D. Richmond). pp12. SIDA-SAREC and University of Dar es Salaam

Paine, R.T. (1980). Food webs: linkage, interaction strength and community infrastructure. *J. Anim. Ecol.* 49, 667-685

Pearson, T.H. and Rosenberg, R. (1978). Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanography and Marine Biology: an Annual Review* 16, 229-311

Peschak, T. (2006). *Currents of Contrast: Life in Southern Africa's two oceans:* Struik Publishers

Petraitis, P.S. (1990). Direct and indirect effects of predation, herbivory and surface rugosity on mussel recruitment. *Oecologia* 85, 405-413

Pombo, O.A. and Escofet, A. (1996). Effect of exploitation on the Limpet *Lottia gigantea*: A field study in Baja California (Mexico) and California (USA). *Pac. Sci.* 50(4), 393-403

Pople, A., Simpson, R.D. and. Cairns, S.C. (1990). An incident of southern oil pollution: Effects of a spillage of diesel fuel on the rocky shore of Macquarie Island (sub-Antarctic). *Aust. J. Mar. Fresh. Res.* 41, 603-620

Raffaelli, D. and Hawkins. S. (1996). *Intertidal Ecology*. Chapman and Hall, London

Ramsay, P.J. (1996). Quaternary marine geology of the Sodwana Bay continental shelf, northern KwaZulu-Natal. *Bulletin of the Geological Survey of South Africa* 117, 1-86

Ramsay, P.J. and Mason T.R. (1990). Development of a type zoning model for Zululand coral reefs, Sodwana Bay, South Africa. *J. Coastal Res.*6, 829-852

Roy, K., Collins, A.G., Becker, B.J., Begovic, E and Engle, J.M. (2003). Anthropogenic impacts and historical decline in body size of rocky intertidal gastropods in southern California. *Ecol. Lett.* 6, 205-211

Ruwa, R.K. (1996). Intertidal wetlands. In *East African Ecosystems and Conservation* (eds. T.R. McClanahan and T.P. Young). pp. 101-127. Oxford University Press

Sagarin, R.D., Barry, J.P., Gilman, S.E. and Baxter, C.H. (1999). Climate-related change in an intertidal community over short and long time scales. *Ecol. Monogr.* 69, 465-490

Saiz-Salinas, J.I. and Urdangarin, I.I. (1994). Response of sublittoral hard substrate invertebrates to estuarine sedimentation in the outer harbour of Bilbao (N. Spain). *Mar.Ecol.* 15,105-131

Sanford, E. (1999). Regulation of keystone predation by small changes in ocean temperature. *Science* 283, 2095-2097

Sarojini, R., Khan, A. K. and Nagabhushanam, R. (1989). Oxygen consumption in the marine portunid crab *Ozius rugulosus* exposed to organophosphate (nuvan) and organochlorine (DDT) pesticides. *Indian J. Fish.* 36, 82-84

Schiel, D.R. and Taylor, D.I. (1999). Effects of trampling on a rocky intertidal algal assemblage in southern New Zealand. *J. Exp. Mar. Biol. Ecol.* 235, 213-235

Schramm, W. (1996). The Baltic Sea and its transition zones. In *Marine Benthic Vegetation: Recent Changes and the Effects of Eutrophication* (eds. W. Schramm and Nienhuis, P.) pp. 131-164. Springer, Berlin

Scrosati, R.A., Knox, A.S., Valdivia, N. and Molis, M. (2011). Species richness and diversity across rocky intertidal elevation gradients in Helgoland: testing predictions from an environmental stress model. *Helgoland Mar. Res.* 65(2), 91-102

Shackleton, L.Y., Lennon, S.J. and Tosen, G.R. (1996). *Global Climate Change and South Africa*. Cleveland: Envi-

ronmental Scientific Association

Siegfried, W.R. (1994). *Rocky Shores-Exploitation in Chile and South Africa*. Springer-Verlag

Smith, J.R. (2002). *The effects of bait collection and trampling on Mytilus californianus communities in the southern California intertidal zone*. MSc. Thesis, Department of Biological Sciences, California State University, Fullerton

Smith, S.V. (1981). Marine macrophytes as a global carbon sink. *Science* 211, 838-840.

Sousa, W.P. (1985). Disturbance and patch dynamics on rocky intertidal shores. In *The Ecology of Natural Disturbance and Patch Dynamics*. (eds. S.T. Pickett and White, P.S.) pp. 101-124. Academic Press, New York

Steffani, N.C. (2000). Possible effects of climate change on the biodiversity of Southern African rocky shores. In *The effects of climate change on Marine Biodiversity in South Africa* (eds. B.M. Clark, Steffani, N.C., Young, S., Richardson, A.J. and Lombard, A.T.) Report prepared for the Foundation for Research Development, South African country study on Climate Change, Vulnerability and Adaptation Assessment. Marine Biodiversity Section

Stephenson, T.A. and Stephenson, A. (1972). *Life between Tidemarks on Rocky Shores*. W. H. Freeman and Co. San Francisco

Terlizzi, A., Benedetti-Cecchi, L., Bevilacqua, S., Fraschetti, S., Guidetti, P. and Anderson, M.J. (2005). Multivariate and univariate asymmetrical analyses in environmental impact assessment: a case study of Mediterranean subtidal sessile assemblages. *Mar. Ecol. Prog. Ser.* 289, 27-42

Terlizzi, A., Fraschetti, S., Guidetti, P. and Boero, F. (2002). The effect of sewage discharge on shallow hard substrate sessile assemblages. *Mar. Pollut. Bull.* 44, 544-550

Thompson, R.C., Crowe, T.P. and Hawkins, S.J. (2002). Rocky intertidal communities: past environmental changes, present status and predictions for the next 25 years. *Environ. Conserv.* 29,168-191

Thompson, R.C., Jenkins, S.R. and Bussell, J.A. (2000). A method of recording prey encounters between crabs and limpets using wax replicas. *J. Mar. Biol. Assoc. U.K.* 80, 633-638

TRANSMAP (2011): Transboundary Networks of Marine Protected Areas for Integrated Conservation and Sustainable Development: Biophysical, Socio-economic and Governance Assessment in East Africa. Final Report. http://cordis.europa.eu/CORDIS_report_51928_en

Troell, M., Robertson-Andersson, D. Anderson, R.J., Bolton, J.J. Maneveldt, G., C. Halling, C, and Probyn, T. (2006). Abalone farming in South Africa: An overview with perspectives on kelp resources, abalone feed, potential for on-farm seaweed production and socio-economic importance. *Aquaculture* 257 (1-4), 266-281

UNEP/Nairobi Convention Secretariat (2009). *Transboundary Diagnostic Analysis of Land-based Sources and Activities Affecting the Western Indian Ocean Coastal and Marine Environment*. UNEP Nairobi, Kenya

Underwood, A.J. (1981). Structure of a rocky intertidal community in New South Wales: patterns of vertical distribution and seasonal changes. *J. Exp. Mar. Biol. Ecol.* 51, 57-85

Underwood, A.J. and Jernakoff, A. (1984). The effects of tidal height, wave-exposure, seasonality and rock-pools on grazing and the distribution of intertidal macroalgae in New South-Wales. *J. Exp. Mar. Biol. Ecol.* 75,71-96

Underwood, A.J. (2000). Experimental ecology of rocky intertidal habitats: what are what are we learning? *J. Exp. Mar. Biol. Ecol.* 250, 51-76

Vadas, R.L., Keser, M. and Larson, B. (1978). Effects of reduced temperatures on previously stressed populations of an intertidal alga. In *Energy and Environmental Stress in Aquatic Systems* (eds. J. H. Thorp and Gibbons, J. W.) DOE Symposium Series. (Conf-771114). pp. 434-451. National Technical Information Service, Springfield, Virginia, USA

Wafar, M., Venkataraman, K., Ingole, B., Ajmal Khan, S., LokaBharathi, P. (2011). State of knowledge of coastal and marine biodiversity of Indian Ocean countries. *PLoS ONE* 6(1), e14613

Walther, G.R., Post, E., Convey, P., Menzel, A., Parmesan, C., Beebee, T.J.C., Fromentin, M., Hoegh-Guldberg, O. and Bairlein, F. (2002). Ecological responses to recent climate change. *Nature* 416, 389-395

Watt, I., Woodhouse, T. and Jones, D. A. (1993). Intertidal clean-up activities and natural regeneration on the Gulf Coast of Saudi Arabia from 1991 to 1992 after the 1991 Gulf oil spill. *Mar. Pollut. Bull.* 27, 325-331

Williams, P.W. and Phillips, G.O. (2000). *Handbook of Hydrocolloids*. Cambridge: Woodhead

Worm, B. and Lotze, H.K. (2006). Effects of eutrophication, grazing and algal blooms on rocky shores. *Limnol. Oceanogr.* 51(1), 569-579

Worm, B., Lotze, H.K. and Sommer, U. (2000). Coastal food web structure, carbon storage and nitrogen retention

regulated by consumer pressure and nutrient loading. *Limnol. Oceanogr.* 45, 339-349

Yorath, C.J. and Nasmith, H.W. (2001). *The Geology of Southern Vancouver Island; a field guide*. Orca Book Publishers



8
Shelf Sediments and Biodiversity

Sean Fennessy and Andrew Green

Opposite page: Sediment banks off Maputo Bay, Mozambique. © José Paula.

WHAT ARE CONTINENTAL SHELVES?

Together with continental slopes and rises, continental shelves (geologically defined differently from the legal definition, as defined in Article 76 of UNCLOS) form the submerged margins of continents (Figure 8.1). Shelves are amongst some of the flattest portions of the Earth's surface (Pinet 2009) and act as halfway houses for sediment transported from the coast to the deep ocean basins. The shelves of the East African continental margin form connections between the steep upper continental slope and the adjoining coastal plain and comprise passive continental margins, having originated at the edge of divergent tectonic plates that spread (rifted) away from the mid-Indian oceanic ridge (Scrutton 1982). The continental margins of the Western Indian Ocean (WIO) are in contrast to many of the eastern Indian Ocean margins which formed instead by subduction processes. These margins are tectonically active and frequently experience earthquakes or volcanic eruptions. Passive margins, such as those in the Western Indian Ocean, are subsiding areas, often characterised by thick accumulations of sediment where fluvial sediment supply is high (Scrutton

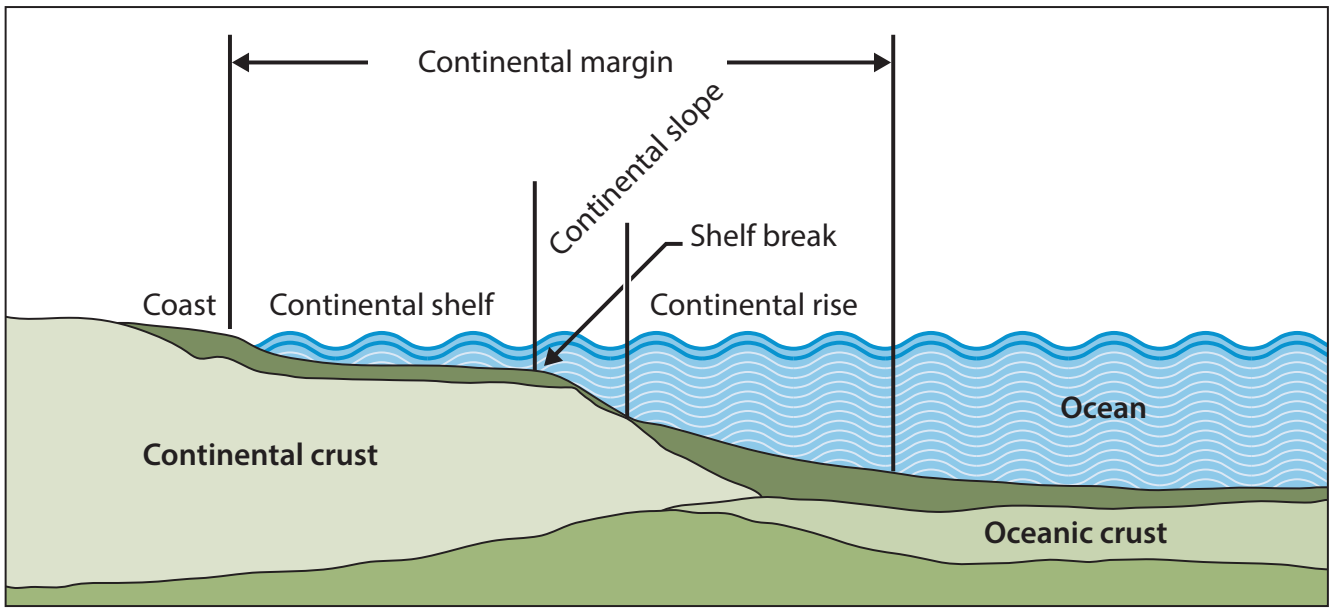


Figure 8.1. Schematic of the components of a generalized passive continental margin.

1982). Typically, the shelves of passive margins have a gentle gradient (Pinet 2009), though this can vary with some shelves being particularly steep (eg Green and others, 2007). Each shelf is separated from the continental slope by the shelf break or edge, where the gradient increases sharply. In many instances, the shelf break approximates the lowstand shorelines associated with glacial maxima ie periods of very low sea level coincident with glaciation phases. On average, the shelf break is located at a depth of about 140 m (Gross 1972), but this too can vary according to local conditions. Many shelves can be shallower, with some shelf breaks occurring at depths of 100 m or shallower (eg Green 2009a).

The location of the shelf break, which determines the width of the shelf, is a function of interactions between sedimentation processes, sea level changes and tectonics (uplift or subsidence). In addition, reefs and submerged shorelines, for example, form barriers, allowing sediment to accumulate between them and the shore, cutting off sediment supply to deeper water (eg Puga-Bernabéu and others, 2011). These also produce significant volumes of carbonate sediment in the form of rubble and bioclastic detritus (eg Flemming and Hay 1988). Continental margins with poor sediment supply, such as in arid regions, tend to have narrower continental shelves. They are characterised by little sediment transport by rivers, or by redistribution of recent sediments by longshore and geostrophic currents (Scrutton 1982, Green 2009a). The WIO is notable for its narrow shelves (Figure 8.2), with the exceptions of the central Mozambican region, where sediments from the largest river in East Africa, the Zambezi River, have extended the shelf break some 140 km offshore, and off parts of the Malagasy west coast, where large rivers such as the Betsiboka have been similarly influential. The East African shelf only averages 15-25 km in width (UNEP-GEF 2008), compared to a global average of around 80 km (Shepard 1963, Pinet 2009). Other areas where the shelf widens considerably beyond the local average are off the Thukela River in South Africa, the Limpopo River in southern Mozambique, the Ruvuma, Rufiji and Pangani rivers in Tanzania, and the Tana and Sabaki Rivers in Kenya. In parts of Kenya, northern Mozambique and the east coast of South Africa, the shelf break is as little as a few hundred metres to <4 km from the coast (Flemming 1981, Abuodha 2003, Green 2009a).

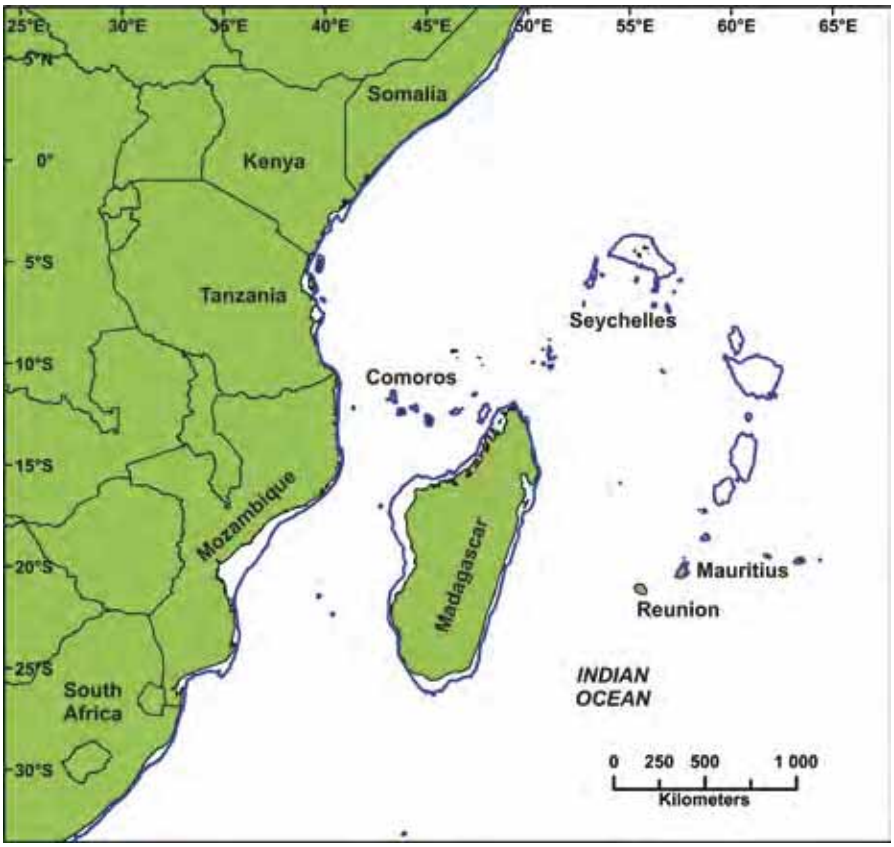


Figure 8.2. The western Indian Ocean region showing the 200 m bathymetric contour (adapted from IOC and others, 2003).

TYPES OF SEDIMENT

Assuming that the coral reef area in the Western Indian Ocean is around 13 000 km^2 (derived from Muthiga and others, 2008, Ahamada and others, 2008, UNEP-GEF 2008), when compared to the estimated total shelf area (Table 8.1), it is apparent that the vast majority of the sea bed of the shelf in the western Indian Ocean comprises unconsolidated sediments. These are terrigenous sediments derived mainly from erosion of the continents. Where there is an increased supply of these sediments, the shelf break is pushed further offshore as the newly-eroded sediments accumulate over older layers. Large quantities of the surface sediments on continental shelves are relict, in other words, deposited during earlier cycles of sea level rise and fall. Many of the sediments have been reworked by erosion cycles associated with varying sea levels and are exposed as palimpsest (relict) pavements along the mid and outer shelves, exposed to the action of fringing shelf-edge currents such as the Agulhas Current (Green and MacKay in press). These may be interspersed with submerged shorelines of varying ages which have added small, in situ quantities of rubble and bioclastic debris to the shelf system (Green and MacKay in press). Along the east coast of South Africa, the relict sediment is thinly overlain by a sheet of Holocene aged material, on average no more than 10 m thick with a few localised depocentres up to 30 m thick, usually associated with the localised convergence of littoral and geostrophic currents. The nearshore sediments are thus younger than those on the outer shelf (Flemming and Hay 1988), typically being produced by deposition of sand, silt, and clay from rivers, with subsequent redistribution by longshore currents (Flemming and Hay 1988). However, where these riverine clastic sediment inputs are small, biogenic (bioclastic) sedimentation, produced by erosion of the skeletal carbonate remains of marine organisms, can dominate. The type of sediment can thus change substantially along and across a shelf, depending on the relative contributions from carbonate and/or clastic sediment production.

The outer continental shelf and upper slope are locally incised by old river courses (Green 2009b, Green and others, 2013) that have been infilled by up to 60 m of Holocene aged sediment. Submarine canyons, particularly in northern South Africa and northern Mozambique (Parson and Evans 2005, Green 2011), are also a common feature at the shelf edge and upper slope. Submarine canyons that strongly impinge onto the shelf may act as sediment traps for littoral sediment, or can modify the nearshore currents, inducing localised deposition of sediment (Green 2009a). It is now thought that the majority of these features do not actively transfer sediment to the adjacent deep ocean basin (Green and others, 2008).

Table 8.1. Estimates of continental shelf areas of the WIO to the 200 m depth contour, ie FAO Area 51. NB: the South Africa component of the WIO only extends to latitude 31°18 S. Source: Sea Around Us Project.

Country	Shelf km^2	%
Comoros	1 618	0.4
Kenya	8 874	2.4
La Reunion	182	0.05
Madagascar	124 551	33
Mauritius	39 855	10.6
Mozambique	79 451	21
Seychelles	48 787	12.9
Somalia	47 511	12.6
South Africa	9 768	2.6
Tanzania	16 929	4.5
TOTAL WIO shelf area	377 526	

The distribution patterns of the various sediment textures (mud, sand, gravel etc.) on the shelf vary according to proximity to river mouths, depth, wave action and currents (Nichols 2009), with the fine fractions (mud and fine sand) being the most easily dispersed. There are few available studies on shelf sediment distribution patterns in the WIO; qualitative reference is made to muddy sediments off river mouths, such as on the Sofala Bank in Mozambique, and Malindi-Ungwana Bay in Kenya (Munga and others, 2013). Detailed studies have been confined to the east coast of South Africa, and were undertaken by Flemming and Hay (1988) and Bosman and others (2007); surface sediment distributions described in the latter have been recently improved and expanded by Green and MacKay (in press) and Figure 8.3 below. Knowledge of these patterns is important, as they enable us to understand the habitat requirements of the biodiversity of shelf organisms, as well as having implications for exploitation of both renewable (Figure 8.3) and non-renewable resources (eg sand extraction, heavy minerals of terrigenous origin) associated with particular sedimentary facies.

BIODIVERSITY AND SHELF SEDIMENTS

Organisms associated with the sea bed are termed benthos, and the faunal component may be divided into infauna

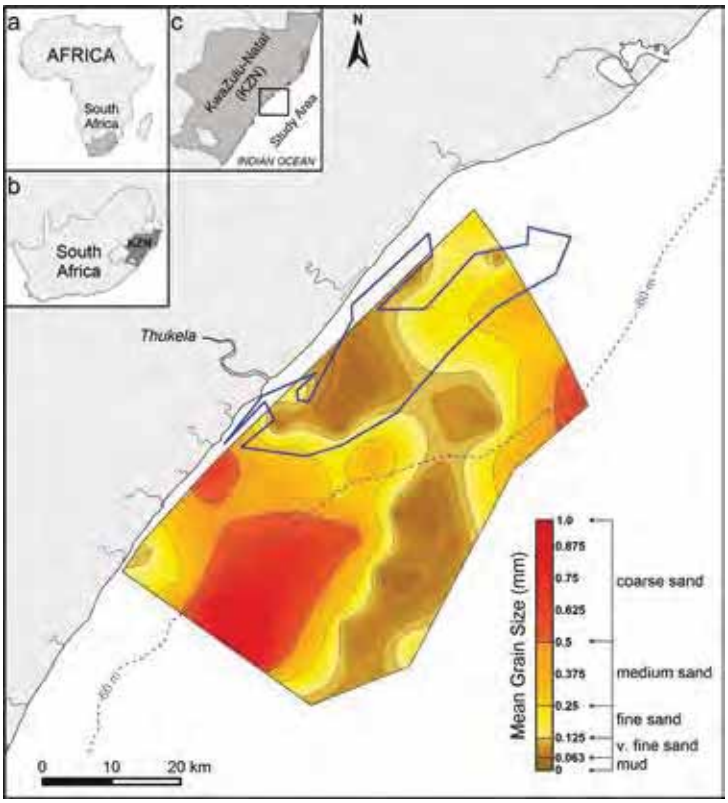


Figure 8.3. Map showing the distribution of surface sediment facies off the coast of central KwaZulu-Natal, South Africa (after Green and MacKay in press), and the close association of the shallow prawn trawling grounds (outlined in blue) with the finer facies (Oceanographic Research Institute, unpubl. data).

(found in the sediment), epifauna (on the sediment) and demersal (just above the sediment). Further distinctions can be made on the basis of the size of the organism: macrofauna (such as amphipods, isopods, gastropods and polychaetes) are >1 000 µm, meiofauna (rotifers, harpacticoid copepods, nematodes) are between 45 and 1 000 µm, while microfauna (ciliates) are <45 µm. Then there are the benthic microalgae or microphytobenthos (cyanobacteria, benthic diatoms, and flagellates) which form a layer on shelf sediments in the euphotic zone and which can contribute substantially to continental shelf productivity (Gattuso and others, 2006); these are more correctly considered as bentho-pelagic, as they can be suspended in the water column, particularly during turbulent seas, thereby forming part of the plankton. Also included in the benthos are the non-planktonic foraminifera, either living or dead, with carbonate tests which are typically <1 000 mm in diameter.

Sediment characteristics such as texture, grain size and composition are important drivers of benthic species composition, albeit in combination with other factors such as depth and temperature (Snelgrove and Butman 1994, Reiss and others, 2009). Generally, unconsolidated sediments support high diversity, and macrobenthic invertebrates are a major contributor to this (Hall 2002, Gray and Elliott 2009). Classically, polychaete worms predominate in the macrobenthos, followed by crustaceans, molluscs and echinoderms (Gray and Elliott 2009). The benthic infauna, be they deposit-feeders from sediments or suspension-feeders from the water column, or those which are capable of both, provide an important link to higher trophic levels like the demersal ichthyofauna. However, studies of benthic macro-infauna of tropical marine sediments are far fewer than their temperate counterparts (Alongi 1990) and, as with the paucity of information on sediment characteristics of the region, there are very few infaunal studies on shelf sediment habitats in the WIO. Consequently, literature on these fauna from the region are limited (Mackie and others, 2005).

Generally, a decline in diversity of macrobenthic fauna with increasing latitude may be expected, albeit reportedly less so for the infauna and sessile epifauna than for mobile epifauna (Hillebrand 2004, but see Gray and others, 1997). This was demonstrated for polychaete and molluscan taxa from the equatorial Seychelles relative to their counterparts at high latitudes in the Atlantic and Pacific (Mackie and others, 2005). There is evidence, though, that there are

considerable differences between some WIO benthic macrofaunal taxa from tropical oceanic islands and the adjacent east African mainland (Taylor 1997, Crame 2000), possibly as a result of the influence of reefs as well as mainland terrigenous inputs. Another example of the non-generality of the relationship between latitude and diversity is that of MacKay and others (in press), who found that the soft sediment shelf macrobenthos of the central KwaZulu-Natal Bight on the east coast of South Africa (~28-29ºS) are abundant and rich, and are comparable to some of the highest levels of richness in marine unconsolidated sediments found elsewhere, as reported by Gray and others (1997). MacKay and others (in press) found Annelida (760 taxa), Arthropoda (535 taxa), Mollusca (163 taxa), Echinodermata (75 taxa), Sipuncula (60 taxa) and Cnidaria (54 taxa) to be dominant; other phyla were Brachiopoda, Bryozoa, Chordata, Echiura, Nematoda, Nemertea and Platyhelminthes. The Annelida were dominated by Polychaeta which were particularly diverse (49 families). Amphipod crustaceans (34 families) dominated the Arthropoda, followed by the isopods. At the individual taxon level, a hermit crab and a sipunculid worm were most abundant. Although molluscan shell material was prevalent in bioclastic sediments (as crushed shells), live molluscs were not particularly abundant. Grain size was an important driver of macrobenthic community composition, probably due to its influence on sediment organic content and infaunal feeding modes, and riverine outflow was positively influenced abundance and diversity, probably due to increased food supply in the form of macrophytic detritus and suspended organic matter. The study by MacKay and others (in press) supersedes the generalized review by McClurg (1988), based on limited sampling in the same geographic area, and appears to be the only study of its kind in the WIO, and for which results are available.

It is possible that the diversity of benthic macrofauna of the KwaZulu-Natal Bight may differ markedly, at least at lower taxonomic levels, from that elsewhere in the WIO, owing to the unique nature of this part of the south-east African shelf. The proximity of a semi-permanent upwelling cell and a large river mouth (Lutjeharms 2000), together with their relatively high latitude, probably mean that the soft sediment shelf habitats differ from those further north, with implications for the benthic macrofaunal community composition. Having said this, it is, however, notable that there are marked similarities in some of the larger demersal shelf fauna found in several countries of the region. The prawns (shrimps) *Penaeus indicus* and *Metapenaeus monoceros* comprise the majority of targeted catches by shallow-water (<50 m) industrial trawlers from South Africa to Kenya, and Madagascar (see Chapter 21), and many of the bycatch species from these fisheries co-occur as well (Brinca and others, 1983, Bianchi 1992, Fennessy and others, 2004, Munga and others, in review). The trawl grounds for these fisheries probably coincide closely with very fine sand or mud (mean grain diameter <0.1 mm) sediment types, as described earlier for the east coast of South Africa, mud being the preferred habitat for these prawns (de Freitas 2004). Members of the family Sciaenidae (croakers; Fennessy and others, 2004) are prominent among the fishes in these mud-dominated shelf habitats, and can be considered indicators of the presence of prawns (Pauly and Neal 1985).

Broadly, it may be expected that the demersal ichthyofauna on WIO sediments conform to the "bathymetric progression" patterns described by Longhurst and Pauly (1987) for unconsolidated sediments in tropical waters. Thus, in inner shelf waters associated with river mouths, members of the Sciaenidae and Cynoglossidae would predominate owing to their preference for turbid or muddy habitats, while Sparidae, Triglidae, Sauridae and Haemulidae are probably more predominant over inner shelf substrata with less mud. Some of these families probably persist into deeper shelf water, being joined by some of the upper slope taxa such as the Squalidae. Thus depth, too, (as a proxy for other physico-chemical parameters such as temperature, salinity, etc.) is influential (Bianchi 1992, Dulvy and others, 2008). The shelf communities are probably quite distinct from those on the slope, as described generally by Longhurst and Pauly (1987). Indications that these generalized soft sediment demersal community patterns also prevail in the WIO, or at least in its trawlable areas, are available from unpublished survey reports, notably those emanating from the RV Fridjtof Nansen, including those by Brinca and others (1983), Bianchi (1992), Johnsen and others (2008), Alvheim and others (2010), as well as from the recent South West Indian Ocean Fisheries Project (van der Elst and others, 2009, www.swiofp.net), although the information on sediment composition in the trawlable areas is lacking. Thus, the association of demersal fish communities with particular substratum types has not been demonstrated in the WIO, other than in a general sense by Bianchi (1992), and by Fennessy (in press) in a South African study with limited scope. As described in

other regions (eg Gaertner and others, 1999), this association may be expected to be particularly close for demersal fishes which are in direct contact with the substratum, such as flat fishes and gurnards, and some species are probably specifically linked to substrata and/or turbidity associated with riverine plumes (as is the case with some invertebrates, as described above). Furthermore, it is anticipated that these associations are also a function of the composition of the benthic infauna which are the prey of demersal fishes; again, while these interdependencies are at least partially understood in other regions (eg Darnaude and others, 2004), similar studies are virtually non-existent for the WIO shelf.

Only recently did de Lecea and others (2013) demonstrate these dependencies indirectly on the South African east coast, where their isotope-based study revealed that the soft-sediment demersal food web in a nutrient-poor shelf environment was controlled by total suspended solids of terrestrial origin, via riverine input, with macrobenthos as probable intermediaries. In this case, omnivory was a widespread strategy amongst the sampled demersal organisms, shown by the low variability in trophic position across a wide variety of taxa. This "eat whatever is available" strategy was suggested to be a function of a nutrient-poor environment, and has important implications for ecosystem functioning; a flexible diet can impart resilience, such that changes in species composition may not appreciably affect overall functioning of the system. Untiedt and Mackay (in press) also showed that the infaunal community in this shelf area was dominated by organisms which had a variety of feeding modes, enabling them to adapt to an environmentally variable and heterogeneous shelf environment. Overall, ecosystem models showed that the infauna dominate the shelf benthic food web, with a high reliance on riverine detritus, and with important links to nearby estuaries (Scharler and others, in review). Although these studies were once-off and were confined to the east coast of South Africa, there may well be analogies with soft-sediment shelf habitats elsewhere in the WIO, which is generally nutrient-poor (Mengesha and others, 1999; see also this report – Chapter 16, primary productivity), but with some areas influenced by riverine inputs (UNEP-GEF 2008).

IMPACTS ON SHELF SEDIMENTS

While rivers are important providers of nutrients and sediments to shelf habitats, they are also a source of pollutants, such as persistent organic pesticides and heavy metals, which can accumulate in shelf sediments, particularly if the wave energy is low and the shelf dominated by muddy deposition (eg Palanques and Diaz 1994). Other sources which add to this load are marine disposal outfalls and dumping of harbour dredge spoil. As anthropogenic impacts in the coastal zone and catchments are increasing, levels of these contaminants on the shelf are also likely to be increasing, but studies for which published results are available are extremely limited, and are mostly based on isolated (once-off) sampling. Sediments and demersal invertebrates on the shelf off the Tana and Sabaki rivers in Kenya in the early 1990s were not highly contaminated with heavy metals, which were recorded at levels lower than those in other tropical environments (Everaarts and Niuwenhuize 1995). Carter (2006) found metal levels in mud off the Thukela River in South Africa which exceeded toxicity threshold effect levels. Abundance and richness of shelf macrobenthic infauna off Reunion increased with exposure to slight enrichment from industrial effluents rich in organic matter (Bigot and others, 2006). Results of sampling in 2007 and 2008 during the WIO-Lab project (www.unep.org/NairobiConvention/, UNEP/Nairobi Convention Secretariat, CSIR and WIOMSA 2009), albeit conducted mainly at inshore hotspots, indicated (with some qualification) that sediments from Madagascar and Tanzania had average concentrations of some metals which were higher than those suggested in the WIO Environmental Quality Guidelines (UNEP 2009).

CONCLUSIONS

Generally, there are no long-term datasets available for shelf sediments in the WIO which can be used to examine habitat and biodiversity trends. Some of the demersal industrial fisheries described in Chapter 21 may provide long-term biodiversity indices based on monitoring of catches, although these are confined to quite specific localities, are focused only on fisheries' target species, and the fishing itself alters the ecosystem in which it takes place. From a biodiversity perspective, perhaps it is fortunate that most of the soft-sediment shelf in the region does not support fisheries, apart from shallow inshore areas which are readily accessible to small-scale gill and seine nets, and some specific muddy banks harbouring (declining) industrial-scale prawn trawling. This is mainly attributable to the

low productivity of the shelf soft sediments in terms of their demersal biomass (Neyman and others, 1973), the low densities making fishing non-viable.

So the main pressures on shelf sediments in the region are in the form of terrigenous pollutants in the vicinity of river mouths, altered nutrient supply as a result of impoundments (reduced riverine input), and the potential disruption of habitats by the extraction of non-renewable resources (heavy minerals and hydrocarbons). Prospecting for the latter has produced extensive data sets on sediment distribution, but these are not readily available to environmental managers. Such information would reveal patterns in sediment type, depth and latitude, information that could be used to assess community patterns. Sediment cores, derived either from prospecting or from independent research, would also provide historical baselines against which to assess changing pressures and drivers, such as levels of pollutants and climate change. However, knowledge of the shelf communities suffers from a lack of the taxonomic capacity required to recognize faunistically distinct regions so as to assist conservation management (Mackie and others, 2005); countries and partnerships in the WIO need to foster such skills by sampling hitherto undescribed habitats and publishing their results.

References

Abuodha, P.A. (2003). Geomorphology of the Kenyan coast: Not as a result of sea-level change alone. *Boletim Geologico, Mozambique* 43, 2-7

Ahamada, S., Bijoux, J., Cauvin, B., Hagan, A., Harris, A., Koonjul, M., Meunier, S. and Quod, J.P. (2008). Status of the Coral Reefs of the South-West Indian Ocean Island States: Comoros, Madagascar, Mauritius, Reunion, Seychelles. In *Status of coral reefs of the world: 2008*. (ed. Wilkinson, C.) pp. 105-118. Townsville, Australia

Alongi, D.M. (1990). The ecology of tropical soft-bottom benthic ecosystems. *Oceanogr. Mar. Biol. Ann. Rev* 28, 381-496

Alvheim, O., Torstensen, E., Fennessy, S.T., Groeneveld, J.C., Mackay, F., Zaera, D. and Bemiasa, J. (2010). *Cruise reports 'Dr. Fridtjof Nansen' West Madagascar*. SWIOFP/ASCLME/FAO Cruise 2, 25 August–3 October 2009. FAO-NORAD Project No.: GCP/INT/003/NOR. Institute of Marine Research, Bergen, Norway

Bianchi, G. (1992). Zonation of demersal fishes of the East Africa continental shelf. A study based on the surveys of the R/V *'Dr. Fridtjof Nansen'*. In *Demersal assemblages of tropical continental shelves. A study based on the data collected through the surveys of the R/V 'Dr. Fridtjof Nansen'*. PhD thesis, University of Bergen, Norway

Bigot, L., Conand, C., Amouroux, J.M., Frouin, P., Bruggemann, H., and Grémare, A. (2006). Effects of industrial outfalls on tropical macrobenthic sediment communities in Reunion Island (Southwest Indian Ocean). *Mar. Pollut. Bull.* 52(8), 865-880

Brinca L., Da Silva, A.J., Sousa, I.M. and Saetre, R. (1983). *A survey on the fish resources at Sofala Bank - Mozambique, September 1982*. Reports on surveys with the R/V Dr Fridtjof Nansen. Institute of Marine Research, Bergen, Norway

Bosman, C., Uken, R., Leuci, R., Smith, A.M. and Sinclair, D. (2007). Shelf sediments off the Thukela River mouth: complex interaction between fluvial and oceanographic processes. *S. Afri. J. Sci.* 103, 490–492

Carter, R. (2006). *Environmental investigation programme to determine potential cumulative effects of outfalls and discharges to sea off the KwaZulu-Natal coast*. Unpublished report prepared for the CoastWatch Project: Wildlife and Environment Society of South Africa

Crame, J.A. (2000). Evolution of taxonomic diversity gradients in the marine realm: evidence from the composition of recent bivalve faunas. *Paleobiology* 26, 188- 214

De Freitas, A.J. (2004). The Penaeoidae of southeast Africa: IV. *The Family Penaeidae: Genus Penaeus. Investig. Rep. Oceanogr. Res. Inst.* 59, 1 – 112

Darnaude, A.M., Salen-Picard, C., Polunin, N.V.C. and Harmelin-Vivien, M.L. (2004). Trophodynamic linkage between river runoff and coastal fishery yield elucidated by stable isotope data in the Gulf of Lions (NW Mediterranean). *Oecologia* 138, 325-332

de Lecea, A.M., Fennessy, S.T. and Smit, A.J. (2013). Processes controlling the benthic food web of a mesotrophic bight (KwaZulu-Natal, South Africa) revealed by stable isotope analysis. *Mar. Ecol. Prog. Ser.* 484, 97-114

Dulvy NK, Rogers SI, Jennings S, Stelzenmüller V, Dye SR

and Skjoldal HR. (2008). Climate change and deepening of the North Sea fish assemblage: a biotic indicator of warming seas. *J. App. Ecol.* 45, 1029–1039

Everaarts J.M. and Niuwenhuize J. (1995). Heavy metals in surface sediment and epibenthic macroinvertebrates from the coastal zone and continental slope of Kenya. *Mar. Pollut. Bull.* 31, 281-289

Fennessy, S.T. (in press). Subtropical demersal fish communities on soft sediments in the KwaZulu-Natal Bight, South Africa. *Afri. J. Mar. Sci.*

Fennessy S.T., Mwatha, G.K. and Thiele, W. (eds.) (2004). Report of the regional workshop on approaches to reducing shrimp trawl bycatch in the western Indian Ocean. *FAO Fisheries Report* 734, 58. Mombasa, Kenya

Flemming, B.W. (1981). Factors controlling shelf sediment dispersal along the southeastAfrican continental margin. *Mar. Geol.* 42, 259-277

Flemming, B. and Hay, R. (1988). Sediment distribution and dynamics on the Natal continental shelf. In *Coastal ocean studies off Natal, South Africa*. (ed. Schumann, E.H.) pp. 4780. SpringerVerlag, Berlin

Gaertner, J.C., Mazouni, N., Sabatier, R. and Millet, B. (1999). Spatial structure and habitat associations of demersal assemblages in the Gulf of Lions: a multicompartmental approach. *Mar. Biol.* 135, 199-208

Gattuso, J.P., Gentili, B., Duarte, C.M., Kleypas, J.A., Middelburg, J.J., and Antoine, D. (2006). Light availability in the coastal ocean: impact on the distribution of benthic photosynthetic organisms and their contribution to primary production. *Biogeosciences* 3, 489-513

Gray, J.S. and Elliott, M. (2009). *The ecology of marine sediments: from science to managemen*t. Oxford University Press

Gray, J.S., Poore, G.C.B., Ugland, K.I., Wilson, R.S., Olsgard, F. and Johannessen Ø. (1997). Coastal and deep-sea benthic diversities compared. *Mar. Ecol. Prog. Ser.* 159, 97-103

Green, A.N. (2009a). Sediment dynamics on the narrow, canyon-incised and current swept shelf of the northern KwaZulu-Natal continental shelf, South Africa. *Geo-Mar. Lett.* 29, 201-219

Green, A.N. (2009b). Palaeo-drainage, incised valley fills and transgressive systems tract sedimentation of the northern KwaZulu-Natal continental shelf, South Africa, SW Indian Ocean. *Mar. Geol.* 263, 46-63

Green, A.N. (2011). Submarine canyons associated with alternate sediment starvation and shelf-edge wedge development: northern KwaZulu-Natal continental margin, South Africa. *Mar. Geol.*284, 114-126

Green, A.N., Goff, J.A. and Uken, R. (2007). Geomorphological evidence for upslope canyon-forming processes on the northern KwaZulu-Natal shelf, South Africa. *Geo-Mar. Lett.* 27, 399-409

Green, A.N., Ovechkina, M. and Uken, R. (2008). Nannofossil age constraints on shelf-edge wedge development: implications for continental margin dynamics, northern KwaZulu-Natal, South Africa. *Cont. Shelf Res.* 28, 2442-2449

Green, A.N., Dladla, N.N. and Garlick, G.L. (2013). Spatial and temporal variations in incised valley systems from the Durban continental shelf, KwaZulu-Natal, South Africa. *Mar. Geol.* 335, 148-161

Green, A.N. and MacKay, C.F. (in press). The role of ravinement in separating relict versus passive sediment populations unconsolidated sediment distribution of the KwaZulu-Natal Bight. *Afri. J. Mar. Sci.*

Gross, G.M. (1972). *Oceanography: A View of the Earth.* Englewood Cliffs: Prentice-Hall, Inc.

Hall, S.J. (2002). The continental shelf benthic ecosystem: current status, agents for change and future prospects. *Environ. Conserv.* 29, 350-374

Hillebrand, H. (2004). Strength, slope and variability of marine latitudinal gradients. *Mar. Ecol. Prog. Ser.* 273, 251–267

IOC, IHO and BODC (2003). *Centenary Edition of the GEBCO Digital Atlas*. Published on CD-ROM on behalf of the Intergovernmental Oceanographic Commission and the International Hydrographic Organization as part of the General Bathymetric Chart of the Oceans, British Oceanographic Data Centre, Liverpool, U.K

Johnsen, E., Krakstad, J.O., Ostrowski, M., Serigstad, B., Strømme, T., Alvheim, O., Olsen, M., Zaera, D., André, E.R., Dias, N., Sousa, L., Sousa, B., Malauene, B. and Abdula, S. (2008). *Surveys of the living marine resources of Mozambique: Ecosystem survey and special studies*. FAO-NORAD PROJECT NO: GCP/INT/003/NOR27. September – 21 December 2007. Cruise reports "Dr Fridtjof Nansen". Institute of Marine Research, Bergen

Longhurst, A.R. and Pauly, D. (1987). *Ecology of tropical oceans*. Academic Press, Orlando, Florida

Lutjeharms, J.R.E., Valentine, H.R., and van Ballegooyen, R.C. (2000). The hydrography and water masses of the Natal Bight, South Africa. *Cont. Shelf Res.* 20, 1907-1939

MacKay, C.F., Untiedt, C.B. and Hein, L. (in press). Local habitat drivers of macrobenthos on the northern, central and southern KwaZulu-Natal Bight, South *Afri. J. Mar. Sci.*

Mackie, A.S., Oliver, P.G., Darbyshire, T., and Mortimer, K. (2005). Shallow marine benthic invertebrates of the Seychelles Plateau: high diversity in a tropical oligotrophic environment. *Philos. T. Roy. Soc. A.* 363, 203-228

Mengesha, S., Dehairs, F., Elskens, M. and Goeyens, L. (1999). Phytoplanton nitrogen nutrition in the Western Indian Ocean: Ecophysiological adaptations of neritic and oceanic assemblages to ammonium supply. *Estuar. Coast. Shelf S.* 48(5), 589-598

McClurg, T.M. (1988). Benthos of the Natal continental shelf. In *Coastal Ocean studies off Natal, South Africa. Lecture notes on coastal and estuarine studies* (ed. Schumann E.H.) No 26, pp. 178-208. Springer-Verlag, Berlin

Munga, C.M., Mwangi, S., Ong'anda, H., Ruwa, R., Manyala, J., Kimani, E. and Vanreusel, A. (in review). Comparing fish bycatch of shrimp trawlers with catches made by artisanal fishers in Malindi-Ungwana Bay, Kenya. *Western Indian Ocean J. Mar. Sci.*

Munga, C.N., Mwangi, S., Ong'anda, H., Ruwa, R., Manyala, J., Groeneveld, J.C. and Vanreusel, A. (2013). Species composition, distribution patterns and population structure of penaeid shrimps in Malindi-Ungwana Bay, Kenya, based on experimental bottom trawl surveys. *Fish. Res.* 147, 93-102

Muthiga, N., Costa, A., Motta, H., Muhando, C., Mwaipopo, R. and Schleyer M.H. (2008). Status of coral reefs in East Africa: Kenya, Tanzania, Mozambique and South Africa. In *Status of coral reefs of the world: 2008*. (ed. Wilkinson, C.) pp. 91-104. Townsville, Australia

Neyman, A.A., N. N. Sokolova, N. G. Vinogradova and F.A. Pasternak. (1973). Some patterns of the distribution of bottom fauna of the Indian Ocean. In *The Biology of the Indian Ocean* (ed. Zeitschel, B.) pp. 467-474. Chapman and Hall, London

Nichols, G. (2009). *Sedimentology and stratigraphy*. 2nd edition. Wiley-Blackwell

Parson, L.M., and Evans, A.J. (2005). Seafloor topography and tectonic elements of the Western Indian Ocean. *Philos. T. Roy. Soc. A.* 363, 15-24

Pauly, D. and Neal, R. (1985). Shrimp vs. fish in Southeast Asian fisheries: the biological, technological and social problems. In *Recursos Pesqueros Potenciales de Mexico: La Pesca Acompanante del Camaron*. Progr. Univ. de Alimentos, Inst. Cienc. del Mar y Limnol., Inst. Nal. de Pesca. pp. 487-510. UNAM, Mexico D.F.

Palanques, A., and Diaz, J.I. (1994). Anthropogenic heavy metal pollution in the sediments of the Barcelona continental shelf (Northwestern Mediterranean). *Mar. Environ. Res.* 1, 17-31

Pinet, P.R. (2009). *Invitation to Oceanography*. Jones and Bartlett Publishers. 5th edition

Puga-Bernabéu, A., Webster, J.M., Beaman, R.J., and Guilbaud, V. (2011). Morphology and controls on the evolution of a mixed carbonate-siliciclastic submarine canyon system, Great Barrier Reef margin, north-eastern Australia. *Mar. Geol.* 289, 100-116

Reiss, H., Degraer, S., Duineveld, G.C.A., Kröncke, I., Aldridge, J., Craeymeersch, J.A., Eggleton, J.D., Hillewaert, H., Lavaleye, M.S.S., Mol,l A., Pohlmann, T., Rachor, E., Robertson, M., Van den Berghe, E., van Hoey, G. and Rees, H.L. (2009). Spatial patterns of infauna, epifauna and demersal fish communities in the North Sea. *ICES Journal of Marine Science* 67, 278-293

Scharler, U., van Ballegooyen, R. and Ayers, M. (in press). A system-wide perspective of the KwaZulu-Natal Bight ecosystem, eastern South Africa. *Afr. J. Mar. Sci.*

Scrutton, R.A. (ed.) (1982). *Dynamics of Passive Margins*. Geodynamics Series vol. 6. American Geophysical Union

Sea Around Us Project – Fisheries, Ecosystems and Biodiversity. *EEZ Waters Of Mozambique*. www.seaaroundus.org/eez/508.aspx Accessed 28 Nov 2014.

Shepard, F.P. (1963). *Submarine Geology*. Harper and Row, New York

Snelgrove, P.V.R. and Butman, C.A. (1994). Animal-sediment relationships revisited: causes versus effects. *Oceanogr. Mar. Biol. Ann. Rev* 32, 111-177

South West Indian Ocean Fisheries Project (SWIOFP). www.swiofp.net

Taylor, J.D. (1997). Diversity and structure of tropical Indo-Pacific benthic communities: relation to regimes of nutrient input. In *Marine biodiversity: patterns and processes* (ed. R.F.G. Ormond, J.D. Gage and M.V. Angel), pp. 178–200. Cambridge University Press

UNEP-GEF (2008). *Transboundary diagnostic analysis of land-based sources and activities in the Western Indian Ocean Region*. UNEP-GEF WIO-LaB Project addressing land based activities in the Western Indian Ocean

UNEP (2009). *Guidelines for the establishment of environmen-*

tal quality objectives and targets in the coastal zone of the western Indian Ocean (WIO) region. WIO-LaB Technical Report Series No. 01/2009, United Nations Environment Programme, Kenya, Nairobi

UNEP/Nairobi Convention Secretariat, CSIR and WIOMSA (2009). *Regional synthesis report on the status of pollution in the western Indian Ocean region*. UNEP, Nairobi, Kenya

United Nations Environment Programme. *Nairobi Convention*. www.unep.org/NairobiConvention/

Untiedt, C.B. and MacKay, C.F. (in press). Macrobenthos distribution and feeding modes within three oceanographic feature areas of the KwaZulu-Natal Bight, South Africa. *Afri. J. Mar. Sci.*

van der Elst, R.P., Groeneveld, J.C., Baloi, A.P., Marsac, F., Katonda, K.I., Ruwa, R. and Lane, W.L. (2009). Nine nations, one ocean: A benchmark appraisal of the South Western Indian Ocean Fisheries Project (2008-2012). *Ocean Coast. Manag.* 52, 258-267



9
Deep sea and Offshore/Pelagic Habitats

David Obura

Opposite page: Larval squid in the plankton of the WIO. © Cedric Guiguand/Emmanuel G. Reynaud.

INTRODUCTION

The deep sea habitats of the Western Indian Ocean (WIO) are very poorly known, particularly from the perspective of the governments in the region, which have limited capacity to engage in deep sea research or plan for exploitation of resources in this environment in the near future. Nevertheless, there are some emerging exceptions to this which will be presented in this chapter. In view of the paucity of general knowledge on deep sea habitats in the region, this introduction includes information on their basic structure, followed in later sections by a summary of their status, knowledge on their biodiversity, and pressures/trends in the future.

Plate tectonics

The WIO contains both active and fossil tectonic plate margins, some of the deepest fracture zones in the world, the most complex mid-ocean ridge configurations and some of the thickest sedimentary sequences in the world's ocean basins. The continental land mass of Africa, Madagascar, and the North Seychelles Bank are remnants of the supercontinent Gondwana, which dates from pre-Cambrian times over 650 million years ago (mya), and that started to break up 180 mya. Key events include:

- Formation of the Mozambique Channel, from about 180 -150 mya when Madagascar, Australia, India and Antarctica rifted from the African coast.
- Australia-Antarctica started to separate from Madagascar-India 120 mya.
- India split from Madagascar and moved northwards, leaving behind a fragment which is now the North Seychelles Bank 80 mya.

The WIO floor is composed of two major plates, the African and Indian plates; the Australian plate lies to the east, the Arabian plate to the north. The ocean floor is still tectonically active, with a spreading rift along the South West and Central Indian Ocean ridges, and northwards in the Carlsberg ridge that extends into the Red Sea. This continuous ridge system forms the approximate eastern boundary of the WIO and the African coastline defines the western boundary (ASCLME/SWIOFP 2012a, ASCLME/SWIOFP 2012b, Figure 9.1).

Hotspots and other geological features

Within its broader tectonic margins, the WIO contains a number of active hotspots, two of which are of global significance and scale. The Mascarene-Reunion hotspot became active at the Cretaceous-Tertiary (K-T) boundary about 67-64 mya, through a massive eruption of magma that formed the Deccan Traps in India (classified as a Large Igneous Province, or LIP). As the Indian plate moved northwards over the hotspot, a series of island chains were formed: Lakshadweep – Maldives (57-60 mya), the Chagos Archipelago (48 mya), Saya de Malha (45 mya), Nazareth and Cargados Carajos (34 mya), Mauritius (7-8 mya) and Reunion (0-2 mya). Only the youngest two, Mauritius and Reunion have volcanic features breaking the surface (the

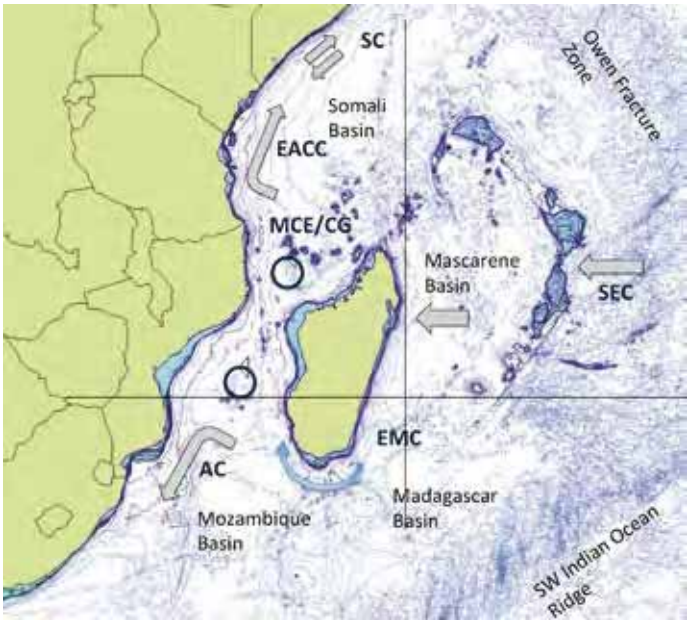


Figure 9.1. Deep sea features of the Western Indian Ocean, including principal basins and currents Bathymetry is shown at 100 m depth (light blue shading) then at 500 m and 500 m intervals thereafter. Abbreviations: AC Agulhas Current, EACC East Africa Coastal Current, EMC East Madagascar Current, MCE/CG Mozambique Channel Eddies/Comoros Gyre, SC Somali Current, SEC South Equatorial Current.

latter is still volcanically active today); all the others have sunken below the ocean surface and are capped by biogenic carbonate platforms and coral atolls or islands. The Central Indian Ocean ridge itself moved over the hotspot about 45 mya, separating the Chagos and Saya de Malha Banks. During the Cretaceous, the continental fragment of Madagascar lay over the Marion hotspot, creating a submarine Plateau which extends southwards some 1 300 km at depths of 1 000-2 000 m, rising above the deeper basins to the east and west up to 5 000 m deep.

Seamounts in the WIO are concentrated on the mid-ocean ridges, particularly the South West Indian Ridge, and scattered around the Mascarene Plateau. Approximately 700 seamounts have been identified in the WIO region from global studies of bathymetry ASCLME/SWIOFP 2012a, ASCLME/SWIOFP 2012b). Most seamounts in the WIO are outside national jurisdiction, with only those scattered around the Mascarene Plateau being within the EEZs of the regional countries. A complex geological history is suggested by the multiple islands and island groups within the Seychelles-Mascarene region (eg Aldabra group, Farquhar/Providence and the Amirantes). Other volcanic features include the island of Rodrigues and Soudan Bank, seamounts in the Seychelles that break the surface as coral reefs, the Comoros Archipelago, the Iles Eparses, and the Davies Ridge in the Mozambique Channel.

Ocean basins

As a result of these various geological features, the WIO is split into four deep basins: the Madagascar (5 500 m, south-east of Madagascar), Mascarene (4 900 m, west of the Mascarene Plateau), Mozambique (5 000 m, south of the Mozambique Channel) and Somali Basins (5 100 m, between Somalia and the Seychelles, Figure 9.1). Little work has been done on the abyssal plains and soft sediments of these basins, though drilling on and near the Mascarene Plateau shows thick accumulations of marine sediments, and terrestrial sediments in the Mozambique Channel, probably washed off the African and Madagascan landmasses by large rivers over >100 million years.

Oceanography

The oceanography of the Western Indian Ocean is determined by interactions between the geological features outlined above with the equatorial and western boundary currents of the ocean basin. The South Equatorial Current (SEC) enters the WIO as a broad slow surface current stretching from about 5-16°S, fed from the Indonesian Through-Flow with waters from the Pacific Ocean, and passing the Chagos Archipelago at its northern edge. At the Mascarene Plateau, the SEC is partially blocked, with 50 per cent of its flow forced through the narrow gap between the Saya de Malha and Nazareth Banks at about 12°S, the remainder flowing both north and south of these two banks.

Approaching Madagascar, the main flow of the current is at about 17°S. The banks and island systems lying in the pathway of the SEC function as stepping stones for species crossing the Indian Ocean, providing genetic connectivity. Interestingly, there is evidence pointing to west-east transport (Sheppard and others, 2012) as well as in the expected east-west direction.

The tip of Madagascar and the Comoros-Glorieuses chain interact with the flow of the SEC and open ocean features such as Rossby waves to generate unique and highly dynamic meso-scale eddies within the northern Mozambique Channel. The "Glorioso Front" probably marks the transition from the SEC to the waters of the channel, where a series of clockwise and anti-clockwise eddies and an intermittent gyre around the Comoros chain are induced (Ternon and others, 2014). Being driven by these features, water may flow in any direction, resulting in a highly mixed and dynamic water body in the northern part of the channel. As the channel narrows at about 17°S, the flow becomes more southward just offshore of the Mozambique coast. Complex forcing of biological parameters results from these dynamics, including up- and downwelling in the eddies and their interactions with the continental shelves and slopes below at least 1 000 m depth. As a result, the Mozambique Channel is one of the most energetic western boundary zones of all the world's oceans (Ternon and others, 2014).

The rapid flow of the East Madagascar Current interacts with the Madagascar Plateau, which extends southwards over 1 000 km at depths of 1 000 to 2 000 m, as it curls around the southern tip of Madagascar. This results in highly dynamic nearshore eddies and nearshore–offshore upwelling over 100s of square kilometres of sea, enriching highly productive food webs. This also results in unique communities and high levels of endemicity at the transition zone between the tropical and subtropical regions. These waters merge with waters from the Mozambique Channel and feed into the Agulhas Current, one of the fastest and narrowest coastal boundary currents in the world. Most of the Agulhas waters turn 180° (retroflect) and return to the southern part of the WIO at about 40°S.

In the north, the seasonally reversing Somali Current and seasonal northern Indian Ocean gyre are dominated by the influence of the Asian land mass and the monsoons, resulting in a highly dynamic system of currents and an intermittent North Equatorial Counter Current (NECC) that returns water from the East African coast towards the Seychelles, at about 0-2°S. The Asian landmass thus drives the seasonal monsoon system that dominates climate in the central and northern parts of the region. Seasonality in the NECC contributes to west-east connectivity that apparently passes through the Chagos/Maldives/Lakshadweep systems, returning genetic material to the Eastern Indian Ocean.

Productivity

Biological diversity patterns in the WIO are driven by the geological and oceanographic features described above. Interactions between water flow and shallow or deep bathymetric features can result in strong downstream dynamics as a result of eddies (mixing and turbulence) induced in the wake of the features, with raised productivity resulting from this and from the addition of nutrients and minerals to otherwise oligotrophic and mineral-poor oceanic waters. Closed circulation cells may also form around seamounts, inducing upwelling, trapping nutrients and enhancing primary productivity (Harris 2011, Keating and others, 1987).

The seasonal dynamics of the Somali Current strongly influence productivity in the northern part of the WIO (Schott and McCreary 2001), with strong upwelling in May to September along certain parts of the coast due to the northward-flowing East African Coastal Current. The seasonal upwelling shuts down during the northeast monsoon in December to April, but complex currents redistribute biological production from the upwelling events throughout the northern Indian Ocean.

Upwelling in the open ocean between 5-10°S in the Central and Western Indian Ocean is indicated by mesozooplankton and biochemistry (Murtugudde and others, 1999) but, although there is some evidence for topographically-induced upwelling on the lee side of the Mascarene Plateau, this is highly variable and has not been consistently or conclusively established (Gallienne and Smythe 2003). Preliminary results from an ASCLME cruise in 2008 revealed no indication of upwelling, nutrient enrichment or enhanced primary production along the leeward edge of the plateau (Stromme and others, 2008).

However, the influence of oceanographic variability and energetics on productivity in the Mozambique Channel is emerging (Ternon and others, 2014). Productivity is influenced by the direction of flow in the eddies. Clockwise (cyclonic) eddies cause upwelling in their

centre of the eddy, thus raising the thermocline and nutricline closer to stronger sunlight near the surface, resulting in greater productivity in the core of the eddy. Conversely, counter-clockwise (anticyclonic) eddies depress the thermocline and nutricline, resulting in reduced productivity in the core. However, eddies frequently interact, particularly when a clockwise and anticlockwise eddy are stably adjoined (called a dipole), raising productivity in the boundary between them. Finally, when eddies (singly or in a dipole) touch the continental slope - which may occur frequently as the eddies may extend over 2 000 m deep - they strip nutrients off the continental slope and make them available to pelagic ecosystems. As a result, the productivity of the Mozambique Channel is uniquely high.

SCALE OF BIOLOGICAL DIVERSITY (MAIN GRADIENTS OF DIVERSITY FOR SPECIES AND COMMUNITIES)

The open ocean and deep sea biota of the WIO are poorly known. Richmond (2001) compiled an inventory of species identified in the WIO from available records, totalling 10 627 species in the littoral and shallow subtidal zones. Griffiths (2005) updated this number to 11 257 through the Census of Marine Life, claiming this is probably half the actual number. Wafar and others (2011) also commented on the lack of biodiversity information for the region. Work in deeper habitats has resulted in the identification of new species (eg Randall and King 2009).

New surveys are revealing previously unknown hotspots of biological diversity for benthic invertebrates (Bouchet 2012), such as the subtropical-temperate southern coastline of Madagascar. It is likely that deeper regions, such as the Madagascar Plateau, will manifest even greater levels of endemism with previously undescribed diversity. Significant investment by the GEF in regional marine assessments over the last 5-10 years, particularly through the ASCLME and SWIOFP programmes, has yielded new data in a number of areas (ASCLME/SWIOFP 2012a, ASCLME/SWIOFP 2012b). The surveys run by SWIOFP and ASCLME covered a range of topics, including physicochemical conditions, plankton sampling, soft-bottom meiofauna, trawl samples, acoustic biomass estimates and megafauna observations; the sections below summarise information in the TDA.

Marine mammals

A variety of marine mammals frequent the open seas of the WIO, though little work has distinguished between those that are open oceanic or pelagic from those found in nearshore waters. Many of the large whales frequent both, though they probably spend the larger part of their time in open ocean waters. Beaked whales are more often restricted to open ocean and deep waters, but little is known of their ecology in the WIO. For example, there are a number of anecdotal records of sightings of colder water species in the WIO, including True's beaked whale (*Mesoplodon mirus*), Shepherd's beaked whale (*Tasmacetus shepherdi*), and the ginkgo-toothed beaked whale (*Mesoplodon ginkgodens*). Recent surveys of islands in the WIO have contributed significantly to distribution records of marine mammals in the WIO (REMMOA 2012)

Marine turtles

Marine turtles migrate thoughout the WIO, which hosts five species of sea turtle. They are well known from inshore waters due to their need to nest on beaches, resulting in their vulnerability to hunting and disturbance on populated shorelines. Recent tagging studies focused around the Mascarene Islands and Mozambique Channel have shown their extensive migrations in all directions (Bourjea 2007) across open ocean areas.

Seabirds

Eleven seabird families occur within the WIO as breeding species, and fall in three broad categories - Indo-Pacific or pan-tropical, highly migratory species from southern latitudes, and predominantly Atlantic species. Though levels of endemism are expectedly low, there are at least nine extant, breeding endemics of which five are listed as globally threatened, including two critically endangered species (BirdLife International 2012). Half of these are from Sub-Antarctic islands, two from Reunion Island and two from the Arabian seas. Some of the species found in the WIO are in globally important numbers: eg 25 per cent of the world's Sooty Terns *Sterna fuscata* are found on Juan de Nova island, Cosmoledo Atoll, Bird Island and Europa Island (Le Corre and Jaquemet 2005, ASCLME/SWIOFP 2012a, ASCLME/SWIOFP 2012b); >10 per cent of the world's Tropical Shearwaters (*Puffinus bailloni*) and Lesser Noddies (*Anous tenuirostris)* occur on Aride Island, Seychelles (Fishpool and Evans 2001); and Aldabra Atoll has the world's second-largest frigatebird

colony and is the only oceanic breeding site for the Caspian Tern *Sterna caspia* (Fishpool and Evans 2001). All of these critical seabird nesting habitats are found in just three countries of the WIO - the French islands, Seychelles and South Africa (other subtropical or temperate species).

As with marine turtles, while seabirds nest on land and rocks within the coastal zone, their migratory routes and often their most important feeding grounds are in open ocean areas. Tropical seabirds associate very strongly with tuna and feed in association with them (Le Corre and others, 2012). Thus, their post-breeding dispersal is probably linked to broad-scale oceanic features (such as upwelling or mixing areas) to which fish are attracted. Recent tracking has identified five large-scale Important Bird Areas (IBAs) in the WIO, all in the open sea (Le Corre and others, 2012): 1) the Seychelles basin (east of the granitic Seychelles); 2) the pelagic waters encompassing the Aldabra Group northwards and west of the Seychelles Basin; 3) from Reunion southwards; 4) the area south of Madagascar and 5) the southern third of the Mozambique Channel and southwards to ~30°S (ASCLME/SWIOFP 2012a, ASCLME/SWIOFP 2012b).

Elasmobranchs

Less than 200 elasmobranch species have been recorded in the WIO and, except for South Africa, little effort has been made to assess the status of sharks and rays in the region. Some emblematic species have been the focus of attention, such as the whale shark (*Rhyncodon typus*), and there is now an increase in interest in open ocean sharks under the auspices of the Indian Ocean Tuna Commission (IOTC) and its Working Party on Ecosystems and Bycatch (WPEB). The most abundant pelagic shark families in the South West Indian Ocean (SWIO) are the Lamnidae, Carcharhinidae and Alopiidae ASCLME/SWIOFP 2012a, ASCLME/SWIOFP 2012b). Among the Lamnidae, great white sharks are mostly confined to southern Africa but occasionally make incursions into tropical waters and are caught occasionally off most countries.

Bony fish

While fish are among the best known of marine taxa, and some 2 200 species are reported from the WIO (Smith and Heemstra 1986, Nelson 2006), a tally of those present in the open ocean or deep sea has not been made and there would probably be significant gaps. Notably, the coelacanth *Latimeria chalumnae* was first found live in the WIO (Box 9.1) and, though originally thought to be restricted to a few sites in South Africa and the Comoros, it is now known to be widespread on continental rises throughout the Mozambique Channel and up the East African coast to Kenya. It may be no coincidence that the age and stability of this continental margin, going back 180 million years, and the deeply cut canyons that are the coelacanth's home, have probably been stable throughout this time, even with sea level fluctuations. This might be the reason for persistence of this 'living fossil' here, as it has gone locally extinct from continental slope habitats elsewhere.

PROPORTION OF MAJOR GROUPS OF SPECIES THAT ARE ASSESSED ON A SYSTEMATIC BASIS FOR STATUS

There is insufficient information for oceanic and deep sea habitats to estimate the proportion of groups that have been assessed systematically. The International Indian Ocean Expedition (IIOE) of 1959–1965 collected information on a broad range of subjects, including taxonomy, but the coverage of the WIO was patchy. Information on the megafauna named above is reasonably complete due to global interest in the species, and many are wide-ranging. However, limited sampling of invertebrate and even fish species with a view to their biodiversity assessment at all depths in the water column and on the deep sea floor renders systematic estimates impossible.

Recent surveys by the MESOBIO and ASCLME programmes have nevertheless resulted in significant additions to our knowledge. ASCLME cruises covered parts of the Mozambique Channel and Seychelles Basin, and west of the Mascarene Plateau (see reports at www.asclme.org), while the MESOBIO programme focused on the Mozambique Channel (Ternon and others, 2014). However, in both cases, the bulk of work was on oceanographic and ecosystem processes, not diversity and taxonomy. Nevertheless, Huggett (2014) quantified the abundance of zooplankton species in the Mozambique Channel from four cruises undertaken in 2007-2010, but did not attempt to estimate the proportion of biodiversity identified or assessed. ASCLME cruises collected voucher specimens of fish, zooplankton and jellyfish, as well as tissue specimens for later DNA analysis.

TRENDS AND THREATS

Future trends and threats to the deep sea and pelagic environments were most recently and comprehensively covered in the ASCLME/SWIOFP TDA (2012) and are discussed below within the DPSIR framework.

Drivers

The TDA identified ten root causes (or drivers) of change, all of them applicable to threats to deep sea and offshore areas: inappropriate governance, economic drivers, inadequate financial resources, inadequate knowledge and awareness, cultural traditions, population pressure and demographics, poverty and inequality, climate change and natural processes, and personal attitudes

Of particular importance for the open ocean, which remains the last frontier for intensive human activity, are the following consequences of growing human populations and the attendant increase in pressures.

• Globalization of markets and trade, with the open ocean providing the main transport and shipping channels. For example, 30 per cent of global tanker traffic passes through the Mozambique Channel, transporting oil from the Middle East to Atlantic markets, the tankers being too large to pass through the Suez Canal.

• Climate change and ocean acidification impacts on marine environments are becoming increasingly well known, these being driven by rising concentrations of greenhouse gases in the atmosphere. Carbon dioxide has the greatest impact on ocean chemistry as it affects the buffering system in seawater, resulting in acidification and changes to the biochemistry of marine life.

Pressures, state and impacts

Four 'main areas of concern' are summarised here, combining information on pressures, state and impacts through causal chain analysis, providing guidance on needs at the both national and transboundary level.

• Water quality: a) alteration of natural river flow and changes in freshwater input and sediment load, b) degradation of ground and surface water quality, c) microbiological contamination from land-based and marine sources, d) solid wastes and marine debris from shipping and land-based sources and e) oil spills from drilling, exploitation, transport, processing, storage and shipping.

• Habitat and community modification: a) a broad range of habitat disturbances in watershed and nearshore areas, which may have cascading effects in offshore and deep waters; b) the introduction of invasive alien species. The emerging threat of deep sea mining was not included in the assessment (eg minerals on the seabed), neither were other extractive industries (eg for oil and gas), which can have severe impacts on surrounding habitats through physical alteration and/or pollution.

Declines in living marine resources, including sharks and rays, pelagic and bottom fish, and excessive bycatch and discards as a result of fisheries expansion in artisanal, national and trans-national operations. Of twelve fish listed as threatened (ASCLME/SWIOFP 2012a, ASCLME/SWIOFP 2012b) three are deep sea or open ocean species - the coelacanth (Critically Endangered), southern bluefin tuna (*Thunnus maccoyii*, Critically Endangered) and the big eye tuna (*Thunnus obesus*, Vulnerable). At present, marine mammal mortality through fisheries interactions in the SWIO, while not exhaustively studied, are generally low and certainly lower than in many other regions of the world. Expansion in mariculture and associated consequences in terms of biosecurity, the introduction of diseases to wild stocks, invasive species, habitat implications, and water quality were noted. While mariculture occurs mainly in shallow waters, impacts to connected deeper waters and to the seabed are possible.

• Unpredictable environmental variability and extreme events, including climate hazards and extreme weather events: a) ocean acidification, b) changes in seawater temperatures, c) changes to hydrodynamics and ocean circulation, d) changes in productivity (shifts in primary and secondary production) and e) geo-hazards, which in the deep sea may include volcanic eruptions and earthquakes.

The TDA finally identified a number of emerging issues that may intensify and become significant threats in the future, including noise pollution, radioactive contamination and bio-prospecting. Prospecting for hydrocarbons and minerals, particularly for the former in the Mozambique Channel in the immediate future, and further afield in future decades, will become major pressures on these presently unexploited resources.

Responses

Countries of the WIO are hampered from action in the open ocean and deep sea by a lack of resources to manage remote expanses of sea beyond their immediate coastlines. Nevertheless, almost the entire region recognized as the

WIO is within the Exclusive Economic Zones of its member states, more so with the extension granted to Mauritius and Seychelles for the inclusion of the Saya de Malha Bank in their continental shelf claims. Apart from South Africa, France, Mauritius and the Seychelles, other countries of the region have few resources to actively manage the waters under their jurisdiction.

Beyond territorial waters, responses by states of the WIO to threats in the deep sea are dealt with under the aegis of regional agencies mandated with resource extraction and management (eg the Regional Fishery Management Organizations, or RFMOs), the regional marine environmental protection convention arising from the UNEP Regional Seas process (Nairobi Convention), or more bilateral actions (eg the seabed extension jointly sought by Mauritius and Seychelles). Other avenues to reduce threats in the open sea such as the risk of pollution and oils spills, include the 'Marine Highway Project' (GEF-WIOMHD 2012).

The generation and provision of information on deep sea and offshore ecosystems is increasing, building on the recent round of regional projects such as the ASCLME and SWIOFP. These and other projects have compiled existing knowledge and conducted fresh research that is being disseminated through online portals and information resources, such as the Africa Marine Atlas (www.africanmarineatlas.org) supported by UNESCO and the Nairobi Convention Clearing House Mechanism, supported by UNEP/Nairobi Convention Secretariat (2009). Linking these portals with global resources, such as the Ocean Biogeographic Information System (OBIS) is underway, and will do much to fill the information gaps noted here. New regional programmes, such as the SAPPHIRE and SWIOFish programmes that will succeed those aforementioned, will include major components on biodiversity data and information systems in support of this process.

In terms of on-the-ground interventions, there are several global conventions that include mechanisms to protect marine waters, summarised below. A process to clearly identify Ecological and Biologically Significant Areas (EBSAs) has been underway under the umbrella of the Convention on Biological Diversity (CBD). As in other processes, marine ecosystems, and particularly the open oceans and deep seas – termed Areas Beyond National Jurisdiction (ABNJ) or the High Seas – have been among the last to be considered. Since 2007, a process has been convened to rectify this, assisted by the Global Oceans Biodiversity Initiative (GOBI). Scientific and technical experts have met to provide scientific and technical guidance on the use and further development of biogeographic classification systems, and to identify sites which meet the criteria, including deep sea and open ocean sites (Table 1). This was accomplished in a workshop that focused on the Indian Ocean in July 2012 and its findings were accepted by the 12th Conference of Parties of the CBD in Pyeongchang, South Korea, in October 2014, laying a framework for marine spatial planning by states in the region.

Table 9.1. Ecologically and Biologically Significant Areas (EBSAs) described in the open ocean and deep seas of the Western Indian Ocean. Source CBD (2012).

1 Agulhas Bank Nursery Area
2 Agulhas slope and seamounts
3 Offshore of Port Elizabeth
4 Protea Banks and sardine route
5 Natal Bight
7 Delagoa shelf edge, canyons and slope
9 Morrumbene to Zavora bay (Southern Mozambique)
19 Mozambique Channel
22 Walters Shoal
23 Coral Seamount and fracture zone feature
24 Northern Mozambique Channel
26 Prince Edward Islands , Del Cano Rise and Crozet Islands
27 Southern Madagascar (Part of Mozambique Channel)
28 Tromelin Island
29 Mahe, Alphonse and Amirantes Plateau
30 Atlantis Seamount
32 Saya de Malha Bank
Areas mentioned, but not assessed due to lack of information:
1 Coco de Mer (north Seychelles)
2 North Seychelles Oceanic Basin
4 Saint Brandon*
6 Dragon Vent Field, SW Indian Ridge

The UN Food and Agricultural Organization (FAO) has noted the importance of identifying Vulnerable Marine Ecosystems (VMEs) to promote the sustainability of fisheries worldwide (FAO 2009). The agency established standards and prepared International Guidelines for VMEs and, in July 2012, held a workshop in Mauritius to introduce the concept of VMEs to WIO countries (FAO 2013). VME standards have been formulated at the global level for both national waters and areas beyond national jurisdiction (ABNJs), as well as for deep sea areas vulnerable to

BOX 9.1. COELACANTHS IN THE WIO by Matt Richmond and David Obura



A coelacanth and technical diver in the iSimangaliso Wetland Park, South Africa. © L. Ballesta.

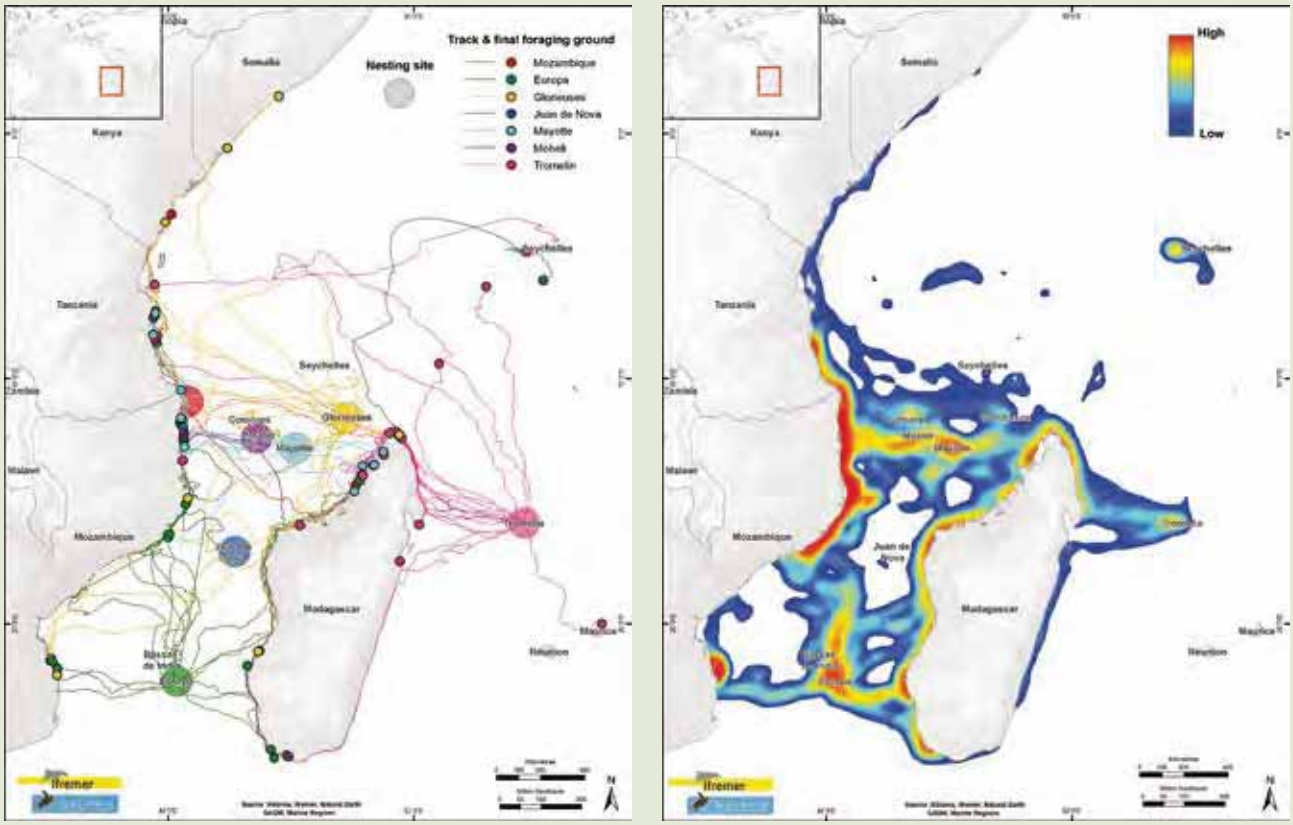
Coelacanths (*Latimeria chalumnae*) are unique fish that surprised the world when discovered alive in 1938 after they were thought to have become extinct along with the dinosaurs. Coelacanths belong to a special division of bony fish (Subclass Sarcopterygii), characterised by their unique lobed fins that are considered to be the origins of fleshy limbs in vertebrates. They have a hollow fluid-filled notochord rather than the hard spine of other fish or the cartilaginous backbone of sharks. They also have a distinct tail with a small epicaudal fin at its tip. Coelacanths live for up to 60 years, give birth to as many as 26 live young, and can attain 2 m in length (or 70 kg) with females growing larger than males. Apart from the WIO species, *Latimeria chalumnae*, a more restricted species is found in Indonesia, *L. menadoensis*.

In the WIO, coelacanths live in deep tropical and subtropical waters in South Africa, Tanzania, Madagascar and Comoros, with single catch records in Mozambique and Kenya. They occur at depths between 40 m and 400 m. Their persistence in the Mozambique Channel may be related to the age and stability of the coastline, going back over 100 my. Coelacanths have been studied using mixed gas diving, by submersible and by Remotely Operated Vehicle (ROV). They are considered rare fish and are globally IUCN Red-listed as critically endangered. Each individual has a unique white spot pattern that allows for recognition and monitoring.

Coelacanths are believed to be slow-growing and very vulnerable to overfishing. With increasing numbers of fishers, and greater use of shark and deep gill nets, larger numbers of coelacanth are being caught. For example, 37 specimens had been landed up to October 2010 in Tanga, Tanzania, alone, leading to the formation of the Tanga Coelacanth Marine Protected Area.

deep fishing technologies. The most vulnerable ecosystems are those that are both easily disturbed and very slow to recover, or may never recover. The aim of identifying VMEs is to facilitate the adoption and implementation of conservation and management measures by Regional Fishery Management Organizations (RFMOs) and flag states of

BOX 9.2. OCEANIC CONNECTIVITY BY GREEN TURTLES IN THE WIO by Jérôme Bourjea and Mayeul Dalleau



Tracks of green turtles from nesting to foraging grounds (left) and space utilization density during migration (right). Extracted from Bourjea and others (2013) and Dalleau (2013).

Sea turtles have migrated for millions of years between nesting sites and feeding grounds, sometimes swimming thousands of kilometers, passing through several countries and ecosystems, and interacting with human activities along the way—sometimes to their advantage but sometimes resulting in a premature end of their lives' journeys. So it is in the Southwest Indian Ocean (SWIO). This region hosts some of the most important green turtle (*Chelonia mydas*) nesting sites in the world, most of which are isolated on remote islands (for example, at Europa [Îles Eparses, France], Aldabra and Cosmoledo [Seychelles], and Moheli [Union of the Comoros]). Nesting also occurs in significant numbers along the coasts of East Africa and Madagascar, which are better known for their vast seagrass pastures where green turtles graze. Mayotte (France), Grande Comoros, and Mauritius also have noteworthy foraging areas adjacent to their shores. However, very little is known about the migratory pathways that sea turtles ply between their nesting and feeding grounds—and even less is known about how they spend their time among the various countries in the SWIO.

To shed light on regional migratory issues related to interaction with human activities, Ifremer and Kélonia, both based in Reunion, finished in 2013 an ambitious satellite tagging project that started in 2009 to better understand the spatial dynamics and connectivity of SWIO marine turtle populations. The project deployed 105 satellite tags on nesting green turtles at Europa, Juan de Nova, Mayotte, Glorieuses, Moheli, and Tromelin (left map) and cooperated with Mozambique to gather tracks from Vamizi Island. Results showed that tracked turtles did their migration in 21,4 ± 16,2 days and travelled an average of 1359 ± 832 km from nesting site to their foraging ground, crossing from 2 to 7 different EEZ. This dataset also allowed identifying 5 key foraging hotspots in the SWIO, 2 in Mozambique (Bazaruto and Quirimbas archipelagos), 2 in Madagascar (northwest and south) and one in Tanzania (Mafia area). Thirty-five per cent of the final foraging grounds of tracked turtles were in Marine Protected Areas.

To better estimate migratory corridors, a Movement-based Kernel Density Estimation (MKDE) was used to characterize the space utilization density during the migration (right map). Results allowed highlighting hotspots of migration at the oce-

anic and coastal scales. Oceanic corridors are diffused all along the Mozambique Channel and migrating individuals most probably faced few threats from open sea fisheries, composed on purse-seiners and longliners that do not interact with adult green turtle. Coastal corridors are more interesting as they are very dense from the north of Mozambique to south Tanzania, in Bazaruto and all along the west Malagasy coast. Knowing that interaction between East African and Malagasy artisanal fisheries and adults green turtles are very important in all the SWIO, and that coastal development due to the discovery of Gas fields in the Mozambique Channel (ie in the Quirimbas area, Mozambique) is increasing, such results are of great importance for management issues, allowing to identify areas of priority for the conservation of this endangered species.

fishing vessels.

Furthermore, the designation of Particularly Sensitive Sea Area (PSSA) under the International Maritime Organization (IMO) may be of assistance, particularly in limiting impacts from maritime operations. However, this designation has not yet been applied in the WIO, though its value has been recognized (Guerreiro and others, 2011). The provisions of the United Nations Convention on the Law of the Sea (UNCLOS) are also relevant, as they identify 'Special Areas' relative to their vulnerability to maritime pollution under MARPOL, and an ongoing process under UNCLOS to establish mechanisms for governance of Areas Under National Jurisdiction will make this increasingly relevant.

CONCLUSION

Until recently, countries of the WIO have taken few steps to fully use, or manage, open sea areas under their jurisdiction. However, with growing evidence of the limits to terrestrial resources, the oceans are being seen as a final frontier to support economic development. Use of these areas without their adequate protection and knowledge of the associated consequences could result in severe degradation of the open ocean resources. As countries begin to embrace a 'Blue Economy' for wealth creation, ensuring the sustainability and protection of deep sea assets that may support such growth will be essential.

References

ASCLME/SWIOFP (2012a). Transboundary Diagnostic Analysis for the western Indian Ocean. vol.1: Baseline. South Africa

ASCLME/SWIOFP (2012b). Transboundary Diagnostic Analysis for the western Indian Ocean. vol.2: Diagnostic Analysis. South Africa

ASCLME *ASCLME Cruise Results*. http://www.asclme.org/data-and-information/asclme-cruise-results.html

African Coastal & Marine Atlas. http://www.africanmarineatlas.org

BirdLife International (2012). *Marine Protected Areas and Regional Synthesis Report on Birds as Indicators of Ecosystem Health*. The Seventh Conference of the Parties to the Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Western Indian Ocean (Nairobi Convention). UNEP-DEPI-EAF-CP.7.12

Bouchet, P. (2012). The "Atimo Vatae" Expedition. Museum of National History of Paris. http://www.laplaneterevisitee.org/fr/87/accueil

Bourjea, J., Ciccione, S. and Dalleau, M. (2013). Dynamique migratoire des tortues marines nidifiant dans les îles françaises de l'océan Indien. Rapport Scientifique et Technique Ifremer, RST-DOI/2013-02, 55 pp

Bourjea, J., LapèGue, S., Gagnevin, L., Broderick, D., Mortimer, J.A., Ciccione, S., Roos D., Taquet, C. and Grizel, H. (2007). Phylogeography of the green turtle, Chelonia mydas, in the Southwest Indian Ocean. *Molecular Ecology* 16, 175–186

CBD (2012). Southern Indian Ocean Regional Workshop To Facilitate The Description Of Ecologically Or Biologically Significant Marine Areas. Flic en Flac, Mauritius. 31 July - 3 August

Dalleau, M. (2013). Ecologie spatiale des tortues marines dans le Sud-ouest de l'océan Indien. Apport de la géomatique et de la modélisation pour la conservation. PhD thesis, University of La Réunion, 330 pp

FAO (2009). International Guidelines for the Management of Deep-Sea Fisheries in the High Seas. FAO, Rome

FAO (2013). Report of the Regional Workshop On Vulner-

able Marine Ecosystems (VMEs) in the Indian Ocean. Flic en Flac, Mauritius, 25–27 July 2012. FAO Fisheries and Aquaculture Report No. 1030

Fishpool, L.D.C. and Evans, M.I. (eds.). (2001). *Important Bird Areas in Africa and Associated Islands: Priority Sites for Conservation*. Newbury and Cambridge, UK: Pisces Publications and BirdLife International

Gallienne, C.P. and Smythe-Wright, D. (2005). Epipelagic mesozooplankton dynamics around the Mascarene Plateau and Basin, Southwestern Indian Ocean. *Phil. Trans. R. Soc. A.* 363, 191–202

GEF-WIOMHD (2012). GEF-Western Indian Ocean marine highway development and coastal and marine contamination prevention project, GEF-WIOMHD. Environmental Components B & C. Post completion Report

Griffiths, C. (2005). Coral marine biodiversity in East Africa. *Indian J Mar Sci,* 34, 35–41

Guerreiro, J., Chircop, A., Dzidzornu, D., Grilo, C., Ribeiro, R., van der Elst, R. and Viras, A. (2011). The role of international environmental instruments in enhancing transboundary marine protected areas: An approach in East Africa. *Marine Policy*, 35, 95–104

Harris, P.T. (2011). Seafloor Geomorphology–Coast, Shelf, and Abyss. In *Seafloor Geomorphology as Benthic Habitat: GeoHAB Atlas of Seafloor Geomorphic Features and Benthic Habitats* (eds. Harris P.T. and Baker E.K) pp. 125–127. Elsevier.

Huggett J.A. (2014) Mesoscale distribution and community composition of zooplankton in the Mozambique Channel. *Deep Sea Research Part II: Topical Studies in Oceanography*, 100, 119–135

Keating, B.H., Fryer, P., Batiza, R. and Boehlert, G.W. (eds.) (1987). *Seamounts, Islands and Atolls*. Geophysical Monograph 43. American Geophysical Union

Le Corre, M., Jaeger, A., Pinet, P., Kappes, M.A., Weimerskirch, H., Catry, T., Ramos, J.A., Russell, J.C., Shah, N. and Jaquemet, S. (2012). Tracking seabirds to identify potential Marine Protected Areas in the tropical western Indian Ocean. *Biol. Conserv.* 156, 83–93

Le Corre, M. and Jaquemet, S. (2005). Assessment of the seabird community of the Mozambique Channel and its potential use as an indicator of tuna abundance. *Estuar. Coast. Shelf. S.* 63, 421–428

Murtugudde, R.G., Signorini, S. R., Christian, J.R., Busalacchi, A.J., McClain, C.R. and Picaut, J. (1999). Ocean color variability of the tropical Indo-Pacific basin observed by SeaWiFS during 1997–1998. *Journal of Geophysical Research: Oceans* 104(C8), 18351-18366

Nelson, J.S. (2006). *Fishes of the world, 4th edition*. John Wiley & Sons, Inc. New Jersey

Randall, J.E. and King, D.R. (2009). *Parupeneus fraserorum*, a new species of goatfish (Perciformes: Mullidae) from South Africa and Madagascar. *Smithiana Bulletin* 10, 31-35

REMMOA (2012). Campagnes REMMOA: *Recensement des Mammifères marins et autre Mégafaune pélagique par Observation Aérienne*. Agence des aires marines protégées. France

Richmond, M.D. (2001) The marine biodiversity of the western Indian Ocean and its biogeography: How much do we know? In *Marine science development in Tanzania and eastern Africa. Proceedings of the 20th Anniversary Conference on Advances in Marine Science in Tanzania (IMS/WIOMSA)* (eds. Richmond, M.D. and Francis, J.) pp. 241–261. Dar es Salaam, Tanzania

Schott, F.A. and McCreary, J.P. (2001). The monsoon circulation of the Indian Ocean. *Prog Oceanogr.* 51(1), 1-123

Sheppard, C.R.C., Ateweberhan, M., Bowen, B.W., Carr, P., Chen, C.A., Clubbe, C., Craig, M.T., Ebinghaus, R., Eble, J., Fitzsimmons, N., Gaither, M. R., Gan, C-H., Gollock, M., Guzman, N., Graham, N.A.J., Harris, A., Jones, R., Keshavmurthy, S., Koldewey, H., Lundin, C.G., Mortimer, J.A., Obura, D., Pfeiffer, M., Price, A.R.G., Purkis, S., Raines, P., Readman, J.W., Riegl, B., Roger, A., Schleyer, M., Seaward, M.R.D, Sheppard, A.L.S., Tamelander, J., Turner, J.R., Visram, S., Vogler, C., Vogt, S., Wolschke, H., Yang, J.M-C., Yang, S-Y. and Yesson, C. (2012). Reefs and islands of the Chagos Archipelago, Indian Ocean: why it is the world's largest no-take marine protected area. *Aquatic Conservation: Marine and Freshwater Ecosystems*. 22, 232-261

Smith, M.M. and Heemstra, P.C.H. (1986). *Smiths' Sea Fishes*. McMillan, Johannesburg

Stromme, T., Ansorge, I., Bornman, T., Kaehler, S., Ostrowski, M., Tweddle, D. and Alvheim, O. (2008). *Survey of the Mascarene Plateau*. ASCLME Survey number 3. ASCLME FAO Preliminary report

Ternon, J.F., Bach, P., Barlow, R., Huggett, J., Jaquemet, S., Marsac, F., Ménard, F., Penven, P., Potier, M. and Roberts, M.J. (2014). The Mozambique Channel: From physics to upper trophic levels. *Deep Sea Research Part II: Topical Studies in Oceanography* 100, 1–9

UNEP/Nairobi Convention Secretariat. (2009). Strategic

Action Programme for the Protection of the Coastal and Marine Environment of the Western Indian Ocean from Land-based Sources and Activities, Nairobi, Kenya

Wafar, M., Venkataraman, K., Ingole, B., Khan, S.A. and LokaBharathi, P. (2011). State of knowledge of coastal and marine biodiversity of Indian Ocean countries. *PLoS ONE* 6, e14613



10
Threatened Marine Species

Matthew D. Richmond

Opposite page: Sperm whales in the WIO. © Hughes Vitry.

INTRODUCTION

This chapter describes the marine species whose continued presence in the western Indian Ocean (WIO) is considered threatened. Decades ago it would have been inconceivable for most people to consider marine creatures becoming scarce or even going extinct. The vastness of the oceans compared to the seemingly tiny footprint of human activities should surely preclude species disappearing. Unfortunately, things have changed dramatically. Humans all but exterminated the last blue whales over one hundred years ago. In recent history, numerous terrestrial mammals, birds, snakes and frogs can no longer survive in the wild in large enough populations to ensure their continued existence on Earth (eg Myers and others, 2000, Brooks and others, 2006).

Threatened species are those considered Critically Endangered, Endangered or Vulnerable (Figure 10.1). In these categories, the best available evidence indicates that a taxon is facing a high to extremely high risk of extinction in the wild. Criteria that result in taxa being categorised as threatened relate to the reduction in size of their populations, their geographic range, existing population sizes, and the probability of their extinction in the wild over a given time period (see IUCN Red List).

The total number of species in the WIO region is not precisely known, but the estimated range is between 11 000 and 20 000 or more (eg Griffiths 2005), with estimates varying depending on the water depth and organism size, mindful that invertebrate fauna in most deep sea environments are the least known. Determining which of these species are threatened was achieved by scrutinizing

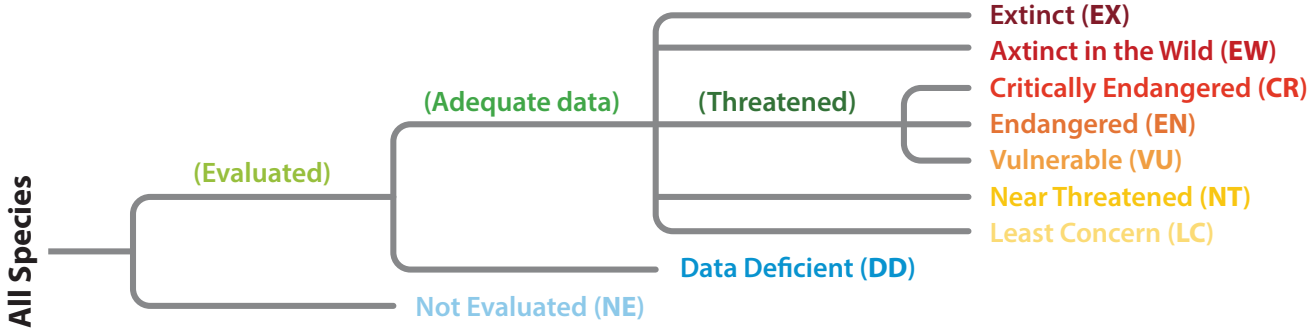


Figure 10.1. The IUCN Red List categories, used to identify the species in the WIO that are threatened.

the latest edition (2014.2) of the *IUCN Red List of Threatened Species* (or simply the Red List) and facilitating the process using the filter available on the MarineBio Conservation Society website. A review revealed that, globally, there around 800 marine species (and/or sub-populations) on the Red List that are categorised as threatened. Since we know considerably more about the diversity of life on land than in the sea (eg Pimm and others, 1995), and even less about threats to marine life (especially in the deep sea), this figure is considered conservative. It should also be noted that, while the trend in general is unfortunately for species to move up the threat ladder, for example, from Near Threatened to Extinct in the Wild, there are exceptions whereby species that were Vulnerable have dropped to one of Least Concern because numbers or populations have increased and threats have reduced.

VULNERABLE OR THREATENED MARINE SPECIES IN THE WESTERN INDIAN OCEAN

The marine portion of the Red List was checked for those species occurring in the WIO region at least for part of their lives. There are 161 species (including two subpopulations) listed as threatened (Table 10.1). The great majority of these, 126 species, are listed as Vulnerable (VU), with 27 considered Endangered (EN) and eight species listed as Critically Endangered (CE; a ray, three sharks, two fish and two marine turtle species). Near Threatened, Least Concern and those listed as Data Deficient (see Figure 10.1) are excluded here, though these include many species that are now far less common in the WIO than they once were, and that may end up higher up the list in future. The full list of threatened marine species in the WIO is presented in Appendix 10.1.

As stated on the IUCN Red List website, the "Categories and Criteria are intended to be an easily and widely understood system for classifying species at high risk of global extinction. The general aim of the system is to provide an explicit, objective framework for the classification of the broadest range of species according to their extinction risk. However, while the Red List may focus attention on those taxa at the highest risk, it is not the sole means of setting priorities for conservation measures for their protection."

In the descriptions that follow, species are mainly listed in the three highest categories of the Red List, with the top two categories, EN and CE, the most critical (see Table 10.2). Where relevant, additional species are noted in the ensuing sections based on other international criteria. Many are listed by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES); the Convention on the Conservation of Migratory Species of Wild Animals (also known as CMS or Bonn Convention), an inter-governmental treaty concluded under the aegis of the United Nations Environment Programme, concerned with the conservation of wildlife and habitats on a global scale; the UN 1982 Convention on the Law of the Sea (UNCLOS), with respect to Articles 64 and 65 on highly migratory species and marine mammals, respectively (as listed in its Annex I); and, the Convention on Biological Diversity (CBD

Table 10.1. Vulnerable and endangered taxonomic groups.

Major taxa	Vulnerable (VU)	Endangered (EN)	Critically Endangered (CE)	Totals
Seagrasses	1	0	0	1
Corals	76	8	0	84
Gastropods	2	0	0	2
Holothurians	6	4	0	10
Rays	7	4	3	14
Sharks	22	4	1	27
Fish	9	2	2	13
Marine Turtles	1	2	2	5
Marine Mammals	2	3	0	5
Totals	**126**	**27**	**8**	**161**

2000), also known as the Nairobi Convention.

The main threats currently applicable to each species or group of species are categorised under seven themes (eg overharvest, habitat destruction, limited reproductive output/slow recovery, limited geographical distribution/endemicity, restricted depth range, susceptibility to climate change and disease and increased predation due to habitat degradation (eg crown-of-thorn starfish on coral). These are included in the full list of the threatened WIO marine species (Appendix 10.1).

SEAGRASSES

Of the twelve species of seagrass widely found in the WIO region (Bandeira 2011) only *Zostera capensis* is listed as Vulnerable. It occurs exclusively in the WIO with a small portion in the southeast Atlantic, on sand in shallow waters. Extending from the southern Angola coast, through parts of South Africa (especially northern KwaZulu-Natal) and north to Kenya, it occupies less than 2 000 km² and is absent from the smaller islands states (Short and others,

Table 10.2. Endangered (EN) and critically endangered (CE) WIO species and their CITES listing.

Major taxa	Scientific name	Status	Common English name	CITES Appendix
Corals	*Acropora roseni*	EN	Scleractinian hard coral	II
	Acropora rudis	EN	Scleractinian hard coral	II
	Anacropora spinosa	EN	Scleractinian hard coral	II
	Ctenella chagius	EN	Scleractinian hard coral	II
	Parasimplastrea sheppardi	EN	Scleractinian hard coral	II
	Pocillopora fungiformis	EN	Scleractinian hard coral	II
	Stylophora madagascarensis	EN	Scleractinian hard coral	II
	Millepora tuberosa	EN	Hydrozoan fire coral	II
Holothurians	*Holothuria lessoni*	EN	Golden sandfish	-
	Holothuria nobilis	EN	Black teatfish	-
	Holothuria scabra	EN	Golden sandfish	-
	Thelenota ananas	EN	Prickly redfish	-
Rays	*Aetobatus flagellum*	EN	Longheaded eagle ray	-
	Aetomylaeus vespertilio	EN	Reticulate eagle ray	-
	Electrolux addisoni	CE	Ornate electric sleeper ray	-
	Anoxypristis cuspidata	EN	Narrow sawfish	I
	Pristis clavata	EN	Dwarf sawfish	I
	Pristis pristis	CE	Largetooth sawfish	I
	Pristis zijsron	CE	Green/Narrowsnout sawfish	I
Sharks	*Haploblepharus kistnasamyi*	CE	Natal shyshark	-
	Holohalaelurus favus	EN	Honeycomb Izak, Natal Izak	-
	Holohalaelurus punctatus	EN	African Spotted catshark	-
	Sphyrna lewini	EN	Scalloped hammerhead	-
	Sphyrna mokarran	EN	Great hammerhead	-
Fish	*Latimeria chalumnae*	CE	Coelacanth	I
	Argyrosomus hololepidotus	EN	Madagascar Kob	-
	Cheilinus undulatus	EN	Humphead wrasse	II
	Thunnus maccoyii	CE	Southern Bluefin tuna	-
Turtles	*Caretta caretta*	EN	Loggerhead Ttrtle	I
	Chelonia mydas	EN	Green turtle	I
	Dermochelys coriacea	CE	Leatherback turtle (sub-pop)	I
	Eretmochelys imbricata	CE	Hawksbill turtle	I
Mammals	*Balaenoptera borealis*	EN	Sei whale	I
	Balaenoptera musculus	EN	Blue whale	I
	Balaenoptera physalus	EN	Fin whale	I

2010). Recently, a new seagrass species, *Thalassodendron leptocaule*, was described from southern Mozambique (see Duarte and others, 2012). The species is similar to the widespread *T. thalassodendron*, though differing slightly in habitat preference and, as far as is known, recorded only in eight scattered localities between Richards Bay in South Africa and Inhambane in Mozambique. Given its relatively small distribution in a region where human anthropogenic activities are well documented and climate change is of concern (see Bandeira and Paula 2014), this species is a potential candidate for threatened status in future evaluations.

The main *driving force* affecting the continued existence of *Z. capensis* is human population growth that leads to increased coastal development, destructive fishing pressure, coastal pollution and sedimentation, and climate change, resulting in a rise in sea temperatures that may affect the whole environment and particularly the seagrass ecosystem. Here, seagrasses are considered "ecosystem engineers" in the benthic environment (see Jackson 2001). These factors are considered *pressures indicators* that damage habitats, at times exacerbated by flooding which may be related to climate change or river catchment degradation. Such pressures are particularly prevalent in Mozambique where this species occupies possibly the greatest area, since it is recognised that the distribution of this species in temperate regions (notably South Africa) is limited by available habitat (Short and others, 2010).

HARD CORALS

Globally, most hard coral species (Scleractinia) are considered Vulnerable, primarily due to overall habitat degradation which is used as a proxy for population decline. Within the WIO region, of the approximate 200 recorded species (Schleyer 2011), eight species are Endangered (Table 10.2). The *driving forces* behind their threatened status are several, and include population growth that leads to increased coastal development, the changes listed for seagrasses (above) as well as the trade in corals (dead and live for the aquarium industry), and climate change. Increased seawater temperatures lead to coral bleaching, a *pressure indicator* that has been devastating and is well-documented, especially for coral reef communities in the Seychelles during the 1996-97 El Niño event. Coral disease and predation by crown-of-thorns starfish (COTS) are additional pressures that are on the increase, while species restricted in depth or geographic range, such as *Ctenella chagius*, *Parasimplastrea sheppardi*, *Pocillopora fungiformis* and *Stylophora madagascarensis*, are particularly vulnerable, as are those with limited reproductive/dispersal abilities, particularly brooders (Wilkinson 2004). The full details on threatened WIO corals are provided in Appendix 10.1 Table 10. A1.

Black corals (Antipatharia) occur in deep water, where they are slow-growing. Global populations were heavily overharvested by the jewellery trade in many parts of the world, though not necessarily in the WIO region, a reason for their inclusion in CITES Appendix II in 1981. Blue corals (*Heliopora coerulea*), listed as Vulnerable, are also CITES Appendix II-listed. Species included in Appendix II are not necessarily threatened with extinction, but trade in them is regulated to avoid usage incompatible with their survival.

GASTROPOD MOLLUSCS

The WIO region is home to over 3 200 shelled marine molluscs, including 2 500 gastropods plus 700 species of bivalve, oysters, clams and mussels (Richmond and Rabesandratana 2011). Two species of cone shells, *Conus jeanmartini* and *C. julii*, are considered Vulnerable (see Appendix 10.1 Table 10.A2), both occurring exclusively around the Mascarene Islands of Mauritius and Réunion (Raybaudi-Massilia 2013). Their status is defined under Red List criterion B, based on the observed decline in mature individuals inferred from their reduced appearance in the shell trade – both species are valued by collectors (Rice 2007). While the observed reduction may also be a consequence of increased protection, the precautionary approach was used in the Red List for these very rare species, until proven otherwise. The main *driving forces* are likely to be demand by the shell collecting trade, especially given the rarity of these species. Meanwhile, the *pressure indicator* appears to be demand for income/food and resultant deep-water prawn trawling, with cone shells landed as a by-catch.

There are seven species of giant clams (*Tridacna*), of which two are present in the WIO region (*T. squamosa* and *T. maxima*). These are not threatened, and listed as "Lower Risk/conservation dependent", yet there is concern for the sustainability of the intensive fishery in some parts of the tropics, and universal degradation of coral reef habitat in which they live (see above). The largest species (*T. gigas*) occurs only in parts of the western Pacific Ocean, where it

and two other small-territory species are very threatened and duly listed as Vulnerable. These bivalves were included in CITES II in 1985 due to concern regarding the sustainable harvest of all giant clams.

SEA CUCUMBERS

Of the 140 species of sea cucumber (holothurians) recorded in the WIO region (Rowe and Richmond 2011), ten are considered threatened and four Endangered (Table 10.2, Appendix 10.1 Table 10.A2). The overall *driving force* affecting many of the larger sea cucumbers is human population growth and income needs, leading to increased fishing pressure by WIO fishermen, primarily for consumers in Asia where beche-de-mer is considered a delicacy (Marshall and others, 1999). Consequently, over-fishing is the main pressures indicator. Species most affected are those with the highest value, namely *Holothuria lessoni* (and the related species *H. scabra*), *H. nobilis* (endemic to the Indian Ocean) and one species of the Stichopodidae family, *Thelenota ananas* (see Box 10.1). These four species are listed as Endangered due to declines in their abundance of ~50-90 per cent over more than half of their range (see Appendix 10.1 Table 10.A2).

RAYS

There are over 30 species of rays in ten families reported in the WIO region (Esseen and Richmond 2011), of which the continued existence of three true rays and four sawfishes is threatened (Appendix 10.1 Table 10.A3). Two of the sawfish (*Pristis pristis* and *P. zijsron*) and the ornate electric sleeper ray (*Electrolux addisoni*) are listed higher up the threat ladder as Critically Endangered. The ray was only discovered in 2007, known from a very small territory and, like most rays and sharks, is of slow reproductive capacity. Further, its habitat is reportedly disturbed by recreational diving and commercial fishing. There is also increasing development along the coastline where it occurs, increasing future risk from pollution, and further habitat degradation (Compagno 2009).

Though only two of the four species of sawfishes are Critically Endangered, all sawtooth species are listed in CITES Appendix I which effectively bans commercial international trade in sawfish or their parts. Most have narrow depth ranges, low fecundity, have been heavily fished, are caught in by-catch and their shallow reef habitat is being degraded by anthropogenic and climate changes (eg coral bleaching). The need for seafood, and for income from the sale of seafood to expanding coastal populations, constitute major *driving forces* that cause rays to be targeted, with sawfish caught as a by-catch. *Pressure indicators* affecting WIO populations of rays are fishing effort (eg numbers of fishers and gear types).

SHARKS

Twenty-seven species of shark, over 50 per cent of an estimated 50 species in at least 13 different families reported in the WIO region (Esseen and Richmond 2011) are considered threatened (Appendix 10.1 Table 10.A3). Of these twenty-seven, the Natal shyshark (*Haploblepharus kistnasamyi*) is the only species considered Critically Endangered. This rank was allocated primarily because of its localized occurrence and presumably small population, but also in view of threats from coastal development, particularly in the vicinity of Durban where industrial and tourism development have expanded rapidly, and heavy commercial fishing pressure for prawns (Human 2008).

Four sharks are listed as Endangered: the honeycomb Izka and African spotted catshark (*Holohalaelurus favus* and *H. punctatus*), and the scalloped and great hammerhead (*Sphyrna lewini* and *S. mokarran)*. Hammerhead shark fins are some of the most highly valued, leading to increased targeting of these species in some areas (Clarke and others, 2006).

The remaining 22 species of shark are listed as Vulnerable and include the great white, oceanic whitetip, two species of mako, guitar shark, whale shark and others (see Appendix 10.1 Table 10.A4). The whale shark and two species of mako sharks (*Isurus oxyrinhchus* and *I. paucus*) are also included in CITES Appendix II, in which the trade in shark products is not banned, if sustainability of the harvest can be demonstrated, accompanied by appropriate CITES documentation. Individual whale sharks are occasionally caught, accidentally as by-catch in gill-nets and other nets, though there is no (visible) trade in the species and their fins are not in high demand. The whale shark is also listed in Appendix II of CMS and together with hammerhead sharks and other oceanic species in Annex I of the Highly Migratory Species list of UNCLOS (1982). Whale sharks are regularly observed off southern Mozambique, Seychelles and other locations, and it has recently been demonstrated that a population is resident all year in the

waters around Mafia Island, Tanzania (Cagua and others, 2015).

In 2013, CITES signatory countries agreed to increase the protection of five commercially exploited species of sharks and manta rays, elevating them to CITES Appendix II. Effective from September 2014, the international trade of four species of WIO sharks was banned (oceanic white-tip shark, scalloped, smooth, and great hammerhead and manta rays). At the 17th Session of the Indian Ocean Tuna Commission (IOTC) meeting (December 2014), members agreed to the release of oceanic white-tip sharks if caught in fishing gear and to ban retention on board, shipping, landing or storing of this species by any vessels under IOTC jurisdiction. Combined with the recent CITES protection, the oceanic white-tip is now protected around the world. The IOTC also adopted a proposal to ban the setting of purse-seine fishing nets around whale sharks, which can result in their death.

The IOTC 17th Session concluded that at least the oceanic white-tip and scalloped hammerhead sharks in the WIO are likely to be vulnerable to overfishing; there is a paucity of information available on them, both are commonly taken by a range of fisheries and their life history characteristics make them vulnerable – they are relatively long-lived, and have relativity few offspring. Their stock status is considered uncertain as they lack quantitative stock assessments and basic fishery indicators are limited for these species in the Indian Ocean. The outlook is that maintained or increased fishing effort on them may result in declines in their biomass and productivity.

As with rays, the need for seafood and income (from sale of shark fins) for expanding coastal populations are major *driving forces* affecting the capture of WIO sharks. The increasing demand for shark fins in Asia, where local stocks have dwindled and increased affluence is driving the demand, add to the *driving forces*. Such forces result in increasing pressure, involving greater fishing intensity and the use of destructive gear as well as specific gear that targets sharks, notably deep-set gill-nets.

BONY FISH

Thirteen species of bony fish, of an estimated 1 900 species reported in the WIO region (Esseen and Richmond 2011), are considered threatened (Appendix 10.1 Table 10.A4). Among these, two are listed as Critically Endangered, the coelacanth (*Latimera chalumnae*), included in CITES Appendix I, and the southern bluefin tuna (*Thunnus maccoyii*). While the southern bluefin tuna is managed by the Commission for the Conservation of Southern Bluefin Tuna (CCSBT) the coelacanth is subject to individual country efforts to protect its populations (see Chapter 9).

Listed as Endangered are two species, the humphead wrasse (*Cheilinus undulatus*) and Madagascar kob (*Argyrosomus hololepidotus*). The geographic and depth ranges of these and the above two species are very different. Coelacanth and Madagascar kob have limited geographic ranges and narrow water depth ranges; humphead wrasse are widely distributed throughout the Indo-Pacific region, yet in small numbers; and southern bluefin tuna are widely distributed and occur from the surface to 500 meters depth.

The remaining nine fish species, listed as Vulnerable, include bigeye tuna, three groupers (black-saddle, giant and lunartail), the green humphead parrot, two seahorse (*Hippocampus*) species and the Indo-Pacific bonefish, all seven typically associated with inshore coral reef/seagrass habitats, plus the blue marlin (an oceanic species). Seahorses of the genus *Hippocampus* are listed under CITES Appendix II and considered highly threatened in some localities in the WIO region due to overfishing fuelled by demand from Asia for dried seahorses (Mcphearson and Vincent 2004; Vincent and others, 2011). Blue and black marlin, swordfish, sailfish, dolphinfish, southern bluefin and bigeye plus nine other tuna species are included in the highly migratory species list in Annex I of the 1982 UNCLOS.

Bigeye tuna are important in commercial fisheries in both the Pacific and Indian Oceans. There is a single stock in the Indian Ocean, considered in relatively good condition and effectively managed. However, because Western and Central Pacific stocks, that represent >20 per cent of the global population, are being overfished, the species is listed as Vulnerable (Collette and others, 2011). Added to this is a possible further decline due to heavy fishing pressure on the much smaller skipjack tuna on which it feeds (Collette and others, 2011). In the WIO, where purse seine and longline fisheries target this species, reduced fishing pressure has recently come about largely due to the security risk of fishing in pirate waters in the NW of the region. Reduced fishing in that region on juvenile bigeye and other species has, unfortunately, been offset by the longline fleet (mainly Taiwanese and Japanese vessels) moving to the south and east, and consequently increasing the pressure on albacore tuna (IOTC-SC17 2014).

According to recent IOTC assessments, the stock status of black marlin in the Indian Ocean is that it is not overfished but subject to overfishing; the status for blue marlin was changed from that reported in 2013 and it is now determined to be overfished but not subject to overfishing; striped marlin are considered overfished and subject to overfishing (IOTC-SC17 2014).

Driving forces affecting endangered reef and bottom-associated fish species are the same as for rays and sharks: the need for seafood by WIO consumers and income from seafood to supply expanding local coastal populations. *Driving forces* affecting threatened tuna and some billfish species have roots further afield, with foreign fishing fleets targeting these high-value commercial species for export to Europe, USA and Asiatic markets. *Pressure indicators* include overfishing and the use of destructive fishing methods (eg explosives in Tanzania) and widespread habitat degradation (especially of coral reefs) from destructive fishing practices and sedimentation. *Pressure indicators* that are linked to regional fisheries management organisations such as the IOTC include catch per unit effort (CPUE) by different fishing gear. While the coelacanth has benefitted from protection under CITES I, and is the focus of the gazettement of a new marine protected area (MPA) in Tanzania, it is still accidentally caught in deep waters by bottom-set shark nets and longlines.

MARINE TURTLES

There are five species of marine turtle in the WIO region, nesting and foraging in specific areas. All are threatened, with two that are Critically Endangered: the hawksbill turtle (*Eretmochelys imbricata*) and a south-west Indian Ocean leatherback subpopulation (*Dermochelys coriacea*). The two Endangered species are the green turtle (*Chelonia mydas*) and loggerhead turtle (*Caretta caretta*). The fifth species, the olive ridley (*Lepidochelys olivacea*) is listed as Vulnerable. All are in the CITES Appendix I and Appendices I and II of CMS, and included in the CMS under the Memorandum of Understanding for the conservation and management of marine turtles and their habitats (see Appendix 10.1 Table 10.A5). Signatories to the latter include states in the Indian Ocean and South East Asia (known as IOSEA), as well as in other regions, within whose waters these species migrate, forage or nest.

The **hawksbill** turtle is an example of a species climbing the extinction ladder, being listed as Endangered by the IUCN up until 1996, and being moved to Critically Endangered from 1996 onwards due to dramatic worldwide population declines caused by international trade in their raw shell (Mortimer and Donnelly 2008; Mortimer and Collie 1998). After the trading ban resulting from CITES Appendix I listing, international trade in this commodity was significantly reduced but by-catch and habitat destruction remain threats in some countries (Meylan and Donnelly 1999). In the WIO, numerous islands and atolls provide extensive nesting and foraging habitat for hawksbills, but the main nesting sites are in the Seychelles (Mortimer and Collie 1998) with significant increases in nesting activity on Cousin Island (Allen and others, 2010). Nesting has also been recorded on small islands off the NW of Madagascar (Bourjea and others, 2006), on Juan de Nova island (Lauret-Stepler and others, 2010), and occasionally in the Misali Island MPA, off Pemba Island, Tanzania (Pharoah and others, 2003). Nesting also takes place beyond the region in Oman, India and Western Australia.

Leatherbacks in the WIO are a subpopulation that nests principally along South Africa's KwaZulu-Natal coast, but this extends into southern Mozambique and around the Cape of Good Hope into the Atlantic Ocean. Nesting populations in South Africa have been monitored consistently for 50 years, and account for >90 per cent of the total abundance of the subpopulation, which surprisingly includes only a small number of mature individuals (estimated 148 adult males and females) with evidence of a low but continuing decline (Nel and others, 2013). These are the main arguments for its Critically Endangered listing.

This abundance trend for leatherbacks contrasts with the increasing trend and greater abundance of **loggerheads** that nest along the same coastline, but drivers of these divergent patterns are unclear at present (Nel and others, 2013). The SW Indian Ocean population is one of six in the IOSEA region, nesting coinciding with beaches used by leatherbacks, principally in the southern Mozambique-northern KwaZulu-Natal area (Hamann and others, 2013). There is also nesting in the southern and south-western parts of Madagascar (Baldwin and others, 2003). Recent research has revealed that immature loggerheads are found in high density in the SWIO pelagic area, most of them probably originating from the stock from Oman (see Dalleau and others, 2014). This species is highly sensitive to the longline fishery, the most important fishery in the southwest Indian Ocean (Lewison and others, 2004).

Green turtles in equatorial and tropical WIO areas are

the most frequently encountered turtle, with annual estimates for the number of nesting females ("nesters") ranging from about 14 000 to 25 000. These figures are split between many locations: around 3 000 occur around the Comoros island of Moheli (Innocenzi and others, 2010); between 2 000 and 10 000 amongst the French islands in the Mozambique Channel (Le Gall 1988, Lauret-Stepler and others, 2010); some 3 500 at Mayotte (Bourjea and others, 2007); around 2 000 reported amongst the main Seychelles islands (including its granitic islands, and the Amirante and Farquhar islands) (see Mortimer 1984; Mortimer and others, 2011a), plus 3 000 to 5 000 on Aldabra (Mortimer and others, 2011b); and between 750 and 1 000 use Tromelin (Le Gall 1988). In addition, several hundred nesters use beaches in Kenya (eg Okemwa and others, 2004), Tanzania (eg West 2011) and Madagascar (eg Bourjea and others, 2006). Foraging grounds can be extensive and trans-boundary (eg West 2014).

The **olive ridley's** global status is ranked as Vulnerable, yet in the WIO it is reported to have nested in Kenya, Tanzania and Mozambique in the past, though no records of recent nests are known and this species is feared to be close to extinction in the WIO. Fortunately, management of the vast rookeries on the coast of India are effectively maintaining healthy populations of this species. The highest numbers by far nest in the Indian Ocean at Gahirmatha, located in the Bhitarkanika Wildlife Sanctuary, which supports perhaps the largest nesting population, averaging 398 000 females in any given year (Shanker 2003). They are also found nesting on the Andaman and Nicobar Islands and to a lesser extent in the Lakshadweep Islands. This population continues to be threatened by nearshore trawl fisheries and interactions of individuals in their pelagic (drift) phase with the purse seine tuna (see Bourjea and others, 2014) and longline fisheries.

Driving forces affecting WIO marine turtle populations include coastal development and population growth, artisanal fisheries which comprise large numbers of boats using a large range of fishing gear in turtle foraging grounds, and the direct poaching of eggs and adults for meat at nesting sites, especially in Tanzania and Mozambique. *Pressure indicators* include habitat degradation of vital nesting beaches as well as foraging grounds, in places due to increased sedimentation. These can be measured in terms of the number of turtles captured in nets, the destruction of foraging habitats (coral reefs and seagrass beds), the effects of climate change, the alteration of nesting habitat (by human activity and coastal development), and the number of interactions with non-net fisheries.

MAMMALS

Of the 34 species of marine mammals that inhabit the WIO (Guissamulo 2011), five species are considered threatened (Appendix Table 10.A5). Of these, two are listed as Vulnerable, the dugong (*Dugong dugon*) and the sperm whale (*Physeter macrocephalus*), and three are listed as Endangered – the sei (*Balaenoptera borealis*), fin (*B. physalus*) and blue whales (*B. musculus*). Most whales have been protected from commercial harvest in certain regions by the International Whaling Commission (IWC) since the 1970s (some 40-50 years), and through a general moratorium on commercial whaling in 1985, but some regional subpopulations are still threatened by other human and climate-change related factors.

The five threatened whales and the dugong in the WIO region are listed in CITES Appendix I, and some are included in Appendix I and II of the CMS (see Appendix 10.1 Table 10.A5). The dugong is one of the most endangered mammals in Africa (WWF 2004; Muir and Kiszka 2011), though the Red List considers the global population of the **dugong**, spanning 48 countries from Mozambique to Australia as Vulnerable. It is recognized that the WIO population has been significantly depleted over recent decades such that it is considered extinct in Mauritius (Rodrigues) and near-extinct in many other countries, namely Kenya and Tanzania, while it is barely surviving in Mozambique. The *driving forces* behind these declines are human population growth and coastal development, leading to *pressure indicators* such as the degradation of its main habitat, seagrass beds, and its capture for meat and oil (with some incidentally harvested as by-catch in the gill-net fishery, some targeted).

Sperm whales are now only harvested in small-scale fisheries in Japan and Indonesia (Taylor and others, 2008). However, their recovery rate is very low, possibly in the order of one per cent per year (Whitehead 2002). Individuals are seen sporadically in waters off the Seychelles and Mauritius (Box 10.2) and floating dead whales are regularly encountered in the waters of Kenya and Tanzania, for no obvious reason. The most probable threats in the WIO constitute collision with ships and entanglement and drowning in fishing nets. Being predominantly an offshore species, its habitat and food source (deep-water squid) are

largely unaffected by anthropogenic factors. *Driving forces* affecting sperm whales are related to human population growth and increased demand for fish, with resulting *pressure indicators* that are unique and comprise increased shipping as well as offshore fishing.

In the Indian Ocean, **blue whales** are most abundant in the southern Indian Ocean, on the Madagascar plateau, and off South Australia and Western Australia. They are found year round in the northern and equatorial Indian Ocean, especially around Sri Lanka and the Maldives, and at least seasonally near the Seychelles. Protected worldwide since 1966, they are rarely caught by whaling ships but continue to be subject to ship strikes and entanglement in small numbers (NMFS 1998).

A cosmopolitan species, the **sei whale** favours deep, colder waters, so few are seen in the tropics. Numbers off South Africa suggest a decline lasting into the 1970s and a global decline over the last three generations, hence its Endangered listing. Sei whales are still hunted in Iceland. Its overall decline is attributed to southern hemisphere losses (declining by >70 per cent over the last three generations); while north Atlantic subpopulations may have increased recently, north Pacific trends are unknown. In general, the global status of **fin** whales is poorly understood (Reilly and others, 2013).

Driving forces affecting baleen whales are related to human population growth and increased demand for fish, with resulting *pressure indicators* that include their incidental capture in gill-nets, collisions with shipping, offshore fishing and chemical pollution. Growing development in the region and its need for energy are also *drivers* that lead to increased seismic surveys for oil and gas in the marine environment, yet another *pressure indicator* (see Chapter 26 this volume).

Whales and dolphins within seven families, including the species dealt with above, are included in Annex I of the Highly Migratory Species list of UNCLOS (1982). The Indo-Pacific humpback dolphin (*Sousa chinensis*) and Orca (*Orcinus orca*) are also found in the WIO, yet neither are listed as threatened in the IUCN Red List, nor by CITES, but are included in Appendix II of the CMS. The humpback dolphin is presently under study as to whether it comprises two or three distinct species. If separated from *S. chinensis*, *S. plumbea* would become the WIO form, in which case it would qualify as Vulnerable or higher (see Reeves and others, 2008). Following the precautionary principle, WIO humpback dolphins should be regarded as such.

A recent SWIOPF (2012) analysis concluded that marine mammal mortality through fisheries interactions in the SW Indian Ocean is generally low, and certainly lower than in many other regions of the world. However, the effects of climate change involving a reduction in the extent of sea ice in the Antarctic is expected, possibly with its complete disappearance in summer, as mean Antarctic temperatures are rising faster than the global average (Turner and others, 2006). The implications of this for baleen whales that feed in these waters during the southern summer, and over-winter and give birth in the warm WIO waters, are unclear.

CURRENT TRENDS AMONG POPULATIONS OF THREATENED MARINE SPECIES

The overall trend is one of a continuing decline in populations of most of the 161 marine species (including two subpopulations) identified as threatened in waters of the WIO region. There are encouraging signs of recovery in certain species (for example some of the whales) or specific groups in specific locations (eg most marine turtles in Seychelles and green turtles throughout much of the WIO), and populations of other species have stabilized. However, many of the marine creatures that live in or are dependent on inshore marine habitats, in this case mainly seagrass beds and coral reefs, are threatened because their habitat is being degraded or destroyed by humans. These two habitats have been reduced in geographic extent, especially over the last twenty years, and their biological integrity is being compromised by unsustainable coastal resource use and the consequence of coastal and industrial development (see Chapters 5-6).

Habitat destruction is a major problem in the marine and coastal environment in many parts of the world, the WIO region being no exception. Marine and coastal habitats are degraded by a multitude of factors, often due to seemingly universal *driving forces* involving population growth and coastal development. Destructive fishing practices, particularly bottom trawling (eg Mozambique, Madagascar, South Africa) and dynamiting coral reefs (exclusively in Tanzania) destroys entire ecosystems. Over-fishing weakens the sustainability of resources and may damage habitats and change ecosystem equilibrium. Environmental degradation (often measured in terms of seawater quality or changes in seabed life) is common close to large WIO coastal conurbations.

Coastal development is taking place at unprecedented rates around many large coastal cities in the WIO and its effects include destruction of marshes and floodplains that are in-filled for real estate development (eg Dar es Salaam), agricultural runoff that results in nutrient pollution from fertilizers and/or agro-chemicals (eg Mauritius), domestic sewage and solid waste pollution of coastal waters (eg Mombasa) leading to harmful algae blooms that block sunlight and deplete the water of oxygen. Sediment and silt originating from river catchment degradation, poor agricultural practices and changes in coastal land use discharge into coastal waters where their build-up on coral reefs can block the sunlight necessary for coral growth (eg NW Madagascar). Marine and beach pollution are associated with development and increased human settlement on the coast. Contaminants, often including toxic substances such as industrial chemicals, pesticides and oil waste, enter the marine environment from large coastal urban and industrial centres (eg Durban). Mining activities introduce metals such as mercury and other chemicals into rivers that discharge into the sea (eg Ruvuma, bordering Mozambique and Tanzania).

The above are only examples of the many environmental threats that appear to be increasing in the WIO, and that directly and indirectly impact on the biodiversity and productivity of coastal waters and their threatened species. These represent *pressure indicators*, some specific to the threatened species in general, others to threatened species in particular localities. Measurement of change in terms of quantity and/or quality (eg stocks of a specific fish population, chemical concentration of a particular pollutant, or prices of rare shells) would represent *state indicators*. These could then be used to monitor and describe changes over time, eg a reduction in area of seagrass cover could represents an *impact indicator* (Table 10.3).

One relevant factor is that, compared to other oceanic regions, the WIO is fringed mainly by developing countries, where marine life constitutes a vital source of subsistence (mainly as food). The challenge is to conserve threatened species while guaranteeing human survival. This is an important issue that must be addressed in the region: marine biodiversity is not only "food" or "money for food", but it can also be a source of revenue through its protection for ecotourism. A few successful community-driven marine resource management ventures are emerging (eg Itsamia, Comoros) but many more are needed to stem the rise in *driving forces*.

CAPACITY AND NEED TO PROTECT THREATENED SPECIES IN THE WIO REGION

Local capacity to implement measures to safeguard threatened marine environments (in some cases the environment in general) are severely lacking in some countries in the WIO. The best equipped in terms of personnel capacity, legislative framework, equipment and enforcement are Sey-

Table 10.3. State and impact indicators for threatened WIO marine species.

Major taxa (and number of species)	State indicators	Impact indicators
Seagrass (1)	Area covered (km^2); shoot density.	Loss in area coverage and density.
Hard corals (84)	Coral reef condition: includes water condition, species diversity, hard coral cover (%).	Reduction in percentage of live cover, diversity indices, water condition.
Gastropod molluscs (2)	Standing stock, indices being by-catch and shell availability/price in the shell trade.	Fewer individuals caught per unit fishing effort, higher price and lower volumes traded.
Holothurians (10)	Standing stock derived from field surveys; fisher/fishery surveys; export volumes, prices; species composition and specimen size.	Lower standing stock and export volumes, increase in less valuable species, smaller sizes and higher prices.
Rays (14)	Standing stock derived from field surveys, fisher/fishery surveys.	Reduced standing stock, landings, smaller sizes, higher prices.
Sharks (27)	Standing stock derived from field surveys, fisher/fishery surveys; dried fin export volumes.	Reduced standing stock, landed and fin export volumes, higher prices.
Fish (13)	Standing stock derived from field surveys, fisher/fishery surveys (eg sea fisheries observer programme).	Reduced standing stock, higher prices, lower volumes landed.
Turtles (5)	Standing stock derived from field (beach nesting activity) surveys, fisher/fishery surveys (eg sea turtle observer programme); surveys of foraging grounds.	Reduction in standing stock and length, condition of nest sites, degraded foraging grounds.
Mammals (5)	Standing stock derived from field surveys (whale watching), fisher/fishery surveys.	Reduction in standing stock.

chelles, Mauritius, Réunion (France) and South Africa. Less well equipped are Tanzania and Mozambique. Kenya and Madagascar lie somewhere in between.

Driving forces that are largely responsible for threatened marine species in the WIO region include fast-growing populations, combined with low levels of education and environmental awareness among coastal people; a low level of confidence in management authorities; high levels of poverty accompanied by a general lack tradition of marine resource stewardship or concern for environmental degradation; a lack of capacity or willingness to implement management measures; widespread corruption in government institutions that fail to prevent environmental degradation; and over-harvesting of resources that results from the need for food and income. These factors significantly affect the abilities of countries like Tanzania and Mozambique to implement effective marine conservation measures and progress in this regard is very slow, in some cases non-existent.

Authorities in many WIO countries are unable to manage stocks of marine life, enforce management regimes or fisheries regulations. Tanzania is held in high esteem when conservation of terrestrial species and ecosystems is concerned, despite recent increases in elephant poaching, yet management of the marine environment continues to present challenges for the responsible authorities. In Kenya, Tanzania, Comoros, Madagascar and Mozambique, marine protected areas (MPAs) do exist, and some achieve at least some of their conservation goals but, overall, marine resources and biodiversity are constantly under pressure from resource users and, in many cases, are at best stable or continue to degrade, albeit slower than if there was no legal protection.

Other than the coelacanth, most threatened marine species in the WIO region are implicated in fisheries that are expanding in intensity, extent and efficiency, and are resulting in increased collateral, non-target damage. Fisheries management is a challenge in most parts of the world, made more difficult in multi-species, coral reef-based fisheries, exploited by fishers with low incomes and few alternatives. In countries like Comoros, Madagascar, Tanzania, Kenya and Mozambique, where 21 of the 35 endangered species shown in Table 10.2 are CITES-listed (Appendices I or II), management and conservation of these species becomes more difficult as population pressures increase. CITES status has, for many (but not all) species, helped reduce trade in most parts of the world and ensure the continued survival of these species in the wild. Most of the successes are terrestrial, though hawksbill turtles remain a hopeful marine success. In many WIO countries, enforcement of CITES procedures and paperwork to acceptable levels is at present unrealistic for the volumes traded. The local capacity, as described above, is simply not there. In these countries, the threats and pressure indicators are likely to worsen.

CONCLUSIONS AND RECOMMENDATIONS

The management of threatened species faces many challenges in the WIO, yet it must be done. Responses to the threats facing the 161 species already considered threatened need to be developed with urgency and their implementation coordinated throughout the national territories of WIO countries. The main challenges will be to meet the increasing demand for biological resources caused by population growth and increased consumption, in the short-term, while always considering the long-term consequences and trends. Failure to achieve these objectives will witness a continued decline in the situation that that will certainly be reflected in a longer list of threatened species by 2050, with a greater number higher up the threat ladder, and a greater portion of degraded coastal habitats.

Developing *response indicators* to prevent, compensate, mitigate or adapt to changes recorded by *impact indicators* (as well as responding to *state* and *pressure* indicators) is often complex and demanding. The surest means to address the primary *driving forces*, viz growth in human population-related pressures, will be to educate populations and provide the means to reduce population growth. While recognizing that this is a slow and longer-term goal, it is a challenge that has been avoided for too long and the time to act is now. Effective action will require considerable effort, dedication and patience. Nine broad recommendations are outlined below to address most of the pressures indicators, some of which can be developed into legislation or other instruments that represent responses.

RECOMMENDATIONS

Raised awareness

This is needed at all levels of society, from marine resource harvesters (fishers, seaweed farmers, mangrove cutters, dive-boat operators, international coastal hotel managers), through local and regional governance structures, to senior management and institutions. The focus needs to be on providing information on threatened species, biodiversity

and the need for sustainable marine resource management, based on sound science (including reliable data). Implementation needs to be integrated across all sectors and stakeholders, following the ecosystem approach and involving local communities. Training and capacity building are also needed, particularly to increase the number and quality of students to generate national experts on threatened species and create a dynamic within each country to follow up on their status.

Increased funding for marine resource management

The costs of protecting marine areas, species or communities can far exceed the income they generate and, consequently, they are often ignored and not financed sustainably, especially in the short-term. Increased support for MPAs is needed, where necessary using novel technologies. Research findings warrant responses, especially where threatened marine species are involved.

WIO Threatened Species Task Force

Small units of specialist are needed to visit WIO countries, under the umbrella of a regional mandate, to identify "national" Red Lists on marine species with certainty and strengthen actions for their protection. This could involve a review of the data capture and management instruments related to the threatened species, introduce the DPSIR approach and generally assist overcome impediments to their protection and improve its effectiveness. For species where such a regional task force exists, links to global organizations that deal with that species need to be strengthened.

National integration and cross-sectoral cooperation

Coordination within governments, and between governments and stakeholders needs to be strengthened on all marine issues, aiming for fully integrated coastal zone management (ICZM) with thourough environmental and social impact assessments (ESIAs).

Strengthened regional integration and coherence

Adherence to the conditions of the Nairobi Convention needs improvement and all IMO conventions and other instruments (eg CBD, IOSEA, CITES, etc.) need to be ratified. Participation in the Regional Fisheries Management Organization (RFMO) and the Southern Indian Ocean Deep-sea Fishers' Association (SIODFA) is warranted, where relevant, for the enhanced protection of marine life and to foster regional cooperation, promote trade rules and practices that promote the sustainable use of biodiversity and threatened species. Illegal, unreported and unregulated fisheries (IUU) in the WIO region needs to be addressed and requires regional collaboration.

Alternative livelihoods

Alternative income generating activities for fishers and coastal communities need to be developed and promoted. Regional successes and the latest technology need to be shared; ecotourism is an example which delivers results.

Alternative food sources/equivalents

Alternative food sources need development for coastal populations, as well as value-adding for existing harvests. Regional successes and the latest technology again need to be shared. This must be done without adding pressure to other species (including commercial species) for which stocks are not in good shape, hence avoiding transfer of effort from one threatened species to another.

Monitoring the harvest of threatened species

Adequate monitoring of marine resource use is needed, especially of threatened species, using improve methods where necessary, once again sharing regional successes and the latest technology.

Targeted research

Research on threatened species needs promotion and support to identify research priorities, investigate their distribution, ecology, dispersal and connectivity, migration, population structure and breeding. Also important are fisheries by-catch and habitat biodiversity. Finally, there remains the need to develop environmental indicators and mitigation measures, and to improve harvesting techniques and alternatives (eg mariculture, or enhancements like "casitas" for lobsters, artificial reefs, or re-stocking).

BOX 10.1. SEA CUCUMBERS IN THE WIO



Close-up of a red prickly sandfish, *Thelenota ananas*, showing the distinctive soft, irregular papillae which give it a shaggy appearance.
© Michael H. Schleyer.

Sea cucumbers (or holothurians) are elongate, soft-bodied echinoderms without projecting arms. They have a mouth at the anterior end, surrounded by a ring of 10–30 food-capturing tentacles, and an anus at the posterior. Tube-feet, which are used mainly for locomotion, occur in various arrangements. The skeleton comprises microscopic ossicles of different shapes and sizes embedded in the dermis (skin) of the body wall. Sea cucumbers feed by using their tentacles to collect sediment into their mouths or by suspension feeding from the water. The tentacle shape reflects the type of feeding strategy and aid species identification. There are some 1 400 species worldwide, of which about 140 species occur in shallow waters of the WIO (Rowe and Richmond 2011).

Most holothurians are of little interest to humans, but demand for bêche-de-mer or dried sea cucumber in SE Asia and China has led to massive overfishing of the twenty or so species in demand. As a result, ten species from the WIO are now on the IUCN Red List, with one of the most endangered being the Red prickly sandfish (*Thelenota ananas*), partly due to its low fecundity. Of the family Stichopodidae, *T. ananas* reaches 70 cm in length, and is unmistakable due to it long, firm, loaf-shaped body covered in distinctive soft, irregular papillae giving a shaggy appearance. It is dark reddish-brown and lives among shallow reefs from the WIO and Red Sea to the western Pacific Ocean.

Over the last ten years, increased scarcity of sought-after bêche-de-mer species has encouraged research that has led to successful breeding of some to a size where they can be introduced to the natural environment (ranching or re-stocking). There are now ongoing projects to artificially breed and culture sea cucumbers (eg *Holuthuria scabra*) at various locations in the tropics, including the WIO, some in cooperation with private companies. Though mortality of cultured juveniles is high, once they reach 20 g and are placed in the wild, the survival rate is very good. Studies reveal that it can take six months for juveniles to reach 250 g, the desired weight for the export market. Farming or ranching sea cucumbers is expected to be profitable and environmentally friendly, providing a livelihood for coastal communities in the WIO and many tropical areas.

Useful reference: Toral-Granda, V., Lovatelli, A. and Vasconcellos, M. (eds.) (2008). Sea Cucumbers. A global review of fisheries and trade. FAO Fisheries and Aquaculture Technical Paper No. 516. Rome, FAO, 317 pp

BOX 10.2. SPERM WHALES IN THE WIO



A sperm whale mother and calf off Mauritius in the WIO. © Hughes Vitry.

Sperm whales (*Physeter macrocephalus*) are the most iconic of whales, made famous in popular culture by Hermann Melville's 1851 novel 'Moby Dick'. They are found in the tropical zones of all major oceans, including the WIO. Although males undertake seasonal migrations to higher latitudes, female-led groups are likely to be resident in the tropics throughout the year. Sperm whales are characterised by significant sexual dimorphism. While males can attain 18 m in length and 30-50 t in weight, females are typically only 10-12 m and 10-12 t in weight. Sperm whales feed on giant squid at depths of up to 2 000 m and can live for 60-70 years (Berggren 2009).

Filling much of the characteristically large head of sperm whales (the species' latin name of *macrocephalus* translates as *large-head*) is the spermaceti organ, producing a waxy liquid called spermaceti. This organ may play a role in both buoyancy and echolocation; Sperm whales may also use bursts of high-energy sound to stun their prey, and spermaceti may play a role in focusing these soundwaves. However, spermaceti has properties that made it unrivalled as an industrial lubricant, for use as candle-wax and for use in cosmetics and medicines. It was even used in space technology. Although whaling declined in the first half of the 20th century, there was an upsurge after WWII. Records suggest that between 1950 and 1976, Japan and the Soviet Union alone killed more than 220 000 sperm whales (WDCS 2010). The hunting of Sperm whales was made illegal in 1985.

Current estimates for global Sperm whale populations are in the order of 300 000 individuals, compared to the estimated pre-whaling era population of c.1million. There is no separate estimate for population sizes in the WIO (Berggren 2009).

Useful reference:

Hoare, P. (2008) Leviathan or, The Whale. Harper Collins. pp. 453

WDCS (2010). Reinventing the Whale. The whaling industry's development of new applications for whale oil and other products in pharmaceuticals, health supplements and animal feed. Whale and Dolphin Conservation Society, UK. May 2010, pp. 11

References

Allen, Z.C., Shah, N.J., Grant, A., Derand, G-D. and Bell, D. (2010). Hawksbill turtle monitoring in Cousin Island Special Reserve, Seychelles: an eight-fold increase in annual nesting numbers. *Endang. Species Res.* 11, 195–200

Baldwin, R., Hughes, G.R. and Prince, R.I.T. (2003). Loggerhead turtles in the Indian Ocean. In *Loggerhead Sea Turtles* (eds. Bolten A.B and Witherington, B.E.) p. 218-232. Smithsonian Institution Press, Washington, D.C.

Bandeira, S. (2011). Seagrasses. *In A Field Guide to the Seashores of Eastern Africa and the western Indian Ocean Islands* (ed. Richmond, M.D.) 3rd edition, pp. 74-77. Sida/WIOMSA

Bandeira, S. and Paula, J. (eds.) (2014). *The Maputo Bay Ecosystem*. WIOMSA. Zanzibar Town

Berggren, P. (2009). *Whales and Dolphins – A field guide to marine mammals of East Africa*. WIOMSA and East Publishing. www.wiomsa.org

Bourjea, J., Ciccione, S. and Rantsimbazafy, R. (2006). Marine turtle survey in Nosy Iranja Kely, North-Western Madagascar. Western Indian Ocean *J. Mar. Sci.* 5, 209–212

Bourjea J., Clermont, C., Delgado, A., Murua, H., Ruiz, J., Ciccione, C. and Chavance, P. (2014). Marine turtle interaction with purse-seine fishery in the Atlantic and Indian oceans: Lessons for management. *Biol. Cons.* 178, 74–87

Bourjea, J., Frappier J., Quillard, M., Ciccione, S., Roos, S., Hughes, G. and Grizel, H. (2007). Mayotte Island: Another important green turtle nesting site in the South West Indian Ocean. *Endang. Species Res.* 3, 273-282

Brooks, T.M., Mittermeier, R.A., da Fonseca, G.A.B., Gerlach, J., Hoffmann, M., Lamoreux, L.F., Mittermeier, C.G., Pilgrim, J.D. and Rodrigues, A.S.L. (2006). Global Biodiversity Conservation Priorities. *Science* 313, 58-61

Cagua, E.F., Cochran, J.E.M., Rohner, C.A., Prebble, C.E.M., Sinclair-Taylor, T.H., Pierce, S.J., and Berumen, M.L. (2015). Acoustic telemetry reveals cryptic residency of whale sharks. *Biol. Lett.* 11(4)

CBD (2000). *Sustaining life on Earth How the Convention on Biological Diversity promotes nature and human well-being*. Secretariat of the Convention on Biological Diversity

CITES. http://www.cites.org/

Clarke, S.C., McAllister, M.K., Milner-Gulland, E.J., Kirkwood, G.P., Michielsens, C.G.J., Agnew, D.J., Pikitch, E.K., Nakano, E. and Shivji, M.J. (2006). Global estimates of shark catches using trade records from commercial markets. *Ecol. Lett.* 9,(10), 1115–1126

Collette, B., Acero, A., Amorim, A.F., Boustany, A., Canales Ramirez, C., Cardenas, G., Carpenter, K.E., Chang, S.-K., Chiang, W., de Oliveira Leite Jr., N., Di Natale, A., Die, D., Fox, W., Fredou, F.L., Graves, J., Viera Hazin, F.H., Hinton, M., Juan Jorda, M., Minte Vera, C., Miyabe, N., Montano Cruz, R., Nelson, R., Oxenford, H., Restrepo, V., Schaefer, K., Schratwieser, J., Serra, R., Sun, C., Teixeira Lessa, R.P., Pires Ferreira Travassos, P.E., Uozumi, Y. and Yanez, E. (2011). *Thunnus obesus*. The IUCN Red List of Threatened Species. Version 2014.2

Compagno, L.J.V. (2009). *Electrolux addisoni*. The IUCN Red List of Threatened Species. Version 2014.2

Dalleau, M., Benhamou, S., Sudre, J., Ciccione, S. and Bourjea, J. (2014). The spatial ecology of juvenile loggerhead turtles (*Caretta caretta*) in the Indian Ocean sheds light on the "lost years" mystery. *Mar. Biol.* 161, 1835–1849

Duarte, M.C., Bandeira, S. and Romeiras, M.M. (2012). Systematics and ecology of a new species of seagrass (*Thlassodendron*: Cymodoceacea) from Southeast African coasts. *Novon 22*, 16-24

Esseen, M. and Richmond, M.D. (2011). Superclass Pisces – Fish. *In A Field Guide to the Seashores of Eastern Africa and the western Indian Ocean Islands* (ed. Richmond, M.D.) 3rd edition, pp. 340-379. Sida/WIOMSA

Griffiths, C. (2005). Coastal marine biodiversity in East Africa. *Indian J. Mar. Sci.* 34(1), 35-41

Guissamulo, A. (2011). Class mammalia – Mammals. *In A Field Guide to the Seashores of Eastern Africa and the western Indian Ocean Islands* (ed. Richmond, M.D.) 3rd edition, pp. 398-403. Sida/WIOMSA

Hamann, M., Kamrowski, R.L. and Bodine, T. (2013). *Assessment of the conservation status of the loggerhead turtle in the Indian Ocean and South-East Asia*. IOSEA Marnie Turtle MoU Secretariat. Bangkok

Human, B. (2008). "*Haploblepharus kistnasamyi*". IUCN Red List of Threatened Species. Version 2010.2. International Union for Conservation of Nature. Downloaded on 9 October 2010

IOTC–SC17 (2014). *Report of the Seventeenth Session of the*

IOTC Scientific Committee. Seychelles, 8–12 December 2014. IOTC–2014–SC17–R[E]: 357 pp

Innocenzi, J., Maury, J., M'soili A. and Ciccione, S. (2010). Reproduction biology of green turtle in Itsamia, Mohéli (Union of Comoros). *Indian Ocean Turtle Newsletter* 11, 5-7

IUCN (2012). *IUCN Red List Categories and Criteria: Version 3.1*. Second edition. Gland, Switzerland and Cambridge, UK: IUCN. iv.

Jackson, J.B.C. (2001). What was natural in the coastal oceans? *Proc. Natl. Acad. Sci. U.S.A.* 98(10), 5411–5418

Lauret-Stepler, M., Ciccione, S. and Bourjea, J. (2010). Monitoring of marine turtles reproductive activities in Juan de Nova, Eparses Islands, South Western Indian Ocean, based on tracks counts and width. *Indian Ocean Marine Turtle Newsletter* 11, 18–24

Le Gall, J.Y. (1988). Biologie et évaluation des populations de tortues vertes Chelonia mydas des atolls Tromelin et Europa (Océan Indien S.O.). *Mésogée* 48, 33–42.

Lewison, R.L., Freman, S.A. and Crowder, L.B. (2004). Quantifying the effects of fisheries on threatened species: the impact of pelagic longlines on loggerhead and leatherback sea turtles. *Ecol. Lett.* 7, 221–231

MarineBio Conservation Society. http://marinebio.org/oceans/red-list-species/

Marshall, N.T., Milledge, S. and Afonso, P.S. (1999). *Storm seas for marine invertebrates: trade in sea cucumbers, seashells and lobsters in Kenya, Tanzania and Mozambique*. Final Report for Project No. 9F0070

Mcpherson, J.M. and Vincent, A.C.J. (2004). Assessing East African trade in seahorse species as a basis for conservation under international controls. *Aquat. Conserv. Mar. Freshw. Ecosys.* 14, 521–538

Meylan, A.B. and Donnelly, M. (1999). Status justification for listing the hawksbill turtle (*Eretmochelys imbricata*) as critically endangered on the 1996 IUCN Red List of Threatened Animals. *Chelonian Conserv. Biol.* 3, 200–224

Mortimer, J.A. (1984). *Marine turtles in the Republic of Seychelles: status and management*. IUCN. Gland, Switzerland

Mortimer, J.A., Camille, J.-C., Boniface, N. (2011a). Seasonality and status of nesting hawksbill (*Eretmochelys imbricata*) and green turtles (*Chelonia mydas*) at D'Arros Island, Amirantes Group, Seychelles. *Chelonian Conserv. Biol.* 10(1), 26–33

Mortimer J.A., and Collie, J. (1998). Status and conservation of sea turtles in the Republic of Seychelles. In *Proc 17th Annu Sea Turtle Symp.*(eds.Epperly, S.E. and Braun, J.). pp. 74–75. NOAA Tech Memo NMFS-SEFSC-415

Mortimer J.A. and Donnelly, M. (2008). *Eretmochelys imbricata*. IUCN Red List of Threatened Species. Version 2010.1

Mortimer, J.A., von Brandis, R.G., Liljevik, A., Chapman, R. and Collie, J. (2011b). Fall and rise of nesting green turtles (*Chelonia mydas*) at Aldabra Atoll, Seychelles: positive response to four decades of protection (1968-2008). *Chelonian Conserv. Biol.* 10(2), 165–176.

Muir, C.E. and Kiszka, J. (2012). Eastern African dugongs. In *Sirenian Conservation: Issues and Strategies in Developing Countries* (eds. E. Hines, J. Reynolds, L. Aragones, T. Mignucci, and M. Marmontel) University Press of Florida, USA

Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A.B. and Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature* 403, 853–858

Nel, R., Punt, A.E. and Hughes, G.R. (2013). Are coastal protected areas always effective in achieving population recovery for nesting sea turtles? *PLoS ONE* 8(5):e63525

NMFS (1998). *Recovery plan for the blue whale (Balaenoptera musculus)*. Prepared by Reeves R.R., P.J. Clapham, R.L. Brownell, Jr., and G.K. Silber for the National Marine Fisheries Service, Silver Spring, MD

Okemwa, G.M., Nzuki, S. and Mueni, E.M. (2004). The Status and Conservation of Sea Turtles in Kenya. *Marine Turtle Newsletter* 105, 1-6

Pharoah, A.M., Fanning, E. and Said, A. (2003). Observations of sea turtles nesting on Misali island, Pemba. *Journal of East African Natural History*. 92(1 and 2), 127-134

Pimm, S.L., Russell, G.J., Gilleman, J.L. and Brooks, T.M., (1995). The future of biodiversity. *Science* 269 (5222), 347–350

Raybaudi-Massilia, G. (2013). *Conus julii*. The IUCN Red List of Threatened Species. Version 2014.2.

Reeves, R.R., Dalebout, M.L., Jefferson, T.A., Karczmarski, L., Laidre, K., O'Corry-Crowe, G., Rojas-Bracho, L., Secchi, E.R., Slooten, E., Smith, B.D., Wang, J.Y. and Zhou, K. (2008). *Sousa chinensis*. The IUCN Red List of Threatened Species. Version 2014.2

Reilly, S.B., Bannister, J.L., Best, P.B., Brown, M., Brownell Jr., R.L., Butterworth, D.S., Clapham, P.J., Cooke, J., Donovan, G.P., Urbán, J. and Zerbini, A.N. (2013). *Bal-*

aenoptera physalus. The IUCN Red List of Threatened Species. Version 2014.2

Rice, T. (2007). *A Catalog of Dealers' Prices for Shells: Marine, Land and Freshwater*, 23rd edition. Of Sea and Shore Publications

Richmond, M.S. and Rabesandratana, H.D. (2011). Phylum Mollsca – Molluscs. *In A Field Guide to the Seashores of Eastern Africa and the western Indian Ocean Islands* (ed. Richmond, M.D.) 3rd edition, pp.248 -257 and 284-297. Sida/WIOMSA

Rowe, F.W.E and Richmond, M.D. (2011). Phylum Echinodermata- Echinoderms. *In A Field Guide to the Seashores of Eastern Africa and the western Indian Ocean Islands* (ed. Richmond, M.D.) 3rd edition, pp. 300-329. Sida/WIOMSA

Schleyer, M. (2011). Order Scleractinia (Madreporaria) - Hard Corals. *In A Field Guide to the Seashores of Eastern Africa and the western Indian Ocean Islands* (ed. Richmond, M.D.) 3rd edition, pp. 150-163. Sida/WIOMSA

Shanker, K. (2003) (Series Editor) *Manuals on sea turtle conservation*. A GOI UNDP Sea Turtle Project. Centre for Herpetology/Madras Crocodile Bank Trust. Tamil Nadu, India.

Short, F.T., Coles, R., Waycott, M., Bujang, J.S., Fortes, M., Prathep, A., Kamal, A.H.M., Jagtap, T.G., Bandeira, S., Freeman, A., Erftemeijer, P., La Nafie, Y.A., Vergara, S., Calumpong, H.P. and Makm, I. (2010). *Zostera capensis*. The IUCN Red List of Threatened Species. Version 2014.3. http://www.iucnredlist.org. Downloaded on 1 May 2015

SWIOFP (2012). *Mainstreaming biodiversity in fisheries management: a retrospective analysis of existing data on vulnerable organisms in the South West Indian Ocean*. A Specialist Report. Prepared for the South West Indian Ocean Fisheries Project (SWIOFP)

Taylor, B.L., Baird, R., Barlow, J., Dawson, S.M., Ford, J., Mead, J.G., Notarbartolo di Sciara, G., Wade, P. and Pitman, R.L. (2008). *Physeter macrocephalus*. The IUCN Red List of Threatened Species. Version 2014.2

Turner, J., Comiso, J.C., Marshall, G.J., Lachlan-Cope, T.A., Bracegirdle, T., Maksym, T., Meredith, M.P., Wang, Z. and Orr, A. (1996). Non-annular atmospheric circulation change induced by stratospheric ozone depletion and its role in the recent increase of Antarctic sea ice extent. *Geophys. Res.Lett.* 36, pp. 5

UNCLOS (1982). *United Nations Convention on the Law of the Sea*, 10 December 1982, 1833 U.N.T.S.396

Vincent, A.C.J., Giles, B. G., Czembor, C.A. and Foster, S.J. (eds.) (2011). *Trade in seahorses and other syngnathids in countries outside Asia (1998-2001)*. The Fisheries Centre, University of British Columbia

West, L. (2011). A multi-stakeholder approach to the challenges of turtle conservation in the United Republic of Tanzania. *Indian Ocean Turtle Newsletter* No. 1144-49

West, L. (2014). The First Documented Case of Foraging Ground Philopatry in a Female Green Turtle (*Chelonia mydas*) in Tanzania. *African Sea Turtle Newsletter* No. 2

Whitehead, H. (2002). Estimates of the current global population size and historical trajectory for sperm whales. *Mar. Ecol. Prog. Ser.* 242, 295–304

Wilkinson, C. (2004). Status of Coral reefs of the World: 2004. Vol. 1. Australian Institute of Marine Science

WWF (2004). *Eastern Africa Marine Eco-Region 2050 Vision Report*. WWF TZ Office

APPENDIX 10.1

Table 10.A1. Full list of threatened WIO coral species.

Notes on threat codes: a) overall species habitat degradation, used as a proxy for population decline; **b)** susceptible to coral bleaching and disease; **c)** narrow depth range; **d)** Crown-of-thorns (COT) predation; **e)** harvested (for aquaria; **f)** restricted geographic range; **g)** limited reproduction/dispersal (brooders). **Source:** Wilkinson (2004). **Abbreviations:** Indo-West Pacific region - IWP; Indo-Pacific region - I-P; PNG – Papua New Guinea; Pacific Ocean - PO; Western Indian Ocean – WIO.

Species	Red List Category & Criteria:	Distribution	Threat
Acanthastrea brevis	VU A4ce ver 3.1	IWP	a,b
Acanthastrea hemprichii	VU A4c ver 3.1	IWP	a,b
Acanthastrea ishigakiensis	VU A4c ver 3.1	IWP	a,b,c
Acropora aculeus	VU A4ce ver 3.1	IWP	a,b,d,e
Acropora acuminata	VU A4ce ver 3.1	IWP	a,b
Acropora anthocercis	VU A4ce ver 3.1	IWP	a,b,d
Acropora echinata	VU A4cde ver 3.1	IWP	a,b,d,e
Acropora hemprichii	VU A4ce ver 3.1	IWP	a,b,d
Acropora horrida	VU A4cde ver 3.1	IWP	a,b,d
Acropora listeri	VU A4ce ver 3.1	IWP	a,b,d
Acropora lovelli	VU A4ce ver 3.1	IWP	a,b,d
Acropora palmerae	VU A4ce ver 3.1	IWP	a,b,d
Acropora pharaonis	VU A4ce ver 3.1	IWP	a,b,d
Acropora polystoma	VU A4ce ver 3.1	IWP	a,b,d
Acropora retusa	VU A4ce ver 3.1	IWP	a,b,d
Acropora roseni	EN A4ce ver 3.1	IWP	a,b,d
Acropora rudis	EN A4ce ver 3.1	IWP	a,b,d
Acropora solitaryensis	VU A4ce ver 3.1	IWP	a,b,d
Acropora spicifera	VU A4ce ver 3.1	IWP	a,b,d
Acropora vaughani	VU A4ce ver 3.1	IWP	a,b,d,e
Acropora verweyi	VU A4ce ver 3.1	IWP	a,b,d
Acropora willisae	VU A4ce ver 3.1	IWP	a,b,d,e
Alveopora allingi	VU A4cd ver 3.1	IWP	a,b,d
Alveopora daedalea	VU A4c ver 3.1	IWP	a,b,d
Alveopora fenestrata	VU A4c ver 3.1	IWP	a,b,d,e
Alveopora verrilliana	VU A4cd ver 3.1	Red Sea to IP (incl. Mauritius)	a,b,d,e
Anacropora reticulata	VU A4ce ver 3.1	Central IP (incl. Mauritius)	a,b,d
Anacropora spinosa	EN A4ce ver 3.1	Central IP (incl. Mauritius)	a,b,d
Anomastraea irregularis	VU A4ce ver 3.1	IWP	a,b,d
Catalaphyllia jardinei	VU A4cd ver 3.1	IWP	a,e
Caulastrea connata	VU A4c ver 3.1	IWP	a,b,c
Ctenella chagius	EN A4c ver 3.1E	BIOT + Mauritius, Réunion	a,b,f
Echinopora robusta	VU A4c ver 3.1	Sri Lanka + WIO	a,b,f
Euphyllia cristata	VU A4cd ver 3.1	IWP	a,e
Favites spinosa	VU A4c ver 3.1	Red Sea to PNG (incl. WIO)	a,b,c
Fungia curvata	VU A4c ver 3.1	E + WPO, Red Sea (incl. WIO)	a,b
Fungia seychellensis	VU A4c ver 3.1	IWP	a,f
Galaxea astreata	VU A4cd ver 3.1	IWP	a,b,e
Goniastrea deformis	VU A4c ver 3.1	IWP	a,e
Goniopora albiconus	VU A4c ver 3.1	IWP	a
Goniopora planulata	VU A4c ver 3.1	IWP	a,b

Species	Red List Category & Criteria:	Distribution	Threat
Heliopora coerulea	VU A4cde ver 3.1	IWP	a,b,c,e
Horastrea indica	VU A4c ver 3.1	WIO	a
Isopora brueggemanni	VU A4ce ver 3.1	Red Sea - central PO (incl. WIO)	a,g
Isopora cuneata	VU A4ce ver 3.1	WIO to central PO	a,b,d
Isopora crateriformis	VU A4ce ver 3.1	IWP	a,b,g
Leptastrea aequalis	VU A4c ver 3.1	Madagascar - WPO	a,b,c
Leptoria irregularis	VU A4c ver 3.1	WIO - WPO	a,b,c
Leptoseris incrustans	VU A4ce ver 3.1	IWP	a,b,d
Leptoseris yabei	VU A4ce ver 3.1	IWP (Madagascar)	a,b
Millepora tuberosa	EN A4c ver 3.1	WPO + Mauritius	a,b,e (curio trade)
Montastrea serageldini	VU A4c ver 3.1	IWP	a
Montipora australiensis	VU A4ce ver 3.1	IWP	a,b,d
Montipora calcarea	VU A4ce ver 3.1	WIO - WPO	a,b,d
Montipora caliculata	VU A4ce ver 3.1	WIO	a,b,d
Montipora corbettensis	VU A4c ver 3.1	WIO - WPO	a,b,d
Montipora friabilis	VU A4ce ver 3.1	WIO - WPO	a,b,d
Montipora lobulata	VU A4c ver 3.1	IWP	a,b,d
Montipora meandrina	VU A4c ver 3.1	Red Sea, Madagascar, WPO	a,b,d
Montipora orientalis	VU A4c ver 3.1	WIO to WPO	a,b,d
Montipora stilosa	VU A4c ver 3.1	IWP	a,b,d
Pachyseris rugosa	VU A4cd ver 3.1	IWP	a,b,e
Parasimplastrea sheppardi	EN A4c ver 3.1	IWP	a,b,f
Pavona bipartita	VU A4c ver 3.1	IWP	a,b
Pavona cactus	VU A4cd ver 3.1	IWP	a,b,e
Pavona decussata	VU A4c ver 3.1	IWP	a,b
Pavona venosa	VU A4c ver 3.1	IWP	a,b
Pectinia africanus	VU A4c ver 3.1	WIO	a,b,e,f
Pectinia lactuca	VU A4cd ver 3.1	IWP	a,b,e
Physogyra lichtensteini	VU A4cd ver 3.1	IWP	a,e
Pocillopora ankeli	VU A4c ver 3.1	IWP (Madagascar)	a,b,c
Pocillopora fungiformis	EN A4c ver 3.1	WIO (Madagascar)	a,b,f
Pocillopora indiania	VU A4c ver 3.1	WIO	a,b,f
Porites nigrescens	VU A4cde ver 3.1	IWP	a,b,e
Porites sillimaniana	VU A4cde ver 3.1	WIO - WPO	a,b,e
Poritipora paliformis	VU A4c ver 3.1	WIO - Sri Lanka	a
Psammocora stellata	VU A4ce ver 3.1	IWP (incl. Seychelles)	a,b,d
Seriatopora aculeata	VU A4c ver 3.1	Madagascar, WPO - central PO	a,b
Stylophora madagascarensis	EN A4c ver 3.1	Madagascar	a,b,f
Symphyllia hassi	VU A4c ver 3.1	IWP	a,b,c
Turbinaria mesenterina	VU A4cd ver 3.1	IWP	a,e
Turbinaria peltata	VU A4cd ver 3.1	IWP	a,e
Turbinaria reniformis	VU A4c ver 3.1	IWP	a,b,c
Turbinaria stellulata	VU A4c ver 3.1	IWP	a,b,c

Table 10.A2. Full list of threatened WIO seagrass, mollusc and sea cucumber species.

Notes on threat codes: a) overall species habitat degradation, used as a proxy for population decline; **e)** harvested (by collectors of *Conus* shells, assumed black market; holothurian, for food); **f)** restricted geographic range; **g)** limited reproduction/dispersal (low fecundity + late sexual maturation). **Sources** for *Zostera* (Short and others, 2010); and *Conus* (Raybaudi-Massilia 2013). **Abbreviations:** Indo-West Pacific region - IWP; Indo-Pacific region - IP; Pacific Ocean - PO; Western Indian Ocean – WIO.

Species	Red List Category & Criteria:	Distribution	Threat
PLANTAE TRACHEOPHYTA			
Zostera capensis	VU B2ab(ii,iii) ver 3.1	WIO (not small islands) < 2,000 km^2	a (esp. Mozambique)
MOLLUSCA GASTROPODA			
Conus jeanmartini	VU D2 ver 3.1	Réunion (deepwater)	e (shrimp trawling),f
C. julii	VU B1ab(v)+2ab(v) ver 3.1	Mascarenes	e,f + possibly extreme weather events.
ECHINODERMATA HOLOTHUROIDEA			
Actinopyga echinites	VU A2bd ver 3.1	WIO – central PO	e (declined > 60-90% in > 50% of range)
A. mauritiana	VU A2bd ver 3.1	WIO – central PO	e (declined > 60-90% in > 50% of range)
A. miliaris	VU A2bd ver 3.1	WIO – central PO	e (declined > 60-90% in > 50% of range)
Holothuria arenacava	VU D2 ver 3.1	Kenya	f, e (assumed)
H. fuscogilva	VU A2bd ver 3.1	WIO – central PO	e (declined > 60-80% in > 30% of range)
H. lesson	E A2bd ver 3.1	IWP	e (highest value; declined 50% in > 50% of range)
H. nobilis	E A2bd ver 3.1	Indian Ocean	e (high value; declined 60-70% in > 80% of range)
H. scabra	E A2bd ver 3.1	IWP	e (high value; declined > 90% in > 50% of range)
Stichopus herrmanni	VU A2bd ver 3.1	IWP	e (declined > 60-90% in > 50% of range)
Thelenota ananas	E A2bd ver 3.1	IWP	e (high value; declined 80-90% in > 50% of range), g

Table 10.A3. Full list of threatened WIO ray and shark species.

Notes on threat codes: a) overall species habitat degradation, used as a proxy for population decline; **c)** narrow depth range; e) overharvested (for food); **f)** restricted geographic range; **g)** low fecundity; **h)** rare; **i)** by-catch. **Abbreviations:** Indo-West Pacific region - IWP; Indo-Pacific region - IP; Pacific Ocean - PO; Western Indian Ocean – WIO.

Species	Red List Category & Criteria:	Distribution	Threats
RAYS			
Aetobatus flagellum	EN A2d+3d+4d ver 3.1	IWP	g,e,h
Aetomylaeus vespertilio	EN A2bd+3d+4d ver 3.1	WIO – PO	g,e,h
Dipturus crosnieri	VU A3d ver 3.1	Madagascar	a,c,f,g,h,i
Electrolux addison	CE B2ab(ii) ver 3.1	S Africa	a,c,f,g
Heteronarce garmani	VU A2d+4d ver 3.1	Moz., S Africa	a,e,h,i
Himantura uarnak	VU A2bd+3bd+4bd ver 3.1	IWP	a,e,g
Manta alfredi [2]	VU A2abd+3bd+4abd ver 3.1	circumtropical	e,g
Manta birostris [2,a,b]	VU A2abd+3bd+4abd ver 3.1	circumtropical	e,i
Rhinoptera javanica	VU A2d+3cd+4cd ver 3.1	IWP	a,g,i
Taeniurops meyeni	VU A2ad+3d+4ad ver 3.1	IWP	a,e,g
Anoxypristis cuspidate [1]	EN A2cd ver 3.1	WIO - WPO	e,g
Pristis clavata [1]	EN A2cd ver 3.1	WIO - WPO	a,c,e,g,i
Pristis pristis [1]	CE A2cd ver 3.1	IWP-Atlantic	a,c,e,g,i
Pristis zijsron [1]	CE A2cd ver 3.1	IWP	a,c,e,g,i
SHARKS			
Alopias pelagicus	VU A2d+4d ver 3.1	WIO – PO	e,g,i
Alopias superciliosus	VU A2bd ver 3.1	circumglobal	e,g
Alopias vulpinus	VU A2bd+3bd+4bd ver 3.1	circumglobal	e,g,i
Carcharhinus longimanus [2]	VU A2ad+3d+4ad ver 3.1	circumtropical	e,g,i
Carcharhinus obscurus	VU A2bd ver 3.1	cosmopolitan	e,g
Carcharhinus plumbeus	VU A2bd+4bd ver 3.1	circumglobal	e,g
Carcharias taurus	VU A2ab+3d ver 3.1	Subtrop/temp	a,e,g
Carcharodon carcharias [2,a,b]	VU A2cd+3cd ver 3.1	cosmopolitan	e,g,i
Centrophorus granulosus	VU A2abd+3d+4d ver 3.1	circumglobal	e,g,h
Galeorhinus galeus	VU A2bd+3d+4bd ver 3.1	widespread (Moz., S Africa)	e,g
Haploblepharus kistnasamyi	CE B1ab(iii) ver 3.1	S Africa	a,c,e,f,g,h
Hemipristis elongate	VU A2bd+3bd+4bd ver 3.1	IWP	e,g
Holohalaelurus favus	EN A2abcd+3bcd+4abcd ver 3.1	Moz., S Africa	e,f
Holohalaelurus punctatus	EN A2abcd+3bcd+4abcd ver 3.1	Moz., S Africa	c,g,h,i
Isurus oxyrinchus	VU A2bd+4d ver 3.1	IWP	e,h,i
Isurus paucus	VU A2bd+3d+4bd ver 3.1	cosmopolitan	e,h,i
Nebrius ferrugineus	VU A2abcd+3cd+4abcd ver 3.1	IWP	a,c,e,g
Negaprion acutidens	VU A2abcd+3bcd+4abcd ver 3.1	IO-WPO	a,c,e,g
Odontaspis ferox	VU A2bd+4bd ver 3.1	widespread	g,h
Pseudoginglymostoma brevicaudatum	VU A3cd+4cd ver 3.1	WIO	a,e,f,h,i,
Rhina ancylostoma	VU A2bd+3bd+4bd ver 3.1	IWP	a,e,i
Rhincodon typus [2,b]	VU A2bd+3d ver 3.1	cosmopolitan	e
Rhynchobatus djiddensis	VU A2d+3d+4d ver 3.1	Red Sea – WIO	e,g,i
Sphyrna lewini [2]	EN (WIO) A2bd+4bd ver 3.1	circumglobal	e,i
Sphyrna mokarran [2]	EN A2bd+4bd ver 3.1	circumglobal	e,g
Sphyrna zygaena [2]	VU A2bd+3bd+4bd ver 3.1	circumglobal	e,i
Stegostoma fasciatum	VU A2abcd+3cd+4abcd ver 3.1	IP	a,c,e,i
CITES listing: 1. Appendix I; 2. Appendix II; 3. Appendix III; a. Appendix I CMS; b. Appendix II CMS.			

Table 10.A4. Full list of threatened WIO bony fish species.

Notes on threat codes: a) overall species habitat degradation, used as a proxy for population decline; **c)** narrow depth range; **e)** overharvested (for food); **f)** restricted geographic range; **g)** low fecundity; **h)** rare; **i)** by-catch. **Abbreviations:** Indo-West Pacific region - IWP; Indo-Pacific region - IP; Western Indian Ocean – WIO.

Species	Red List Category & Criteria:	Distribution	Threats
SARCOPTERYGII			
Latimeria chalumnae [1]	CE A2bcd ver 2.3	WIO	c,e,f,g,h,i
ACTINOPTERYGII			
Argyrosomus hololepidotus	EN B1ab(ii,iii,v)+2ab(ii,iii,v) ver 3.1	Madagascar	e,f,h,i
Bolbometopon muricatum	VU A2d ver 3.1	IWP	a,e
Albula glossodonta	VU A2bcd ver 3.1	IP	a,e
Cheilinus undulatus [2]	EN A2bd+3bd ver 3.1	IP	a,e
Epinephelus albomarginatus	VU A2d ver 3.1	WIO - India	e,f
Epinephelus lanceolatus	VU A2d ver 3.1	IP	a,e
Hippocampus histrix [2]	VU A2cd+4cd ver 3.1	IP	a,e,h,i
Hippocampus kelloggi [2]	VU A2d+4d ver 3.1	IP	a,e,h,i
Makaira nigricans [a]	VU A2bd ver 3.1	cosmopolitan	e,h,i
Plectropomus laevis	VU A2d+4d ver 3.1	IP	e,i
Thunnus maccoyii [a]	CE A2bd ver 3.1	cosmopolitan	e,i
Thunnus obesus [a]	VU A2bd ver 3.1	circumtropical	e (central PO)
1. CITES Appendix I; 2. CITES Appendix II; a. UNCLOS Annex 1.			

Table 10.A5. Full list of threatened WIO marine turtles and mammals.

Notes on threat codes: a) overall species habitat degradation, used as a proxy for population decline; **c)** narrow depth range; **e)** over-harvested (for food); **f)** restricted geographic range; **g)** low fecundity; **h)** rare; **i)** by-catch. **Abbreviations:** Indo-West Pacific region - I-WP.

Species	Red List Category & Criteria:	Distribution	Threats
REPTILIA			
Caretta caretta [1,a,b]	EN A1abd ver 2.3	circumglobal	a,e,i
Chelonia mydas [1,a,b]	EN A2bd ver 3.1	circumglobal	a,e,i
Dermochelys coriacea [1,a,b]	CE C2a(ii) ver 3.1	circumglobal	a,e,i
Eretmochelys imbricata [1,a,b]	CE A2bd ver 3.1	circumglobal	a,e,i
Lepidochelys olivacea [1,a,b]	VU A2bd ver 3.1	circumtropical	a,e,i
MAMMALIA			
Balaenoptera borealis [1,a,b,c]	EN A1ad ver 3.1	cosmopolitan	e,i
Balaenoptera musculus [a,c]	EN A1abd ver 3.1	cosmopolitan	e,i
Balaenoptera physalus [1,a,b,c]	EN A1d ver 3.1	cosmopolitan	e,i
Physeter macrocephalus [1,a,b,c]	VU A1d ver 3.1	cosmopolitan	e,i
Dugong dugon [1,b]	VU A2bcd ver 3.1	I-WP	e,i
1. CITES Appendix I; a. Appendix I CMS; b. Appendix II CMS; c. UNCLOS Annex 1.			


PGBMC
MICOA
PLANTIO DE MANGAL
PROIBIDO PASSAGEM
CUVIALIWA KWA APA
WACATAZA KUPITA.

11
Significant Social and Economic Aspects of Biodiversity Conservation

Rosemarie Mwaipopo

Opposite page: Community-based mangrove plantation with children as "no trespassing" guards, Ulo village in north Mozambique. © José Paula.

INTRODUCTION

Current practices on coastal and marine resource management in the Western Indian Ocean (WIO) have integrated multiple but interrelated economic and social aspects that impinge on the state of the environment. This is a reflection of changing perceptions on human-environment interactions, and deeper appreciation of the significance and complexities of the human dimension in biodiversity conservation (Cinner and David 2011, Rocliffe and others, 2014). Conceptually, some conservation initiatives have woven together the realities of societal processes, particularly demographic dynamics, people's livelihoods and cultural value systems, with ideas on and estimations of the economic of environmental resources together with their habitats (Sultan 2012, Turpie and Wilson 2011). This understanding is used to influence policy and practice in the management of resources. Also important are policy choices and commitments to management, indicating how global processes or national priorities influence decisions on conservation practice (UNEP 2013) and the adaptation of coastal communities to climate change. Increasingly, economic and social effects of climate change, witnessed by sea level rises or temperature surges in the region, are becoming key components in biodiversity conservation (UNEP 2011), especially with regard to human activities as non-climate stressors (Westerman and Gardner 2013). These effects have been taken into consideration in ecosystem-based management approaches in which the iterative relations between people, nature and institutions inform resource management and conservation projects (Grillo 2011). Community participation is regarded as particularly important in the management of these resources for their effective biodiversity conservation.

A major concern in the region, however, is the nature of human interactions with resources and the differential distribution of costs and benefits among various groups and actions brought about by existing resource governance structures, power relations and interests (Kulindwa and Lokina 2013). The Convention for Biological Diversity (CBD) showed in its Global Biodiversity Outlook 3 that terrestrial and marine biodiversity was declining globally at an alarming rate (CBD 2010). In the WIO, some of the social dimensions of biodiversity loss were identified, including inconsistent government policies, failure to enforce environmental laws, centralization of decision-making on resource management and undue political influence and misguidance (Wood and others, 2000, Kulindwa and others, 2001). Several outcomes can be considered. One is how the political and social contexts have affected biodiversity conservation and vice versa. It is also important to consider the nature of the economic and social costs generated by rules and regulations on resource use. In addition, there are issues concerning trade-offs arising from policy decisions between conservation and the economic benefits drived from resource use. This chapter describes key social and economic aspects of biodiversity conservation in the WIO and management responses that would be meaningful in influencing policy on

biodiversity conservation in the region.

THE SOCIAL CONTEXT OF CONSERVATION

Poverty and the level of dependence on coastal and marine resources are among the key factors that influence the effectiveness of biodiversity conservation. The diversified livelihood patterns of coastal communities are hampered by factors such as declining resource bases, competition, poor resource extraction methods and others. As a result, the viability of many of these activities to sustain households is leading to overexploitation of the most accessible resources (Salagrama 2006, Tobey and Torrel 2006, UNEP 2006). Rapid population growth is an intervening variable and, as illustrated in Chapter 1, population densities are increasing at a rapid rate in the coastal zone of the WIO region (World Bank 2012, UNEP 2011). It is estimated that over 60 per cent of the total population of Sub-Saharan African coastal states live within 100 km of the coast and derive their livelihood from the coastal and marine environment. Heightened competition for resources, which has been influenced by societal dynamics and neoliberal economic policies, has increased the rate of exploitation of resources, thereby challenging management effectiveness. For example, intensification in coastal infrastructural development (see Chapter 29) and economic investment along the coast, magnified recently by the oil and gas industry (see Chapter 26), are impinging on both fragile ecosystems and human livelihood sources (UNEP 2012).

A larger social issue concerns institutional challenges. Management institutions are unable to address compliance, while low skills and technological development in the region, which may otherwise permit improve public attitudes towards conservation, is inadequate. These social aspects are discussed in the rest of this chapter.

TRADITIONAL MANAGEMENT REGIMES

Customary tenure over resources is becoming increasingly unpopular and this has affected people's perceptions on how resources should be managed and, therefore, also how it benefits people and the environment (see Chapter 20). There are nevertheless several examples of coastal communities in the region who have upheld resource use regulations informed by their sense of attachment to a resource base (Cinner and Aswani 2007). Such communities still realise that their existence, indeed their survival and continuation as a people, is dependent upon the said resources or ecosystem. In some, fisherfolk describe their rights to marine commons as akin to communal ownership derived from their ancestors or a spiritual being. Through these rights, they ascribe access, ownership and use of resources, based on membership of the local community (Sunde and Isaacs 2008). These rights also entail management obligations as illustrated by the practice of the Vezo people in Madagascar (Harris 2007) provided in Box 11.1.

Velondriake illustrates how cultures can be used to reinforce or sanctify institutions established for resource conservation, and how participatory conservation processes can serve to reinvigorate local customs, becoming instrumental in maintaining biodiversity. Unfortunately, similar initiatives to those of the Vezo have been eroded due to factors that include societal dynamism in the WIO, population growth, materialism and the proliferation of new value systems regarding resources (Cinner and Aswani 2007, Masalu and others, 2010). This has made their contribution to the sustainable use and conservation of coastal and marine resources questionable, and difficult to integrate into legalised conventional management practice (Sunde and Isaacs 2008). At the same time, inadequate governance arrangements have trivialised traditional management systems and have created discontent, including non-compliance with resource protection (Cinner and others, in press). In areas where the formal integration of traditional or customary systems of governance into national environmental management policies has been possible (eg Madagascar, South Africa), it has permitted local communities to sustain their livelihoods according to a more culturally-sensitive process, which is also beneficial to the resource base (Sunde and Isaccs 2008, Westerman and Gardner 2013).

VALUATION OF RESOURCES AND BENEFITS TO BIODIVERSITY

Valuation of ecosystem services (provisioning, regulating, supporting and cultural) is not straightforward because of limited understanding of the full range of ecosystem functions (Bullock and others, 2008). However, economic estimation of resource use employing the Total Economic Value (TEV) approach (ie economic valuation of direct, indirect, option and non-use values of resources and ecosystems) is currently an integrated aspect of resource management in the region (UNEP 2006, Sultan 2012, Turpie

BOX 11.1. TO LIVE WITH THE SEA – THE VEZO PEOPLE, MADAGASCAR



The sails show the Vezo Aho logo and the message "Don't beach seine, spear fish". Sails have been painted to serve as moving billboards about destructive fishing methods along Madagascar's southwest coast. © Blue Ventures.

The *Velondriake* marine management initiative in Madagascar represents use of customary laws for sustainable management of the fisheries from which people have constructed their meaning of existence. The need for conservation arose after overexploitation of the fisheries due to population growth and commercialisation of traditional fisheries which led to destruction of the surrounding reefs and a decline in fish catches that people depended on. The ensuing efforts to put in place a management framework resulted in the *Velondriake* network, which is largely a community-based management system. '*Velondriake,*' which means 'to live with the sea' signified a series of management agreements in the area, resulting in the institution of a number of short-term closures of reef flats to octopus fishing. This system involves a total of 25 villages, and approximately 7 500 people who depend on the sea for their daily subsistence, income and cultural identity (Westerman and Gardner 2013). The total area under *Velondriake* management is 823 km^2 in size, covering over 40 km of coast (ibid, p 45). As part of the management processes, ancestral ceremonies were performed to sanctify the establishment of the area. On 24 October 2004, fishers of the Andavadoaka area signed a traditional law, called *dina*, to close the reef flat around the island of Nosy Fasy, also known as Ankereo, to octopus fishing for seven months from 1 November 2004. The *dina*, a set of local laws that regulate resource use within the Velondriake was ratified by the Malagasy regional court system in 2006 to become legally binding. It accords to local people several powers including banning destructive fishing practices, regulating closures of temporary octopus and mangrove reserves, governs permanent reef reserves and provides conflict resolution powers (summarised from Westerman and Gardner 2013, Harris 2007, Westerman and Gardner 2013).

and Wilson 2011). The main reasons for this are 'to assess the costs and benefits of an action or policy, as an aid to decision making; [and] to improve understanding of the value of benefits to society from an ecosystem or series of linked ecosystems' (UNEP-WCMC 2011). A common practice in the valuation of resources has been to compare estimates of their consumptive and non-consumptive uses (UNEP 2006). Ecotourism is perhaps the best example of the non-consumptive uses of resources as a conservation strategy in the region. Yet, where it has been adopted, it has often demanded trade-offs in exchange for compliance on the part of users to discard consumptive, presumably more materially beneficial uses, to less attractive but ecologically more sustainable activities with assumed long-term gains such as social benefits (improved income). Both material and non-material incentives have been used to secure

compliance with more environmentally friendly conservation mechanisms (Hicks and others, 2009).

ECOTOURISM AND CONSERVATION THROUGH NON-CONSUMPTIVE USES OF RESOURCES

Ecotourism, referred to as responsible tourism, is discussed in this section in relation to its socially and environmentally responsible attributes, and with reference to its potential to realise key economic and social dimensions in conservation (Gautam 2010). Numerous examples of ecotourism projects are found in the region. Two examples are provided to reflect its economic and social aspects, the willingness to pay principle (WTP) and species-specific conservation. The conservation potential of ecotourism is described in terms of its benefits in minimising direct resource extraction, and contributing differently to social development, mainly through employment generation with specific benefits for women. An added aspect is its potential for fairer benefit-sharing among stakeholders, often an incentive for local people to conserve (Gautam 2010). However, ecotourism, as a non-consumptive use, has proven to demand higher levels of investment to make it sustainable, eg in infrastructure, making its costs also high (Troëng and Drews 2004).

Willingness-to-pay: The conventional economic principle of 'willingness-to-pay'(WTP) for ecosystem services, including recreational, aesthetic and cultural services, is an economic-cum-social value attached to conservation and is widely used in ecotourism projects. This principle equates a relationship between a user and the quality of a resource with the assumption that, if the resource is of good quality, then it is worth paying for [its services]. Efforts to establish people's willingness-to-pay for certain services, such as for their aesthetic value, also provide a reflection of people's willingness to pay for protection of resources or species, and these values demonstrate the value of biodiversity (Bullock and others, 2008).

A study conducted in the Seychelles sought to establish the value of marine national parks (MNPs) to the Seychelles economy by calculating the difference between what visitors would be willing to pay to visit marine parks and what they actually pay (consumer surplus estimate). Out of 300 surveys, 270 surveys yielded an average value for willingness-to-pay of 61 Rupees (US$12.20), which exceeds the R50 (US$10) fee instituted in 1997. The difference between these two amounts is the consumer surplus (CS), representing the portion of the value of visits that is above the market price. The average consumer surplus was 11 Rupees (US$2.20), providing an estimate of the total potential consumer surplus of 440 000 Rupees (US$88 000), given that 40 000 tourists visited the Seychelles MNPs in 1997. Reasons associated with the higher WTP included expectations of good diving, good weather and visits to protected as well as romantic locations; tourists who specifically stated that the protection and conservation of marine resources was their primary motivation were fewer. Users' stated WTP can be related to intended use of the resource (a desire to dive implying that they are attracted by underwater biodiversity), with some secondary interest in the protection of marine resources generally (summarised from Mathieu and others, 2000).

Species-specific conservation from a social dimension: Species-specific conservation incorporates major social and economic aspects. These touch on people's arrangements to earn a livelihood and pressures of the market that often bear negatively on resources, contributing to their over-exploitation to the point of endangerment (Sea Sense 2012). The related interventions integrate not only capacity-building in the management of a species through education, but also through compensation for the loss of traditional consumption patterns with changes in resource use (Gautam 2010). Even though eradicating unregulated exploitation of these resources cannot be fully achieved, efforts in management training, promoting environmental awareness and, equally important, streaming broad-based sources of revenues back to individuals and communities have, to some extent, promoted compliance among users, some of whom have committed themselves to protection (Troëng and Drews 2004).

Marine turtle protection: The Marine Turtle Conservation Strategy and Action Plan for the Western Indian Ocean (1996),which was drafted by countries in the region at Sodwana Bay, South Africa, incorporates among its provisions, the elucidation of social and economic issues related to the protection of marine turtles in the region. This was based on the realisation that economic factors, including the trade in turtle products, have been the most significant factors accounting for their decline, while other anthropogenic problems such as threats at nesting beaches, the opportunistic capture of turtles or harvesting of their eggs, fisheries by-catch associated with trawling operations, and threats from pollution are also seen as contributors to their declining populations (Muir 2005). Management interven-

BOX 11.2. TORTOISESHELL AND TOURISM: HAWKSBILL TURTLES IN THE SEYCHELLES



Hawksbill turtle at sea. © Nils Aukan/WWF-Canon

Fishing hawksbill turtles for their shells has a long history in the Seychelles and has been a significant income earner for local people. Records indicate that at least 83 221 kg of raw shell were exported between 1894 and 1982. Export of shell declined between 1925 and 1940, partly as a result of a decline in the price for shell. Increasing international prices in the 1960s attracted more exports. In 1982, 591 kg of raw shell corresponding to 1 182 hawksbill turtles was exported at a price of ~US$148.7/kg, yielding a gross revenue of US$87 878. Even when the major hawksbill shell importer, Japan, banned imports of tortoiseshell in December 1992, the sale of tortoiseshell items continued in the Seychelles. After 1992, the gross revenue of tortoiseshell artisans from the domestic trade was estimated at US$264 091 (Seychelles Ministry of Industry Statistics). Approximately 40 tortoiseshell artisans (representing 0.15 of the Seychelles workforce at the time) were active in 1993.

In 1993-1994, the Government of the Seychelles made a decision to reverse the decline in marine turtle populations. It compensated 37 hawksbill shell artisans (at an average of US$15 000 per artisan) through a Global Environment Facility (GEF) and Seychelles Government-funded program and retrained them in other trades; they subsequently agreed to sell all their tortoiseshell stocks to the Government. The 2.5 tons of tortoise shell acquired through this process were ceremoniously destroyed and a ban on all consumptive use and harassment of marine turtles was declared in 1994. The total cost of the program, approximately US$805 000, was split between the Seychelles Government and the GEF. Marine turtles have subsequently become an important component in Seychelles tourism, which is the major economic sector of the Seychelles, with gross revenues accounting to a total of US$750 million per year.

Efforts to quantify the economic market value of Seychelles marine turtles to create local incentives for their conservation are on-going. Protection of nesting beaches has resulted in increased nesting within some Seychelles protected areas. It is hoped that, as marine turtle populations recover, their increased abundance will result in more sightings that will facilitate the marketing of marine turtle tours, in the water and on nesting beaches. An equally important consideration will be to make sure that individuals who used to benefit economically from their consumptive use, receive economic benefits from their non-consumptive use (summarised from Troëng and Drews 2004).

tions which followed put in place protective strategies that took the social and economic needs of immediate users into account, such as compensation to stop extractive use, education and ecotourism (Troëng and Drews 2004, Sea Sense 2012). Experience of Seychelles is given in Box 11.2.

Mangrove boardwalk ecotourism: Inclusiveness, benefit-sharing and stakeholder participation in conservation efforts are key considerations in ecotourism efforts. This is evident in **mangrove boardwalk projects** that have been introduced in the WIO to promote ecologically sensitive uses of mangroves through community-based tourism. The projects are managed by women, but also to ensure their inclusion within the diverse uses and needs of conservation practice. The projects have proven a positive intervention for coastal women who having comparatively lower income-earning opportunities than men, and are also key stakeholders in the use of mangroves, both extractive and non-extractive.



Figure 11.1. The Gazi mangrove boardwalk. © José Paula.

In Zanzibar, women around the mangroves of Pete in Menai Bay near Jozani Forest Reserve manage a raised boardwalk inside the mangrove forest. This allows tourists to see the complex communities of flora and fauna found in the ecosystem and revenue earned from the boardwalk is used for community development projects. Such community initiatives provide an incentive to conserve resources, as well as education for local people who live far away from mangrove forests. Other examples are found in Kenya, where women in Gazi and Wasini operate similar projects. Visitors to Gazi Bay are encouraged to visit the women's managed boardwalk. From 2008, the number of visitors increased steadily to reach 1 673 visitors in 2010. The entrance fee is 100 Kenyan shillings (Ksh); students pay less. Some income is acquired though the sale of food at the entrance to the boardwalk at a cost of Ksh 200 per person (UNEP 2011). Cash income from women in Gazi Bay only came from this ecotourism initiative in 2011 (UNEP 2011). At Wasini, the boardwalk project generated US$6 500 from entrance fees in 2002, of which US$2 000 was used to set up a craft shop and US$2 800 given to members as dividends (Zeppel 2006). Although total compliance with unregulated mangrove cutting may not have been achieved consistently amongst the stakeholders, community members acknowledged that capacity-building and the associated financial incentive had promoted compliance with the resource use regulations and management within the mangroves (UNEP 2006).

Benefit-sharing for conservation: Dolphin watching is widely regarded as a sustainable non-consumptive alternative to the direct exploitation of these species. Its added advantage (when compared to turtle conservation) is the recreational opportunity offered to swim with these friendly animals. A study by the Zanzibar Association of Tourism Investors (ZATI) estimated that dolphin trips account for six per cent of all excursions by tourists in Zanzibar. It is estimated that the purpose of approximately 4 800 trips per year are for dolphin viewing and swimming (Gautam 2010). Dolphin tourism has been promoted amongst communities throughout the region, with active engagement of local people, providing some employment in the hospitality industry or as boat operators. Revenues collected by the Menai Bay Conservation Unit (Zanzibar) in dolphin tour boat operations in two of the villages adjacent to the Park at Kizimkazi Dimbani and Kizimkazi Mkunguni between July 2009 and March 2010 b totalled TShs 47 422 000 (~US$34 600) (Gautam 2010). In real terms, however, the benefits do not go to the local communities. Of the entry fee of $3 that the MBCA charges, only $1 is supposed to go back to the 19 villages adjacent to the Park; other returns are shared by boat owners (hotels, restaurants, individuals) and tour guides from outside the area who organize the trips. The proportion of tourists that use local accommodation facilities is also very low, suggesting that most of the benefits accrue outside the communities (Gautam 2010).

Codes of conduct and permits for conservation: Complying with a code of conduct as a social principle in biodiversity conservation constitutes best practice. This is evident in the dugong protection project in Mozambique and boat-based whale watching and shark diving in South Africa. By way of example, boat-based whale watch-

ing is a commercial enterprise in many parts of South Africa, including the KwaZulu-Natal coast, and was legalised in 1998. The industry is regulated by a system of permits whereby permit holders are allowed to operate within designated sections of the coast, usually with only one permit being allocated per coastal section (Turpie and others, 2005, Turpie and Wilson 2011). The South African Boat–based Whale Watching Association (SABBWWA) has developed a Code of Conduct for permitted operators, as well as a training course for guides. The overall number of boat-based whale-watching permits issued by Marine and Coastal Management has steadily increased since 1999, with a maximum of 18 permits issued for 2004 (SAEO 2004). An economic assessment of boat-based whale watching in South Africa established that the industry generated about R45 million in tourism expenditure in 2004 and contributed approximately R37 million to South Africa's gross domestic product per year, with the potential for even greater economic success (SAEO 2004). The potential to increase the number of boat-based whale-watching permits in future was seen to be as great as up to 40 per cent but was to be regulated relative to existing supply and demand, untapped markets and sensitivity to the well-being of the resource (SAEO 2004). Therefore, boat-based whale-watching is seen as a viable industry, adding significant economic value to the marine tourism industry with some conservation benefits (SAEO 2004).

However, several challenges face such ecotourism-initiated strategies in the region. These include the capacity of governance structures to maintain efficiency and compliance in the operations, particularly when management interventions are associated with incentive-driven conservation. Compliance with conservation measures comes under threat when the desired material incentives offered to collaborating local communities are not realised. Inequities in benefit-sharing from ecotourism projects are also problematic, as shown above. In such cases, estimation of the costs of biodiversity loss is needed to inform decision-makers where investment in conservation needs to be prioritised.

THE COSTS OF BIODIVERSITY LOSS

An analysis of replacement costs for biodiversity loss, ie the amount that would have to be spent to replace ecosystem services that would otherwise have been provided by biodiversity, is often invaluable and, in economic terms, very high (Bullock and others, 2008). The loss is actually determined by measuring the economic value of the biological resources and hence, the expected services (UNEP 2011). Dynamite fishing, a pervasive practice in certain parts of the WIO, is indicative of the fact that there are still many challenges regarding compliance in the region, including institutional challenges that are exacerbated by prevailing social and economic contexts. Dynamite fishing causes significant loss of coral reef biodiversity, leading to the loss of the aesthetic value of affected reefs and, hence, their attractiveness for tourism; risk of harm to humans; and eventual loss of livelihoods due to destruction of the resource base (Samoilys and Kanyange 2008, Sea Sense 2012).

Loss caused to an ecosystem by natural factors has also been estimated by costing the value of services lost. For example, "the welfare losses from ecological damage to Zanzibar's coral reefs in **Tanzania** were estimated using the cost of [visitor] trips [to the reef] as a payment vehicle, before and after the actual change in quality occurred. The annual loss from coral bleaching was estimated to be $22.0–$154.0 million, implying $254 to $1,780 per visitor (prices and costs deflated to 1997 USD)" (Conservation International 2008).

MANAGEMENT RESPONSES TO BIODIVERSITY CONSERVATION

Governance regimes that support integrated approaches on the management of marine resources and ecosystems are currently common in the WIO region. Such ecosystem-based management pays attention to both social and ecological dimensions of resource management, and interactions between humans and the environment (Abernethy and others, 2014). Decentralized resource management approaches that embrace community-led initiatives and devolve decision-making processes to the latter (Abernethy and others, 2014) are now accepted, and uphold social benefits, ownership and economic benefit-sharing amongst local communities.

Marine Protected Areas: Marine protected areas (MPAs), which are area-based management systems, incorporate a range of resource use and management arrangements, including no-take zones (NTZ), or temporary or permanent closures. MPAs are the most visible management responses to biodiversity conservation and fisheries management needs (Muthiga and others, 2003, Mwaipopo

BOX 11.3. TOTAL ECONOMIC VALUE (TEV) COMPARED TO REPLACEMENT COSTS



Exploitation of mangrove poles at Gazi Bay. © José Paula.

An economic analysis of the mangrove forest of Gazi Bay in Kenya conducted in 2011 estimated the Total Economic Value (TEV) of these mangroves to be US$1 092.3 $ha^{-1}y^{-1}$. The valuation incorporated the range of goods and services provided by the mangroves, including its contribution to the fishery, provision of building poles, fuel wood, ecotourism, research and education, aquaculture, apiculture, shoreline protection, carbon sequestration, biodiversity and existence value. Direct uses accounted for around 25 per cent of the TEV, indirect uses represented 20 per cent, and non-use values 55 per cent. (UNEP 2011). The replanted area of 7 ha of *Rhizophora mucronata* was valued at US$2 902.9 $ha^{-1}y^{-1}$ which, although debated, is higher than the TEV estimates in the UNEP (2011) study, indicating costs of biodiversity loss to be even greater (UNEP 2011).

2008, Rocliffe and others, 2014). MPAs were introduced largely as state-driven structures for resource governance, followed by fewer privately-managed MPAs (such as Cousin Island, Seychelles, and Chumbe Island Coral Park, Zanzibar). The number of community-based marine parks and reserves are currently increasing, each with different ecological, social and economic objectives and benefits. This has led to increasing experience in MPA management, evolving from initial top-down management initiatives with negative social costs, human exclusion and diminished local livelihoods, to efforts that promote inclusive, co-management approaches and decision-making platforms across different levels of MPA governance (Samoilys and Obura 2011).

The area of currently designated MPAs in the region as provided in Table 11.1 and illustrates the level to which WIO countries are achieving Target 11 of the AICHI Biodiversity Conservation targets. These targets stipulate that by 2020, at least 17 per cent of terrestrial and inland water areas and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscape and seascape' (Convention on Biological Diversity Strategic Plan 2011-2020).

The benefits of co-management approaches in MPA management are becoming increasingly clear, particularly as studies in the region address the multiple dimensions of various ecosystems, covering biological, cultural, economic and political concerns, and empowering communities through collaborative and integrated conservation efforts (Granek and Brown 2005, Westerman and Gardner 2013). The social benefits include reduced costs for management; reduced conflict between stakeholders, especially on access issues and livelihood sustainability; and increased legitimacy as well as acceptance of MPAs by promoting local ownership (Granerk and Brown 2005). MPAs have also been documented to provide economic

Table 11.1. Percentage of surface area under protection in the WIO countries (2012). Source: World Bank databank website (2014).

	Country	% surface area under protection in 2012*
1	Comoros	33.5
2	Kenya	20.5
3	Madagascar	-
4	Mauritius	1.0
5	Mozambique	0.2
6	Reunion	-
7	Seychelles	8.6
8	Somalia	12.8
9	South Africa	9.4
10	Tanzania	30.4

benefits in the long run, such as increased catches per unit effort following conservation measures, all of which have alleviated some negative perceptions regarding displacement from traditional fishing grounds (Cinner and others, in press).

More recent initiatives on area-based conservation are in the form of **Community Conservation Areas (CCAs)** or **Local Marine Management Areas (LMMAs),** which embrace what are regarded as the most socially-responsive structures of governance (Rocliffe and others, 2014). These areas, which are governed by community-based systems, elicit a sense of local ownership, and are credited as being grounded in systems that 'appear to be embedded in the wider social-cultural context of the local communities' (Westerman and Gard-

BOX 11.4. INCLUSION, COMPLIANCE AND BENEFITS



Sign of Moh'eli Marine Park in Comoros. © Chris Poonia.

Moh´eli Marine Park in the Comoros Islands has been operational since 2001 and was designed as well as implemented using a co-management approach. With a land surface area of 212 km², the park is fringed by alternating sandy and rocky beaches with intermittent mangrove forest along the south-eastern and southern coast. During its establishment, it was clear that financial, technical, and personnel assets of the Comorian government were inadequate to address the issues required for conservation. It was noted that one of the ways to succeed should be to rely on the participation of the

local communities. Also, in order to promote conservation at the community level, it was ensured that local people would benefit materially from areas selected for protection. In addition, it was realized that those who would be enticed to encroach on the protected areas, or who would oppose their management as protected areas, should receive legitimate alternative livelihoods. Thus, community members were included in the processes of park boundary delineation and guideline formulation, and were made responsible for coordinating monitoring as well as enforcement within the park. Consensus was reached among the national and regional environmental management authorities and representatives of the villages adjacent to the park and local community organizations, specifically village environmental associations, and fishers' associations. Being a largely patriarchal society (although matrilineal), women were not consulted at the beginning. Yet, since they were key stakeholders in resource extraction, the project recognized that their participation was critical to the long-term success of conservation efforts in the Comoros.

The proposed goals of the park and its core reserves were to protect Comorian biodiversity and improve local as well as regional fisheries. Reserve locations were determined using anecdotal data from fishermen, and sites were selected to represent diversity of regional habitat types (rocky shores, mangroves, channels, reefs, sand flats, sea-grass beds and islets). Sites of biological importance were also reserve targets. They included juvenile fish habitats, spawning grounds, and rare marine habitat types.

Strengths of this approach included the following:

1. Integrating education, use of local knowledge, capacity building, and community commitment. This partially mitigated lack of resources, weak government enforcement and inadequate scientific data, but also created local interest.
2. Use of local eco-guards for each of the ten adjacent villages to police the park, their training and the monitoring approach created a communication network previously absent among neighbouring villages. It fostered trust among villagers previously wary of each other.
3. Co-management empowered community leaders and circumvented traditional hierarchical political structures.
4. Traditional knowledge served as a substitute for limited ecological data and provided an impetus for local monitoring to enhance future conservation efforts, and greater village participation.

Some Lessons: Building trust and achieving consensus for conservation purposes is time-consuming and generates significant local support. The initiative involved daily monitoring by the entire community and generated material benefits from an improved ecosystem (summarized from Granek and Brown 2005).

ner 2013). LMMAs are managed for sustainable use rather than conservation per se, employing a range of management techniques, including periodic closures, gear restrictions, species-specific reserves and permanent, fully protected (closed) no-take zones (Rocliffe and others, 2014). LMMAs are becoming increasingly recognised as creating higher levels of social capital, local responsibility for resources and a commitment to resource ownership (Hicks and others, 2009). CCAs or LMMAs are now found in nine countries in the region. However, WIO countries are acknowledging the complexities of governing the marine environment, taking into account its multiple uses, their different levels of power, and gaps in the knowledge of processes that affect biodiversity such as climate change. Networking is needed to develop a multidimensional approach to marine conservation. Collaborative fisheries and mangrove management areas or networks provide examples of this (Sesabo 2007).

These facts reveal how MPAs have, as management responses, in some ways managed to provide resource protection within largely acceptable measures for management; partnerships between diverse stakeholders (managers, users and others), which are critical for management success; and strategies that promote community ownership with material incentives for local people (Muthiga and others, 2003). Strengths of such community-based strategies include the provision of ownership and responsibilities across horizontal scales. With further regard to scale, many outcomes are, however, challenged by the low capacities of coastal communities as primary stakeholders. In many cases, multiple stakeholders with different uses and powers of access to resources, compete with or override compliance procedures. Sometimes local communities have also failed to address resource degradation when caused by factors beyond their capacity to deal with or control, such as pollution, oil spills and climate change.

BOX 11.5. STRATEGIC ALLIANCE - KURUWITU COMMUNITY MANAGED CONSERVATION AREA (KCMCA), KENYA



Members of the Kuruwitu Conservation and Welfare Association with the candidates of WIO-COMPAS Level 2 and Assessors in Kikambala, 2011. © Peter Chadwick.

The Kuruwitu Community Managed Conservation Area (KCMCA) was established in 2011 by the Kuruwitu Conservation and Welfare Association (KCWA) of Kenya with support from the East African Wildlife Society (EAWLS). The KCMCA was Kenya's first community-based marine protected area. It brings together artisanal fishers and private beach residents along the Kuruwitu-Vipingo coastline in Northern Kenya. The KCMCA's goal is to promote sustainable use and management of coastal and marine resources in the area. It covers six fish landing sites: Mwanamia, Kijangwani, Kuruwitu, Kinuni, Vipingo and Bureni, in Kilifi County. Stakeholders voluntarily agreed to close some of their fishing grounds for conservation with monitoring for use of illegal fishing gear. Spanning a wide area, the KCMCA stakeholders are able to oversee the multiple aspects and processes that impinge on the environmental health of their coast, unlike initiatives that focus on a small area. Ecological monitoring surveys by the Wildlife Conservation Society (WCS) have revealed fish population recovery over a relatively short space of time (McClanahan, unpublished data). Fishery recovery has lately attracted interest from various fishing communities who are now recognising benefits of CCAs in addressing threats to their marine environment, ie overfishing and the use of destructive fishing methods. (Summary from Maina and others, 2011).

RECOMMENDATIONS FOR POLICY

Conservation initiatives in the WIO illustrate that, unless economic and social aspects of biodiversity conservation are addressed more comprehensively, it is highly likely that degradation to the marine environment will continue, to the detriment of humanity and society. At the same time, management interventions have revealed that appropriate options are available on the ground, especially in the form of co-management and community-based protected areas. However, these need to be supported and enhanced to address the challenges imposed upon them by economic and social contexts, as well as by management and institutional issues. Therefore, policy decisions informed by research are needed on relevant approaches and interventions for biodiversity

conservation that fully address its combined economic, social and ecological implications. The following is recommended:

• It is important that ecosystem-based management interventions be rolled out to promote co-management approaches which are inclusive and participatory.

• The capacity of stakeholders needs to be enhanced to respond effectively to the multi-dimensional challenges of conservation management, particularly its human, technological and institutional aspects.

• More comparative research is needed in the region to disseminate good practices and innovative methods such as those applicable to species-specific conservation.

• Research and integrate costing of biodiversity and ecosystem services need up-scaling into policy to establish the cost-benefit biodiversity conservation and biodiversity loss.

• Decision-makers as well as managers should find ways to incorporate ecosystem services that lack ready market values, such as customary and heritage values, as incentives for conservation.

References

Abernethy, K.E., Bodin, O., Olsson, P., Hilly, Z. and Schwarz, A. (2014). Two steps forward, two steps back: The role of innovation in transforming towards community-based marine resource management in Solomon Islands. Glob. Environ. Chang. 28. 309–321

Bullock, C., Kretsch, C., and Candon, E. (2008). *The Economic And Social Aspects Of Biodiversity. Benefits and costs of Biodiversity in Ireland*. The *Stationery Office*.

Cinner, J.E. and Aswani, S. (2007). Integrating customary management into marine conservation. *Biol. Cons. 140(3), 201-216*

Cinner, J.E. and David, G. (2011). The Human Dimensions of Coastal and Marine Ecosystems in the Western Indian Ocean. *Coast.Manage. 39(4), 351-357*

Cinner, J.E. Daw, T., Huchery, C., Thoya, P., Wamukota, A., Cedras, M., and Abunge, C. (in press). Winners and losers in marine conservation: Fisher's displacement andlivelihood benefits from marine reserves. *Soc. Nat. Resour. 27(9), 994-1005*

Conservation International (2008). *Economic Values of Coral Reefs, Mangroves, and Seagrasses: A Global Compilation*. Center for Applied Biodiversity Science. Conservation International. Arlington, USA

CBD (2010). *Global biodiversity Outlook 3*. Montréal. Available at http://www. cbd. int/GBO3

Gautam, A., (2010). *Ecotourism in Menai Bay Conservation Area, Zanzibar: Recommendations for Improvement in the Dolphin Tourism Industry*. Coastal Resources Center, University of Rhode Island. Narragansett

Granek, E.F., and Brown, M.A. (2005). Co-Management Approach to Marine Conservation in Mohéli, Comoros Islands. *Conserv. Biol.* 19(6), 1724–1732

Grillo, C. (2011). Institutional Interplay in Networks of Marine Protected Areas with Community- Based Management. *Coast.Manage.* 39(4), 440-458

Harris, A. (2007). "To live with the Sea" Development of the Velondriake Community - Managed Protected Area Network, Southwest Madagascar. *Madagascar Conservation And Development* 2(1)

Hicks, C.C., McClanahan, T.R. Cinner, J.E. and Hills. J.M. (2009). Trade-Offs in Values Assigned to Ecological Goods and Services Associated with Different Coral Reef Management Strategies. *Ecol.Soc.* 14(1), 10 available at http://www.ecologyandsociety.org/vol14/iss1/art10/

Kulindwa, K. and Lokina, R. (2013). The Winners and Losers in the Finfish Trade on Mafia Island: A Value Chain Analysis. *Western Indian Ocean J. Mar. Sci. 12* (2)151-168

Kulindwa, K., Sosovele, H. and Mgaya, Y.D. (2001). *Socio-economic dimensions of biodiversity loss in Tanzania*. Dar es Salaam University Press

Maina, G.W., Osuka, K. and Samoilys, M. (2011). Opportunities and challenges of community-based marine protected areas in Kenya. CORDIO East Afica. Mombasa, Kenya in, *CORDIO Status Report 2011*. (eds. Obura, D.O. and Samoilys, M.A.) CORDIO East Africa. Mombasa, Kenya

Masalu, D.C.P., Shalli, M.S. and Kitula, R.A. (2010). Customs and Taboos: The role of indigenous knowledge in the management of fish stocks and coral reefs in Tanzania. *Coral reef targeted research, World Bank/GEF and Institute of Marine Sciences, University of Dare s Salaam*

Mathieu, L., Langford, I.H. and Kenyan, W. (2000). Valuing Marine Parks in a Developing Country: A Case Study of

the Seychelles. *Environ. Dev. Econ.* 8(02), 373-390

Muir, C. (2005). *The Status of Marine Turtles in the United Republic of Tanzania, East Africa.* Sea Sense (Tanzania Turtle and Dugong Conservation Programme)

Muthiga, N., Maina, J. and McClanahan, T. (2003). *The Effectiveness of Management of Marine Protected Areas in Kenya. International tropical marine environment management symposium: Manila, Philippines*

Mwaipopo, R. (2008). *The Social Dimensions of Marine Protected Areas: A Case Study of the Mafia Island Marine Park in Tanzania*. Samudra Monograph. Chennai: International Collective in Support of Fishworkers. Chennai, India

Rocliffe, S., Peabody, S., Samoilys, M. and Hawkins, J.P. (2014). Towards A Network of Locally Managed Marine Areas (LMMAs) in the Western Indian Ocean. *PLoS ONE* 9(7), e103000

SAEO (2004). *Marine and Coastal Resources. In South Africa Environmental Outlook. A report on the state of the environment.* Department of Environmental Affairs and Tourism, Pretoria

Salagrama, V. (2006). *Trends in poverty and livelihoods in Coastal Fishing communites of Orissa State India*. No 490. FAO, Rome

Samoilys, M.A. and Kanyange, N.W. (2008). *Assessing links between marine resources and coastal peoples' livelihoods: perceptions from Tanga,* Tanzania. IUCN/CORDIO

Samoilys, M.A. and Obura, D. (2011). *Marine conservation successes in East Africa*. CORDIO Status Report. CORDIO East Africa. http://www.cordioea.org

Sea Sense (2012). *Community-based Conservation of threatened marine species and habitats in Tanzania*. Annual Report

Sesabo, J.K. (2007). *Marine Resource Conservation and Poverty Reduction Strategies in Tanzania*. Springer Science and Business Media

Sultan, R. (2012). *An economic valuation of the marine and coastal ecosystem in Mauritius. The Case of Baie du Tombeau – Pointe aux Sables coast*. Western Indian Ocean Marine Highway Development and Coastal Contamination Prevention Project, Indian Ocean Commission and Ministry of Environment and Sustainable Development, Mauritius

Sunde, J. and Isaacs, M. (2008). *Marine Conservation and Coastal Communities: Who Carries the Costs? A Study of Marine Protected Areas and Their Impact on Traditional Small-scale Fishing Communities in South Africa*. International Collective in Support of Fishworkers, India

Tobey, J. and Torrel, E. (2006). Coastal poverty and MPA management in Mainland Tanzania and Zanzibar. *Ocean Coast. Manage.* 49(11), 834-854

Troëng, S. and Drews, C. (2004). *Money Talks: Economic Aspects of Marine Turtle Use and Conservation*. WWF-International, Gland, Switzerland. http://www.panda.org

Turpie, J. and Wilson G. (2011). *Cost/benefit assessment of marine and coastal resources in the Western Indian Ocean: Mozambique and South Africa. Agulhas and Somali Current Large Marine Ecosystems Project*. South Africa

Turpie, J., Savy, C., Clark, B. and Atkinson, L. (2005). *Boat-Based Whale Watching in South Africa: An Economic Perspective*. Department of Environmental Affairs and Tourism: Marine and Coastal Management. South Africa

UNEP (2006). *Africa Environment Outlook 2*. Nairobi, Kenya. United Nations. Environment Programme

UNEP (2011). *Economic Analysis of Mangrove Forests: A case study in Gazi Bay, Kenya*. UNEP

UNEP (2012). *Oil and Gas Exploration in the South Western Indian Ocean region*. Conference paper. The Seventh Meeting of Contracting Parties to the Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Western Indian Ocean (Nairobi Convention). Maputo, Mozambique 10-14 December. UNEP(DEPI)/EAF/CP.7/Inf/11

UNEP (2013). *Africa Environment Outlook 3. Summary for Policy Makers*. UNEP.

UNEP-WCMC (2011). *Marine and ecosystem services: Valuation methods and their practical application*. UNEP-WCMC Biodiversity Series. No 33

Westerman, K. and Gardner, C.J. (2013). Adoption of socio-cultural norms to increase community compliance in permanent marine reserves in southwest Madagascar. *Conservation Evidence* 10, 4-9

Wood, A., Stedman-Edwards, P. and Mang, J. (eds.) (2000). *The Root Causes of Biodiversity Loss. World Wildlife Fund and Earthscan Publications Ltd., London, UK*

World Bank (2012). *World Development Indicators, 2012*. Washington, D.C.

World Bank (2014). *World Bank databank*. http://www.tradingeconomics.com/tanzania/marine-protected-areas-percent-of-total-surface-area-wb-data.html

Zeppel, H. (2006). *Indigenous Ecotourism: Sustainable Development and Management*. Vol 3. Cabi



12
Summary on Marine Biological Diversity

Michael H. Schleyer

Opposite page: Marine biodiversity in the WIO is found within varied habitats such as coastal dunes, beaches and nearshore rocky reefs. © Michael H. Schleyer.

This Part of the State of the Coast Report presents an **Assessment of Marine Biological Diversity and Habitats** in the Western Indian Ocean. Its scope is thus wide and the various chapters deal with the multiple ecosystems found in the region, as well as the full diversity of biota they support. Some of the latter are found in a number of environments at different stages of their life cycle and thus warrant inclusion in a number of chapters; the best example is that of turtles which nest on beaches, feed on reefs, seagrass beds or in pelagic waters, and traverse the open ocean in their movements. For completion, the Part also includes a chapter on human dependence on the region's biodiversity.

The region is endowed with ecosystems known for their rich biodiversity. While coral reefs are considered amongst the most biodiverse of habitats, tropical and subtropical estuaries, mangroves, seagrass beds and nearshore environments are also well-endowed with prolific lifeforms. There is considerable interdependence between these ecosystems as they mutually provide shared biota with feeding, breeding and nursery grounds. Thus, while they have been given separate consideration in the preceding chapters, this interdependence must be born in mind: a threat to one will have a cascade effect on the others.

Rocky shores are robust and not particularly vulnerable but the benthic and fish resources associated with them are, and are under pressure. These resources include economically important invertebrates such as octopus and fish, for example blackfish and yellowtail. **Sandy beach substrata**, on the other hand, are more dynamic, making beach and dune habitats more vulnerable. Degradation of these results from erosion, sedimentation and sand mining, and adds pressure to their associated fauna. In this case, iconic turtles are most under threat. Sand mining for heavy minerals is of growing concern, in particular, as it affects not only the mined dunes but also the coastal belt where the associated infrastructure is installed, the local hydrology as sand mining places demands on water resources, and the nearshore environment where transhipment of the mined product occurs. Sea level rise is also expected to affect sandy beaches in the medium- to long-term.

Extensive but shrinking **mangrove forests** in the region are also vulnerable as they and their associated fauna are heavily harvested. The effects of climate change, eg sea level rise, flooding, sedimentation and increasingly severe storms are further threatening mangroves. There are nevertheless extensive, fairly intact mangroves at various locations along the East African shoreline and they merit careful management and conservation. **Seagrass beds**, in turn, are noted for their productivity, yet the extent of their distribution in the WIO is uncertain and none are protected in their own right unless secondarily included in MPAs. They are often associated with coral reefs and provide important nursery grounds for estuarine and reef fauna. **Salt marshes** are limited in distribution to the southern subtropical region in the WIO.

Muddy shores and estuaries are dynamic systems under threat from direct perturbation and that which

occurs in the upper reaches of river catchments. Maintenance flows have been disrupted in many cases, and changes in land use have compromised their integrity. Historical records indicate that they are shrinking in area with a concomitant reduction in habitat for the species they harbour.

Coral reefs probably constitute the most vulnerable of the WIO ecosystems as they are prone to bleaching caused by elevated temperatures associated with global warming and climate change. Some parts of the region lost 50-90 per cent of their coral cover during the 1998 bleaching event and most WIO reefs are considered at risk from this and human perturbation. Additionally, reef resources are in high demand. Due to their vulnerability and importance, they have received concomitantly more attention from the media, public, scientists and authorities, but the threats are still growing. Nevertheless, there are a number of initiatives to establish more MPAs in the region; other recommendations for their conservation are dealt with below.

Relatively little information is available on **shelf sediments** in the WIO apart from areas that support demersal fisheries. Areas known to harbour productive muddy sediment derived from fluvial input are known to be diminishing; this is attributable to changes in river catchments and a reduction in maintenance flows, and results in a commensurate decline in their fisheries. Direct perturbation of the shelf sediments is believed to be caused by bottom-trawling and terrestrial pollution. Knowledge of this environment is bound to improve with growing interest in offshore prospecting on the continental shelf. However, proprietary information of this nature is usually restricted and not freely available to scientists or the public.

Deep-sea phenomena are poorly known, in this case because WIO governments have limited capacity to engage in costly deep-sea research, or to effectively manage the outer reaches of their Exclusive Economic Zones. The global move towards offshore prospecting and the adoption of Blue Economies will bring changes in this regard. Internationally-sponsored (CBD, FAO and IMO) efforts are also underway to protect representative and sensitive deep-sea areas.

A number of species in the WIO are CITES-listed as **vulnerable, threatened or endangered**, including seagrasses, corals, certain molluscs, sea cucumbers, certain rays, sharks, fish, turtles and marine mammals. The principal reasons for their threatened status are habitat loss due to human perturbation and overexploitation. A few species are showing encouraging signs of improvement with conservation measures but most face possible extinction this century unless there is urgent remedial action. Recommended measures for their improved conservation are dealt with below.

Socio-economic information relevant to the conservation of marine species and habitats in the WIO clearly reveals that degradation of the marine environment and an associated loss of resources will continue unless economic and social issues are addressed more fully. Complex issues are involved, including increasing coastal urbanisation, a concomitant erosion of traditional fishing rights, overexploitation of resources due to human population expansion, government ignorance of traditional management systems, and a loss of livelihoods with the promulgation of MPAs without the provision of alternatives. Co-management and community-based protected areas have proven effective in the Comoros, Kenya, Tanzania and Madagascar, introducing sustainability in resource extraction and providing alternative livelihoods, but need greater management and institutional support.

Capacity issues were raised by some authors of the preceding chapters as there is concern that WIO biota and habitats are receiving neither the required attention nor protection. However, **capacity-building** was here considered in the narrower context of the regional skills and expertise needed to resolve issues such as regional taxonomy and guidelines for management; capacity-building, as such, is dealt with more extensively in Chapter 35.

In conclusion, the region has a diversity of marine resources but much of this natural capital is either threatened or declining. However, the authors of the chapters in this section have made **recommendations** to mitigate or reverse the current negative trends and the following points have been compiled to summarise these, with some elaboration where needed.

• **Raised awareness is required on a number of fronts.** Resource users and managers, the public, politicians and the authorities need to be better informed of the value and vulnerability of the WIO's natural marine capital. This is not to say that these parties are necessarily diffident or negligent in their outlook regarding the marine environment and its resources, but rather that the complexity of ecosystems is such that they are difficult to understand and even scientists are still unravelling their intricacies. Better communication of the known facts is

thus needed in a form comprehensible to the public and authorities.

• **Increased funding for research.** Knowledge is power, hence the need for a greater understanding of WIO coastal and marine ecosystems and resources for their improved management. While WIO countries do invest in marine science, the preceding chapters have revealed that the region is failing to reverse negative trends in its marine resource and environmental management; more research is needed and this requires funding.

• **Increased investigation of shelf sediments and deep sea phenomena.** As stated, little is known of the offshore habitats and resources in the EEZ of WIO countries. Increased research is needed in this area to prevent deleterious outcomes from current prospecting initiatives and growing WIO expectations of a Blue Economy.

• **Increased funding for marine resource management.** Environmental and resource-related issues are not always given timeous attention by the relevant agencies because of poor funding. The capacity is there but cannot be mobilised and this could be remedied with improved funding.

• **Capacity building** is needed to promote regional skills and expertise on threatened species and their protection. Graduate training within appropriate fields is needed, in particular.

• **WIO Threatened Species Task Forces** were suggested as a means to mobilise capacity to deal with threatened or declining marine species and habitats, or those in need of special attention or protection. A regional Coral Reef Task Force (CRTF) already exists but similar initiatives are needed for the other WIO coastal and marine ecosystems. The WIO Mangrove Network fulfils some functions of a task force in this regard.

• **National and regional integration and cross-sectorial cooperation** will facilitate the above and also provide a more coherent approach to the management of shared, trans-boundary stocks.

• **Alternative livelihoods.** Viable alternative livelihoods are needed to alleviate pressure on overharvested resources, or where traditional fishing rights are lost to conservation or commercial initiatives. These can best be provided by material involvement in such ventures, in terms of employment opportunities and co-management.

• **Alternative food sources/equivalents** should be sought for coastal populations to alleviate overfishing where alternative livelihoods are not an option.

• **Value-adding** would improve the benefits derived from existing harvests, reducing the need for ever-increasing extraction and overfishing. Regional successes and the latest technology should be shared in this regard.

• **Monitoring the harvest of vulnerable species.** Catch monitoring of vulnerable species would provide valuable information on trends in their stock and harvest so that remedial action could be taken before they entered a precipitous decline or became endangered. **Targeted research is needed on such species.**

• **MPAs and closures** provide a valuable means to protect or conserve resources, as well as to restore stocks. However, such initiatives should only be undertaken in close liaison with all affected parties, otherwise they often harm local communities, causing opposition and discontent, leading to their failure.

• **Prioritisation of areas for protection.** The selection of areas in need of protection is important in terms of suitability, size and spacing. Amongst others, consideration must be given to a host of questions concerning the biodiversity of a proposed MPA, its suitability for targeted species, the potential for beneficial spill-over to surrounding areas, the effects on local communities, and the level of their buy-in and involvement in management of the MPA.

• **Identification of areas of resilience.** Vulnerable species vary in their sensitivity to perturbation, corals providing a classical example in their spatially variable response to elevated temperatures associated with global warming. Resilient communities need to be identified as they warrant special consideration for protection to provide refuge communities with restocking potential if their demise occurs elsewhere.

• **Restoration and rehabilitation.** Prevention is better than cure and it is preferable to avoid environmental degradation occurring to a level at which restoration or rehabilitation becomes necessary. However, the need for restoration and rehabilitation does arise on occasions, but both are costly and have proven largely impractical on an ecologically realistic scale. They thus must remain a last resort, usually to provide nodes of growth or corridors for expansion of the affected community/ies.

• **Sustainability** must be an imperative in the harvesting of renewable coastal and marine resources. The Ecosystem Approach to Fisheries rather than discrete management of species in isolation should be employed to avoid collateral fishing damage to the environment and

maintain both sustainability and ecosystem health.

• **Compliance with CBD biodiversity protection targets by 2020.** All WIO countries have adopted the CBD target of conservation of 10 per cent of their coastal and marine territory in protected areas by 2020. To date, overall compliance with this target in the WIO stands at 2 per cent and its governments must take cognisance of the need to speed up this process.

Part IV
Assessment of Major Ecosystem Services from the Marine Environment

Jared Bosire

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13
Scientific Understanding of Ecosystem Services

Jared Bosire

Opposite page: Mangrove clearing for port construction at Lamu, Kenya. © Mike Olendo.

HUMAN DEPENDENCE ON ECOSYSTEM SERVICES

Ecosystem services (Fig. 13.1) are the range of benefits that people obtain from ecosystems (Biggs and others, 2004). While the emphasis in scientific discourses has been more often on goods, which provide direct benefits to humans, these services are more than just goods, and include critical buffering, regulating and life-supporting services or processes, which are commonly neglected or taken for granted by society (Shackleton and others, 2008). Ecosystems also provide less tangible benefits such as recreational, aesthetic, cultural and spiritual values that are important in fulfilling people's emotional and psychological needs (UNEP/IISD 2004). These services are also produced by modified, agricultural and urban ecosystems, albeit with particular trade-offs between specific services.

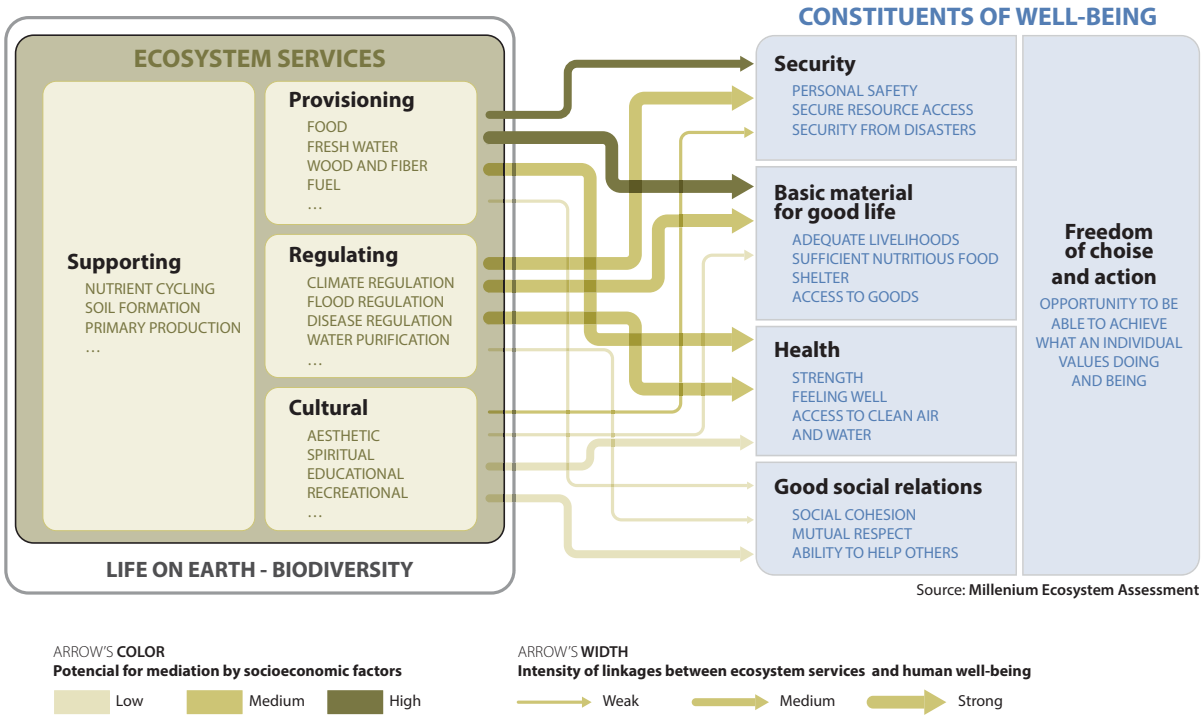


Figure 13.1. Different categories of ecosystem services and their contribution to human well-being. Source: MEA 2005.

Humans have always depended upon natural ecosystems to supply a range of services useful for their survival and well-being. The level of dependency has however kept evolving over the years in consonance with the state of development in different countries. People in least developed countries are thus more directly dependent on ecosystem services making them highly vulnerable when natural ecosystems are degraded (WRI 2005).

The main constituents of human well-being derived from ecosystem services include security (which deals with personal safety and security from disasters eg coastal protection), materials for a decent life (livelihoods and shelter), health (eg feeling of well-being and access to clean water) and good social relations (social cohesion, respect and ability to help others), which are all underpinned by freedom of choice and action (MEA 2005).

Some services are of a public nature with an underlying assumption that such are available to everyone (low exclusivity) eg clean air, good view of nature, coastal protection, clean beaches. Two general characteristics underpin such public services (Bolt and others, 2005; Fig. 13.2):

i) Everybody can use them without depleting their availability for others (economists call this 'non-rivalry') and

ii) It is very difficult, technically, to prevent people from using them. In other words, public goods are 'non-excludable'.

The problem with public goods is that everyone has a relatively small incentive to provide the good. Therefore people will tend to free-ride on others providing it and enjoy it for free. As a consequence, public goods are generally under-provided and state action is usually required to solve the problem (Bolt and others, 2005).

Brown and others (2008) observed that various trends and patterns underpin access to utilization of ecosystem services especially by the poor in society, and include the following:

• The poor have had minimal impacts overall on changes in ecosystem services and have also received a disproportionately small share of the benefits of ecosystem services in coastal and marine systems. However, in particular locations, the unsustainable use of these services by poor stakeholders with limited options is a major driver of degradation of ecosystem services.

• The poor prioritise provisioning services over all other ecosystem services, and identify the most important benefits from these services as being cash, food and employment, which are not explicitly and separately considered in the Millennium Assessment conceptual framework (MEA 2005).

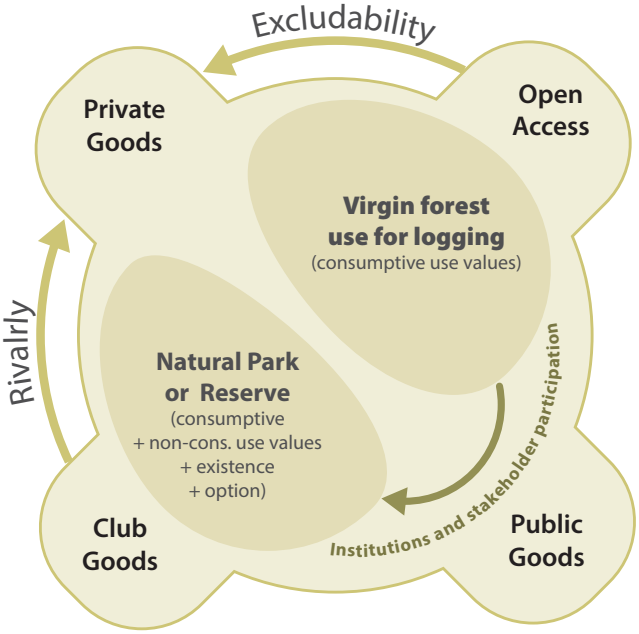


Figure 13.2. Public and private goods: Rivalry and excludability. Source: Bolt and others, 2005.

• Many other ecosystem services are not of direct relevance to the poor and have no straightforward or simple role in alleviating poverty. Supporting services for the provisioning and regulating services are recognized by poor people. Very often their role in protecting livelihoods is extremely important, for example providing the basis to support provisioning services, in protecting homes, providing clean water and moderating environmental risks. However, the role of supporting services in active poverty alleviation is not direct and sometimes much less clear than provisioning services.

• There are few examples of mechanisms to enhance ecosystem services and alleviate poverty; and very little precise information to show exactly how ecosystem services can contribute towards poverty alleviation.

• There is evidence of shifting patterns of dependence on ecosystem services and shifting vulnerabilities to change in ecosystem services. This relates to where poor people live – for example, increasing numbers of people are concentrated in urban coastal areas in many countries and regions; how people construct their livelihoods – related to patterns of diversification and specialisation and movements in and out of fishing; processes of globalisation and changing access and exploitation, particularly penetration by global markets (eg aquaculture transforming coast-

line, and industrial fishing exploiting sea), each of which potentially puts poor people at risk (Brown and others, 2008).

LINK BETWEEN DRIVERS OF CHANGE, ECOSYSTEM SERVICES AND HUMAN WELL-BEING

The way that coastal ecosystem services are distributed and degraded is currently making the poor poorer, more vulnerable and more marginalized thus undermining their ability and incentive to contribute to preserving the ecosystems services that sustain them (Newton and others, 2007).

The Millennium Ecosystem Assessment (MEA 2005) and others (Jackson and others, 2001, Donner and Potere 2007, Adger and others, 2005) have demonstrated how ecosystems and the services they support are under increasing pressure from a range of drivers; they are being seriously degraded; and, if trends persist, will be unable to support human well-being as in the past. Future pressures from population increases in coastal areas, pollution, aquaculture development, greater human mobility, and the spread of invasive species are likely to further exacerbate these trends (Brown and others, 2008). More recently, climate change has exacerbated the impact of anthropogenic pressures to aggravate degradation of natural resources with a resultant impact on dependent livelihoods (Goreau and others, 2000, Obura 2002, McClanahan and others, 2005, Bosire and others, 2010, IPCC 2014). Implications of climate change on livelihoods in the WIO region are elaborated on in Box 13.1.

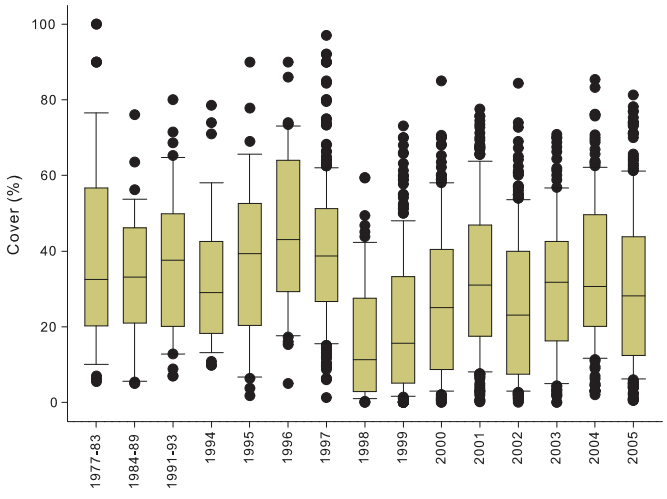


Figure 13.3. Yearly temporal coral cover trends throughout the Indian Ocean region (Ateweberhan and others, 2011).

Past elevated sea surface temperature (SST) episodes have led to widespread coral bleaching in the region (McClanahan and others, 2005, Obura 2002, Ateweberhan and others, 2011) and thus compromised supporting and regulating services provided by coral ecosystems. Fig. 13.3 shows the impact of the bleaching especially in 1998 immediately after the ENSO event and recovery post-event. During this phenomenon, SST was elevated by 1°C, which precipitated widespread coral bleaching.

Brown and others (2008) noted that many of the drivers of change within marine and coastal social-ecological systems lie outside the strict boundaries of the coastal zone and seascape. They concern global economic processes, markets and trade; economic policy and environmental governance; and land use and resource management in terrestrial systems (Maina and others, 2013). They therefore recommended that there is a critical need to understand the interactions between drivers and impacts of change across coastal, marine terrestrial and global systems in order to better devise and implement integrated policy and responses to support ecosystem services and poverty alleviation (Fig. 13.4).

From the Global Living Plant Index (WWF and ZSL 2014), it is clear that the overall integrity of ecosystems has been deteriorating over time despite huge global conservation efforts. A decline of 52 per cent of the earth's species has been reported since 1970, while for marine biodiversity, a reduction of 39 per cent occurred within the same period (Fig. 13.5). This has been compounded by the ever-increasing global ecological footprint on natural resources (Fig. 13.6), which has exceeded the earth's bio-capacity (WWF and ZSL 2014).

AMELIORATING LOSS/IMPOVERISHMENT OF ECOSYSTEM SERVICES

Numerous international initiatives are focusing on restoring ecosystem services in areas affected by land-use changes and biodiversity loss to ensure return of lost or impoverished services (Bosire and others, 2004, Bosire and others, 2008, GEF 2009, Tengberg and Torheim 2007). There is also a growing interest in regulating ecosystem services related to climate change, such as carbon sequestration in different types of ecosystems, including opportunities to protect carbon stocks in tropical forests, eg through Reduction of Emissions from Deforestation and forest Degradation (REDD)

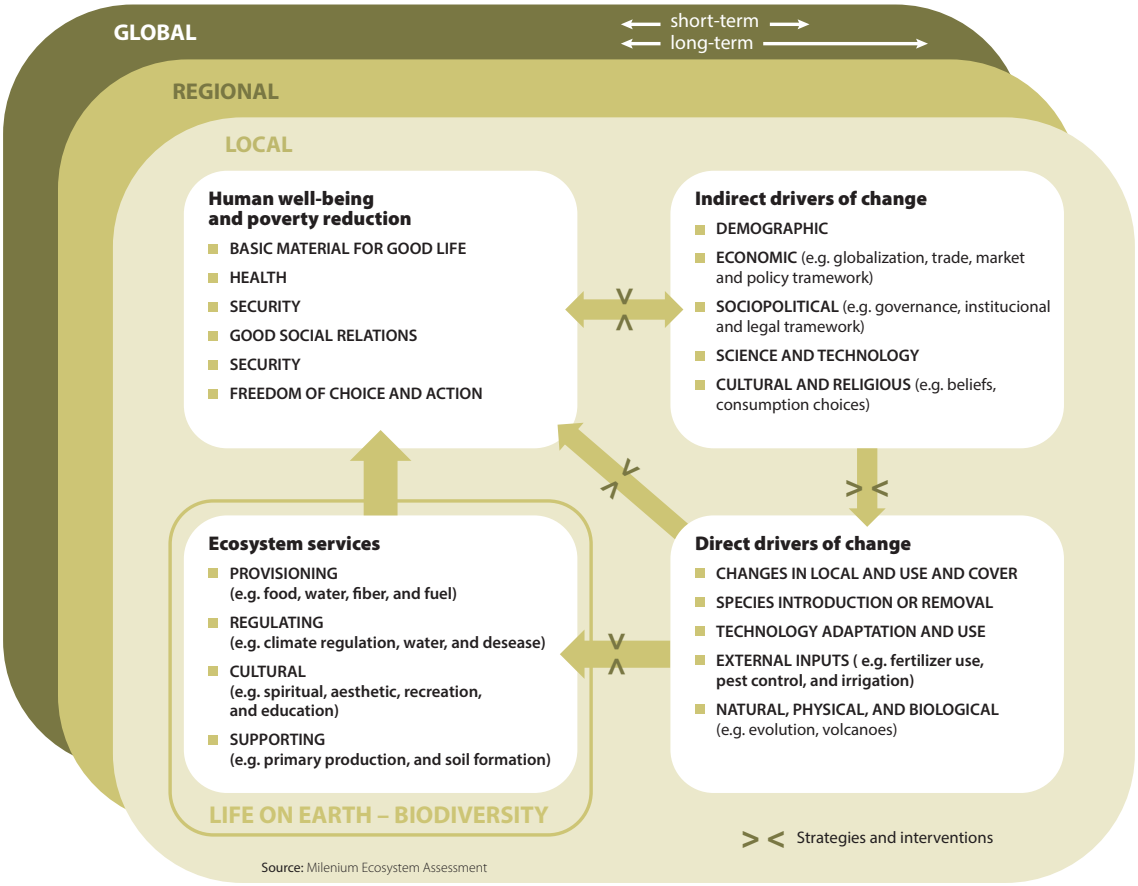


Figure 13.4. Link between ecosystem services, human well-being and drivers of ecosystem change (MEA 2005).

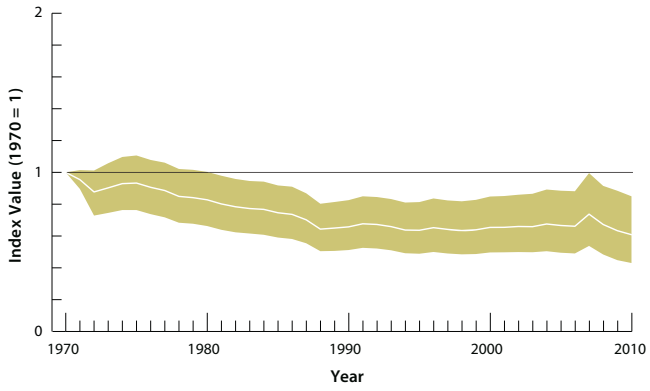


Figure 13.5. Marine Living Planet Index (WWF and ZSL 2014).

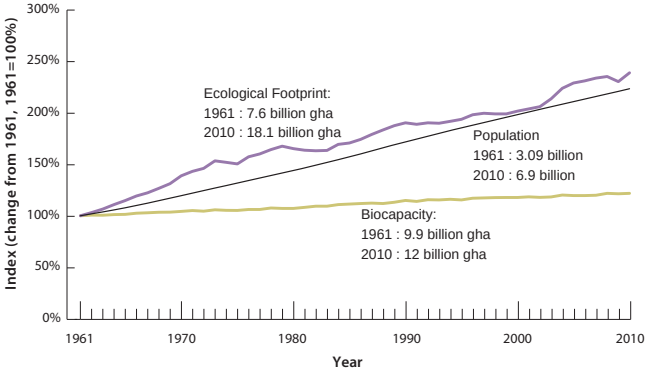


Figure 13.6. Population growth driving the global ecological footprint (WWF and ZSL 2014)

(Miles and Kapos 2008, Donato and others, 2012). An example of a Payment for Ecosystem Services (PES) scheme in the region is the Mikoko Pamoja Project at Gazi Bay, Kenya (Huxham 2012), which is bringing in about US$ 12 000 per annum to Gazi community in support of mangrove conservation (see Box 13.2). Potential exists for expanding such initiatives within Kenya and the WIO region as well. Reduced Emissions from Deforestation and Degradation (REDD+) is a financial incentives-based climate change mitigation initiative designed to compensate national governments and sub-national actors in return for demonstrable reductions in carbon emissions from deforestation and degradation and enhancements of terrestrial carbon stocks (Agrawal and others, 2011). Maina and others (2013) conducted a study simulating river flow and sediment supply in four watersheds adjacent to Madagascar's major coral reef

ecosystems for a range of future climate change projections and land-use change scenarios. They found that deforestation rates far outweigh future climate change impacts on coral. This is as a result of increased sedimentation to coral reefs precipitated by upland deforestation. Management planning which reduces upland deforestation will not only improve the ecological integrity of marine ecosystems downstream, but also help in reducing global GHGs as deforestation contributes about 20 per cent of all global emissions (IPCC 2007). Although it is a generally well-established and accepted maxim, applicable across different ecosystems and resources, McClanahan and others (2011) found that in coastal fisheries in nine WIO countries, different management regimes have a direct bearing on resource productivity and sustainability, thus suggesting that key trade-offs are required to achieve different fisheries and conservation goals. These varying management regimes also determine the vulnerability (or otherwise) of ecosystems to climate change with protected areas or areas with regulated access being more resilient (Cinner and others, 2013). More investments are thus required for climate change mitigation research and enhanced management of the region's coastal and marine ecosystems for improved ecosystem integrity and continued provision of requisite ecosystem services.

Ecosystem restoration has proven critical in returning ecosystem goods and services, when there is positive recovery, especially for mangrove ecosystems (Kairo and others, 2002, Bosire and others, 2004, Bosire and others, 2008). It is important that appropriate restoration pathways are explored in terms of species and site suitability (see Text Box 3) to enhance recovery (Bosire and others, 2008). Evaluation of restoration projects is also important to determine whether

BOX 13.1. SOCIO-ECONOMIC IMPACTS OF CLIMATE CHANGE

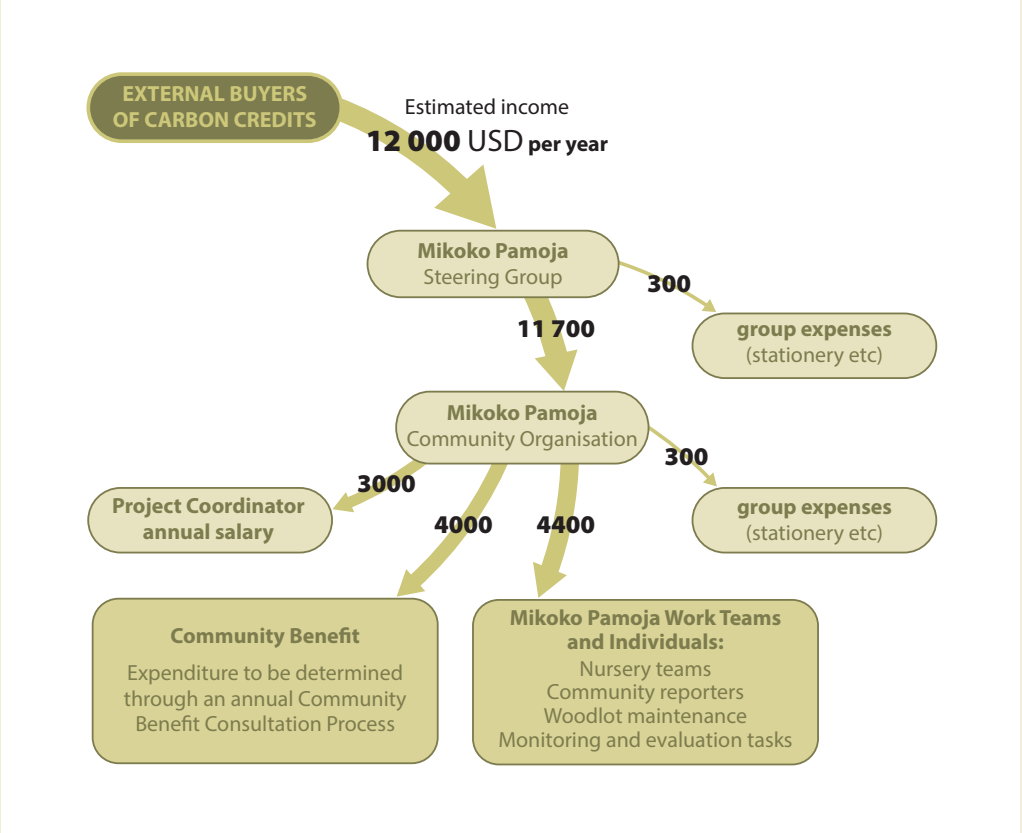


Mangrove die-back due to massive sedimentation at Mwache Creek, Kenya. © Jared Bosire.

Africa will be most impacted by climate variability and change (Allison and others, 2005; Boko and others, 2007). For instance by 2020, it is projected tha between 75 million to 250 million people in Africa will be exposed to increased water stress due to prevalent droughts. This will in turn have profound impact on food production in a region, wich is already food insecure. Coral bleching, mangrove die-back, ocean acidification and elevated temperature will significantly reduce fisheries production, thus aggravating food insecurity in the WIO region (Boko and others, 2007; Cinner and others, 2009). High intensity storms and sea level rise will have localized but considerable impacts, which will threaten coastal developments, farming activities, and even human lives. Migration of communities from vulnerable areas to safer areas has implications on the social fabric. Changing environmental factors may favour proliferations of disease vectors e.g. mosquitoes wich will aggravate disease incidence and threaten the health of local communities.

Low lying coastal cities are also threatened by sea level rise, although the spatial magnitude and extent of this threat will need to be quantified. Where the situation allows, coastal developments must incorporate sea level rise projections in terms of setback lines, avoidance of vulnerable areas and provision of migration corridors for mangroves for landward transgression. Flooding also causes extensive damage to infrastructure leading to elevated development costs, which become a burden to national development. A regional assessment analyzing vulnerability of coastal cities to sea level rise and flooding will be necessary. Developmental gains made by governments of the region stand to be gravely compromised and overall development in the longterm retarded. This is especially due to high dependence on the agricultural sector (which is highly vulnerable in the face of changing climate), the prevalence of poverty and inadequate preparednes to disasters (Bosire and others, 2010).

BOX 13.2. MANGROVE CONSERVATION AND CARBON OFFSET PROJECT



Revenue shering between different activities under *Mikoko Pamoja* Project (Huxham 2012).

***Mikoko Pamoja* Mangrove Conservation and Carbon Offset Project:** This is a pioneering project aiming to save threatened African mangroves and pilot small-scale atmospheric carbon offset. This small-scale project, which is part of wider global efforts on climate change mitigation initiatives was launched on 3 October 2013 at Gazi Bay, Kenya for mangrove conservation and support of community services. *Mikoko Pamoja*, meaning 'Mangroves together' in Swahili, aims to generate and sell carbon credits to companies and individuals looking to improve their green credentials. The project is therefore expected to generate US$ 12 000 per year, covering project costs (70 per cent) and with 30 per cent going to the local community. The carbon credits from the projects are marketed under the Plan Vivo Foundation (Standard), a charity that helps ensure that carbon offset schemes deliver genuine ecological benefits. An initial 117 hectares of mangroves has been set aside for the project with additional expected through improved forest management and restoration of degraded areas. Leakage is being managed through the establishment of *Casuarina* plantations (Huxham 2012).

inherent functions do recover and, where possible, conduct economic valuation of such systems (Kairo and others, 2009).

However, cultural ecosystem services have generally been neglected by these initiatives due to the need for different scientific competencies and methods, including a historical perspective in the analysis. Interdisciplinary approaches are therefore needed to improve the understanding of cultural ecosystem services that takes into account the dynamic nature of human–environment interactions and possible synergies and trade-offs between cultural, supporting, provisioning and regulating ecosystem services.

BOX 13.3. ECONOMIC ANALYSIS OF A RESTORED MANGROVE PLANTATION IN KENYA



Community mangrove restoration at Mwache Creek, Kenya. © Jared Bosire.

Data and examples on total economic valuation (TEV) for restored coastal ecosystems are rare or completely lacking. There is an example from Kenya, where there has been a long history of successful mangrove restoration. Economic analysis of mangrove reforestation was conducted in a replanted *Rhizophora mucronata* forest at Gazi Bay, Kenya. Major goods and services from the 12-year plantation were identified as: firewood and building poles, coastal protection, ecotourism, research and education, carbon sequestration and on-site fisheries. The net value of extractable wood products was estimated at US$ 379.17/ha/a. For non-extractable products, however, the net value ranged from US$ 44.42/ha/a in carbon sequestration to US$ 1 586.66/ha/a in coastal protection. The total economic value of the 12-year-old *Rhizophora* plantation was therefore US$ 2 902.87/ha/a. Since most of these benefits cannot be internalized, there is need for governments to promote community efforts in mangrove reforestation through finding ways of marketing ecosystem services of the replanted forests (Kairo and others, 2009).

References

Adger W.N., Hughes, T.P., Folke, C. and Carpenter, S. (2005). Social-ecological resilience to coastal disasters. *Science* 309(5373), 1036-1039

Agrawal, A., Nepstad, D. and Chhatre, A. (2011). Reducing emissions from deforestation and forest degradation. *Annu. Rev. Environ. Resour.* 36, 373– 396

Allison, E., Adger, W., Badjeck, M.C., Brown, K., Conway, D., Dulvy, N., Halls, A., Perry, A. and Reynolds, J. (2005). *Effects of climate change on the sustainability of capture and enhancement fisheries important to the poor: analysis of the vulnerability and adaptability of fisherfolk living in poverty.* Summary Report R4778J. Fisheries Management Science Programme/Department for International Development

Ateweberhan, M., McClanahan, T.R., Graham, N.A.J. and Sheppard, C.R.C. (2011). Episodic heterogeneous

decline and recovery of coral cover in the Indian Ocean. *Coral Reefs* 30, 739–752

Biggs, R., Bohensky, E., Desanker, P.V., Fabricius, C., Lynam, T., Misslehorn, A.A., Musvoto, C., Mutale, M., Reyers, B., Scholes, R.J., Shikongo, S. and van Jaarsveld, A.S. (2004). *Nature supporting people: The Southern African Millennium Ecosystem Assessment*. Integrated Report. CSIR, Pretoria

Boko, M, Niang, I., Nyong, A., Vogel, C., Githeko, A., Medany, M., Osman-Elasha, B., Tabo, R. and Yanda, P. (2007). Africa. In *Climate Change Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (eds. Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J. and Hanson, C.E.) pp. 433–467. Cambridge University Press. Cambridge,UK

Bolt, K., Ruta, G. and Sarraf, M. (2005). *Estimating the cost of environmental degradation: A Training manual in English, French and Arabic. Environment Department Paper No 106, The World Bank. Washington, D.C.*

Bosire, J., Kairo J. G., Kirui, B., Uku, J., Okemwa, G., Ochiewo, J., and Maina, J. (2010*). Impacts of climate change, and vulnerability assessments and adaptation/mitigation measures on wetland, marine and coastal resources in East Africa*. EAWLS..Nairobi

Bosire, J.O., Dahdouh-Guebas, F., Kairo, J.G., Cannicci, S. and Koedam, N. (2004). Spatial macrobenthic variations in a tropical mangrove Bay. *Biodivers. Conserv.*13(6), 1059-1074

Bosire, J.O., Dahdouh-Guebas, F., Walton, M., Crona, B.I., Lewis, R., Field, C., Kairo, J.G. and Koedam, N. (2008). Functionality of restored mangroves*: a review. Aquatic Botany* 89(2), 251-259

Brown, K., Daw, T., Rosendo, S., Bunce, M. and Cherrett, N. (2008). Ecosystem services for poverty alleviation: marine & coastal situational analysis. UK Department for International Development

Cinner, J.E., Marnane, M.J. and McClanahan T.R. (2005). Community and conservation benefits from traditional coral reef management at Ahus Island, Papua New Guinea. *Conserv. Biol.* 19, 1714 – 1723

Cinner, J., Huchery, C., Darling, E.S., Humphries, A.T., Graham, N.A.J., Hicks, C.H., Marshall, N. and McClanahan, T.R. (2013). Evaluating social and ecological vulnerability of coral reef fisheries to climate change. *PLoS ONE* 8(9), e74321

Donato, D., Kauffman, J., Murdiyarso, D., Kurnianto, S., Stidham, M. and Kanninen, M. (2012). Mangroves among the most C-rich forests in the tropics. *Nat. Geosci.* 4, 293-297

Donner, S.D. and Potere, D. (2007). The Inequity of the Global Threat to Coral Reefs. *BioScience* 57, 314-315

GEF (2009). *Investing in Land Stewardship. GEF's efforts to combat land degradationn and desertification globally.* Global Environment Facility., Washington, D.C.

Goreau, T., McClanahan T R., Hayes, R. and Strong, A. (2000). Conservation of coral reefs after the 1998 global bleaching event. *Conserv. Biol.* 14, 5–15

Huxham, M. (2012). *Mikoko Pamoja: Mangrove Conservation For Community Benefit.* Plan Vivo Project Design Document (PDD)

IPCC (2007). Summary for Policymakers. In *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (eds. S. Solomon, D. Qin, M. Manning, Z. enhen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller) Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC (2014). Climate Change (2014). Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (eds. R.K. Pachauri and L.A. Meyer) Geneva, Switzerland

Jackson, J., Kirby, M. and Berger, W. (2001). Historical Overfishing and the Recent Collapse of Coastal Ecosystems. *Science* 293(5530), 629-637

Kairo, J.G., Wanjiru, C. and Ochiewo, J. (2009). Net Pay: Economic Analysis of a Replanted Mangrove Plantation in Kenya. *J. Sustainable For.* 28, 395–414

Maina, J., de Moel, H., Zinke, J., Madin, J., McClanahan, T.R. and Vermaat, E.J. (2013). Human deforestation outweighs future climate change impacts of sedimentation on coral reefs. *Nature communications* 4, 1986

McClanahan, T.R., Mwaguni, S. and Muthiga, N.A. (2005). Management of the Kenyan coast. *Ocean Coast. Manage.* 48,901-931

McClanahan, T.R., Graham, N.A.J., MacNeil, M.A., Muthiga, N., Cinner, J., Bruggeman, H. and Wilson, S.K. (2011). Critical thresholds and tangible targets for ecosystem-based management of coral reef fisheries. *Proc. Natl. Acad. Sci. U.S.A.* 108(41), 17230-17233.

MEA (2005). *Ecosystems and human well-being: Synthesis.* Washington, D.C.Island Press

Miles, L. and Kapos, V. (2008). Reducing greenhouse gas emissions from deforestation and forest degradation: global land-use implications. *Science* 320 (5882), 1454–1455

Newton, K., Cote, I., Pilling, G., Jennings, S. and Dulvey, N. (2007). Current and Future Sustainability of Island Coral Reef Fisheries. *Curr. Biol.* 17(7), 655-658

Obura, D. (2002). Resilience and climate change: lessons from coral reefs and bleaching in the Western Indian Ocean region. *Estuar. Coast. Shelf S.* 63, 353-372

Shackleton, C., Shackleton, S., Gambiza, J., Nel, E., Rowntree, K. and Urquhart, T. (2008). *Links between Ecosystem Services and Poverty Alleviation: Situation analysis for arid and semi-arid lands in southern Africa*. Consortium on Ecosystems and Poverty in Sub-Saharan Africa (CEPSA)

Tengberg, A., Torheim, S.I. (2007). The role of land degradation in the agriculture and environment nexus. In *Climate and Land Degradation. Environmental Science and Engineering.* (eds Sivakumar, M.V.K., Ndian'gui, N.) Springer-Verlag

UNEP/IISD (2004). *Human well-being, poverty and ecosystem services. Exploring the links*. United Nations Environmental Programme (UNEP) and International Institute for Sustainable Development (IISD). Winnipeg.

WWF and ZSL (2014). *Living Planet Index in Living Planet Report 2014: species and spaces, people and places*. (eds. McClellan, R., Iyengar, L., Jeffries, B. And N. Oerlemans). WWF, Gland, Switzerland

WRI (2005). *World Resources 2005: The Wealth of the Poor—Managing Ecosystems to Fight Poverty.* Collaboration with United Nations Development Programme, United Nations Environment Programme, and World Bank. Washington, D.C.



14
The Oceans' Role in the Hydrological Cycle

Issufo Halo

Opposite page: Splashing waves at Inhaca Island, Mozambique. © José Paula.

INTRODUCTION

More than 70 per cent of the earth's surface is covered by the oceans (Stewart 2008). Because of the water's high heat capacity, the oceans absorb and retain a greater amount of solar energy, far more than the land and atmosphere (Linacre and Geerts 1997). Almost half of the absorbed solar energy at the sea surface is released back to the atmosphere in form of outgoing longwave radiation (OLR) and latent heat flux. The latter produces atmospheric water vapour (Linacre and Geerts 1997). Water vapour plays a key role in the Earth's energy balance and drives important processes within the hydrological cycle (Linacre and Geerts 1997, Talley and others, 2011), upon which human existence and permanence on Earth's surface depend. In this chapter, the hydrological cycle is the process of water circulation and exchange through the hydrosphere - atmosphere - lithosphere systems.

Bengtsson (2010) indicates that the total amount of available water on Earth's surface is about $1.5x10^9$ km^3. When distributed through the components of the hydrological cycle, the oceans retain about 1.4x109 km^3, inland waters, ice and glaciers about 29x106 km^3, and ground-water systems 15x106 km^3 (Bengtsson 2010). These estimates indicate that the oceans retain nearly 97 per cent of the available water.

The different freshwater systems interact with the seawater in diverse and complex ways, causing both short and long-term impacts on the compartments of the Earth's environment, with significant social, economic and ecological implications. For example, large amounts of inland sediments transported by the rivers, when deposited in the coastal ocean systems can lead to high levels of ocean turbidity that can reduce penetration of solar radiation in the water column. Deficiency of solar radiation can negatively affect photosynthetic processes, thus reducing primary production. Another example is the effect of anomalous freshening in the ocean caused by inputs of freshwater that can affect seawater stratification and water mass formation. This in turn can influence the strength of the general thermohaline oceanic circulation, potentially modifying the Earth's climate.

According to Lagerloef and others (2010), the global evaporation process is estimated to be about 13 Sv (1 Sv = 10^6 m^3 s^{-1}), precipitation about 12.2 Sv, river discharge about 1.2 Sv and melting glaciers only about 0.01 Sv. As these estimates suggest, among such processes, evaporation and precipitation greatly dominate the hydrological cycle. However, each oceanic basin exhibits its particular influence on the hydrological cycle, associated with morphologic and hydrographic characteristics. For the purpose of this review, in this chapter only the role of the western Indian Ocean on the hydrological cycle is assessed.

INTERACTIONS BETWEEN SEAWATER AND FRESHWATER SEGMENTS OF THE HYDROLOGICAL CYCLE

The Indian Ocean is the smallest ocean after the Pacific and Atlantic, exhibiting distinct characteristics, which

affect its hydrology. Among many, the most important characteristics are: (1) the shape of the Indian Ocean, ending in the northern subtropics, (2) seasonally reversing monsoons, and (3) the influence of equatorial current system in blocking the spread of thermocline waters (Schott and others, 2009, Talley and others, 2011). The shape of the Indian Ocean with the subtropical northern limit prevents a northward heat export, permitting only a weak ventilation of the thermocline from the north (Schott and others, 2009). The seasonal reversal of the monsoonal winds cause reversal of the ocean currents such as the Somali Current in the western Indian Ocean, and the southwest and northeast Monsoon currents south of India and Sri Lanka (Schott and others, 2009). The prevention of spread of thermocline waters by the equatorial current systems results in the coastal portion of the western Indian Ocean being the only gateway for advective transfer of thermocline water between the southern and northern Indian Ocean sectors (Talley and others, 2011).

Rivers runoff

The total volumes involved in the interaction between the Indian Ocean and the surrounding continental freshwater segments is small when compared with the Atlantic and Pacific Oceans. However, estimates of the net transport of Indian Ocean waters moving to inland freshwater systems is about one-third of the volume, compared to the Atlantic Ocean where an estimated two-thirds of the volume moves inland (Bengtsson 2010).

Dai and Trenberth (2002) compiled information on the fifty-one largest rivers flowing into the world's ocean. For each river, the information consisted of observed and modelled annual mean river discharge both at the river mouth and at a given station, and its respective drainage area. Many rivers flowing into the Indian Ocean also have a strong impact on the hydrology of the region. The ten largest rivers flow, as estimated in the river's mouth, are presented in Table 14.1. These include: Brahmaputra River in Bangladesh, the Ganges River in India and the Irrawady River in Burma, all of which flow into the Gulf of Bengal. Into the Arabian Sea flows the Indus River in Pakistan. Into the Somali Basin flow the Juba River in Somalia and the Rufiji River in Tanzania; while into the Comoros Basin flows the Tsiribihina River from the northwest of Madagascar. Finally, in the eastern side of the Mozambique Channel flows the Mangoky River from central Madagascar, while into the western side flows the Limpopo River at Chokwe and the Zambezi River at the Sofala Bank (Dai and Trenberth 2002).

The Zambezi River is the fourth largest in Africa, and the largest in east Africa. It transports more than 75 per cent of the annual mean runoff of the region's interior and discharges more than 40 per cent (Mukosa and Mwiinga, 2008) through its delta on the Mozambique Channel. These discharges greatly impact the coastal water properties on the continental shelf, significantly enhancing the productivity of the Sofala Bank (Hoguane 2007).

The regime of each of the above-mentioned rivers is strongly modulated by rainfall. Studies on the effect of climate change on water resources indicate that in tropical regions rivers runoff regime and water resources depend entirely on changes in annual precipitation and its distribution during a year. Global warming is expected to result in more changes in extreme minimum and maximum discharges of rivers. Some studies have suggested, that the hydrology of the northern and Western Indian Ocean are

Table 14.1. Main rivers runoff in the north and western Indian Ocean, showing annual mean flow (km^3) and drainage area (km^2), based on model results from Dai and Trenberth (2002).

River Name	Annual Flow (km^3)	Drainage Area (10^3 km^2)
Brahmaputra	628	583
Ganges	404	956
Irrawady	393	406
Indus	104	1143
Juba	7,5	234
Rufiji	40	187
Tsiribihina	31	49
Mangoky	19	60
Limpopo	14	420
Zambezi	117	1989

likely to be very sensitive to such global warming scenarios (eg Shiklomanov 1998).

Precipitation and evaporation rates

Lagerloef and others (2010) computed and mapped global annual average of the dominant processes of the water cycle: evaporation, precipitation, and the difference between evaporation and precipitation (P-E), for the period spanning from 2050 to 2008 (see Figure 14.1). While it is well known that all subtropical oceanic gyres and subtropical margin seas are dominated by excess evaporation, a remarkable feature to observe is a maximum evaporative imbalance in the western Indian Ocean of about 2.2 m per year occurring within the Red Sea, outside the strict WIO region (Lagerloef and others, 2010).

In the northwest Indian Ocean, two contrasting oceanographic regimes dominate, to the west and east of India (see Figure 14.1). The western region, between India and Africa is defined by the Red Sea and Arabian Sea, which are evaporative basins (Beal and others, 2006). As a result of high evaporation rates they have very saline waters, eg Red Sea waters, with observed highest salinity range between 38 and 42 PSU (Talley and others, 2011).

The rainfall distribution is characterized mainly by a large annual mean difference between the western and eastern Indian Ocean. Such a pattern is completely different to what is usually known to occur in subtropical conditions. The precipitation in the former region was estimated at 10 cm per year occurring in the Arabian Sea, and the latter 300 cm per year occurring near Sumatra and Andaman Sea (Tomczak and Godfrey 1994).

In the south Indian Ocean, the rainfall distribution is characterized by small variations of about 200 cm per year in the southwest, near Madagascar, and 50 cm per year in the southeast, near Australia. As a result, the isolines of precipitation are nearly zonal, and the P-E follows closely the rainfall distribution (Tomczak and Godfrey 1994, Schott and others, 2009).

As shown by Talley (2008), the Indian Ocean is a net evaporative basin. This implies that it must import freshwater via ocean circulation (Talley 2008). In order to balance the system with a required volume of about 0.37 ± 0.10 Sv, the Indian Ocean receives tributaries from the Pacific Ocean through the Indonesian Through-Flow (ITF) of about 0.23 ± 0.05 Sv, from the Southern Ocean through a shallow gyre circulation, 0.18 ± 0.02 Sv, and a small southward export of about 0.04 ± 0.03 Sv due to freshening of bottom waters while upwelling into deep and intermediate layers (Talley 2008).

Chemical composition of seawater

Continental freshwater runoff and estuarine systems are linked to regional and large-scale hydrology through interactions among soil, water and evaporation. These systems and the whole water cycle control the movement of major nutrients and trace elements over long distances from the

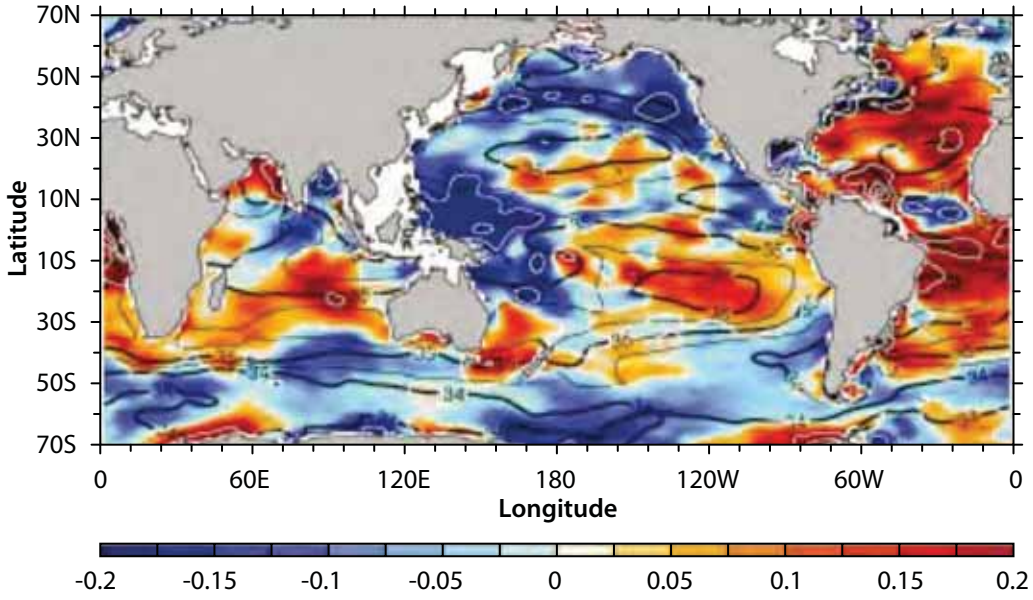


Figure 14.1. Long-term estimate of global sea surface salinity change for period covering 1950 – 2008. Notice the contrast between the northwest and northeast Indian Ocean. (Figure source: Durack and Wijffels, 2010).

land to the oceans. Major nutrients in the ocean are nitrogen, phosphorus and silicon.

The physical and chemical properties of freshwater from the rivers are considerably different from the saline seawater in the oceans. A list of major constituents of the seawater is given by Stewart (2008). It involves the following ions: chlorine (by 55.3 per cent), sodium (30.8 per cent), sulphate (7.7 per cent), magnesium (3.7 per cent), calcium (1.2 per cent) and potassium (1.1 per cent). On average, the Indian Ocean surface water salinity ranges from 32 to 37 PSU, being highest in the Arabian Sea portion.

In-situ observations have shown high salinity content in the Red Sea, Arabian Sea (35.5–36.8 PSU) and Persian Gulf (34.8–35.4 PSU). Relatively low salinity waters from the ITF (34.4–35.0 PSU) are transported into the western Indian Ocean by the South Equatorial Current that feeds the northward East African Coastal Current passing along Tanzanian coast. Low salinity waters from rain-dominated areas such as the Bay of Bengal (28.0–35.0 PSU) can be advected toward the Western Indian Ocean region, where they eventually mix with waters from Indonesian origin. Studies have shown that in the Western Indian Ocean, the salinity maximum linked to Red Sea water can be traced all the way to the coast of South Africa. The salinity core decreases from 38 PSU in the Red Sea to about 34.7 PSU in the Mozambique Channel (Emery 2003).

Among four main studies addressing the observed long-term changes to ocean salinity, the study by Durack and Wijffels (2010) appears to provide a more robust measure of absolute temporal trends (Siedler and others, 2013). Durack and Wijffels (2010) suggest that in general, areas dominated by precipitation have undergone freshening, while evaporation-dominated areas have become saltier (Figure 14.1). Strong amplification of salinity contrast is indicative of an intensification of the hydrological cycle in response to a warmer climate (Held and Soden 2006).

ENVIRONMENTAL, ECONOMIC AND SOCIAL IMPLICATIONS OF OCEAN WARMING AND SEA LEVEL CHANGE

Ocean warming

The tropical Western Indian Ocean encompasses the largest warm sea surface temperature (SST) pool of the world's oceans, hence it has the potential to influence both regional and global climate (Schott and others, 2009, Talley and others, 2011). The 1997-1998 El Niño Southern Oscillation (ENSO), linking anomalous warm SST accompanied by extreme rainfall and drought, with strong social and economic implications is worthy of mention. ENSO is an anomalous warming of the ocean and atmosphere in the tropical Pacific that occurs roughly every three to seven years and lasts for 12 to 18 months. It is the dominant mode of natural climate variability.

The anomalous warming in the tropical eastern Pacific reduces the atmospheric pressure causing weakening of the trade winds. This sets the stage for an evolution of an equatorial rain band stretching from Indonesia to the central Pacific (Siedler and others, 2013). The surface oscillations in the central Pacific induces an eastward propagation of Kelvin waves that on reaching the eastern boundary of the equatorial Pacific trigger a chain of westward propagating Rossby waves. Studies have shown that these waves cross the entire Pacific basin, entering into the tropical Indian Ocean, with far reaching impact in the western region.

The ENSO causes significant climatic disturbances in most parts of Africa, either inducing drought or flooding, or increasing sea temperatures leading to cyclones. The 1997-1998 ENSO devastated both northeastern and western Indian Ocean countries, with unusual torrential convective rains that flooded Somalia, Ethiopia, Kenya, Sudan and Uganda, and severe droughts in Papua New Guinea and Indonesia (FAO 2001). These had severe social consequences: extensive crop failures and livestock losses, food and drink water shortage (McPhaden 1999). Over a thousand people died and hundreds of thousands misplaced (Schott and others, 2009).

It is important to mention that while ENSO induced warming covers the whole tropical Indian Ocean, the cause for the warming in the southwest Indian Ocean is different from that in the rest of the basin (Schott and others, 2009). This indicates that the warming in this oceanic sector cannot be explained only by surface fluxes. The ocean interior dynamics are crucial. The role of the thermocline ridge between 5-10°S has been shown to play an important role on the variability of SST (Xie and others, 2002).

Washington and Preston (2006) have investigated the role of the Indian Ocean SST on extreme wet occurrences over southern Africa during the 19th century. Their results, based on the two most extreme rainfall events in 1974 and 1976, indicate that while ENSO serves as an important control of rainfall variability, other processes that enhance warm SST anomalies in the subtropics and cool anomalies in the northern southwest Indian Ocean are the main driv-

ers of extreme rainfall events. One such critical process was found to be associated with cold SST anomalies in the Mascarene region, which influenced anomalous low-level easterly moisture flux along 10-20°S to the east of southern Africa. This had a direct impact on moist convective uplift leading to enhanced precipitation. Economic and social implications of changes on the hydrological water cycle tend to be large.

According to official retrospectives relating to the year 2000 floods in Mozambique, the costs were estimated at US$ 273 million in physical damage, US$ 247 million in lost production, US$ 48 million in lost exports and US$ 31 million in increased imports. During mid to late January 2001, heavy rains over Zambezia Province caused the Licungo River to flood in Mozambique, with nearly 500 000 people affected by the floods (UNEP 2002), 650 people killed and more than half a million left homeless (UNEP 2002).

Increased warm SST leads to increased cyclone activity. UNEP (2002) reports that "the Western Indian Ocean islands typically experience ten cyclones a year, between November and May, which bring strong winds and heavy rainfall. This causes destruction of infrastructure, particularly in low-lying areas and where settlements have encroached into flood-prone areas". This natural phenomenon also has strong social impacts. For example, cyclones Eline (mid-February) and Gloria (early-March) in the year 2000 in Madagascar left 184 000 people in need of immediate relief support of the total 737 000 affected (UNEP 2002).

Sea level change

Warming SST affects the low atmospheric pressure systems with implication throughout the oceanic water column. Sea level oscillations reflect the vertical movements of the thermocline. Investigating sea level rise around Pacific and Indian Ocean islands, Church and others (2006) have shown large sea surface height (SSH) variability being caused by ENSO. They also suggested that fewer individual tide-gauge records contribute to uncertainty of historical rates of sea level rise. For the period from 1993 to 2001, both satellite and tide-gauge data show large rates of sea level fall in the eastern Pacific and western Indian Ocean (approaching – 10 mm per year), which reflects weak ENSO conditions. Over the region 40°S to 40°N, 30°E to 120°W, the average rise was estimated at about 4 mm per year (Church and others, 2006). Their analysis suggests a continued and increasing rate of sea level rise, causing serious problems for inhabitants of some of these islands during the 21st century (Church and others, 2006). According to recent projections (IPCC 2013), it is very likely that in this century and beyond, sea level change will show strong regional patterns (Figure 14.2), with some places experiencing significant deviations from the global mean change (Church and others, 2013).

Natural variabilities appear to be the main drivers of the regional patterns of the observed sea level change (Siedler and others, 2013). In the Indian Ocean, minimal sea level rise pattern has been observed in the south tropical band (Figure 14.2). While Han and others (2010) attributed such a pattern to a strengthening of the Indian Ocean Walker and Hadley cells, Schwarzkopf and Boning (2011) attributed such a pattern to the change of winds in the western equatorial Pacific that transmit thermocline anomalies through the Indonesian Archipelago, and their subsequent westward propagation by baroclinic Rossby waves (Church and others, 2011).

Information compiled in the IPCC (2007) report in connection with the sea level changes in east Africa, indicated that western Indian Ocean countries, from Sudan in the Red Sea to South Africa, including coastal wetlands and some near-shore islands off the coast of Tanzania and Mozambique, as well as oceanic islands of Madagascar, Seychelles, Comoros, Mauritius, and Reunion, are highly vulnerable. In fact, simulations of sea level rise in Tanzania have shown that for a rise of 0.5 and 1 m per century, about 2 090 and 2 117 km^2 of land would be inundated, respectively, while the latter would erode an additional area of about 9 km^2 (Mwaipopo 2000). Looking at the economic implications of such rising sea level, the projected damage estimated as exceeding US$ 544 million for a 0.5 m rise and US$ 86 000 million for 1 m rise.

A recent study focused on Africa by Brown and others (2011), for period from 2000 to 2100, based on an integrated biophysical and socio-economic impact model, has shown that for the Western Indian Ocean, Mozambique and Tanzania stand out as countries with high people-based impacts associated with flooding and forced migration. For South Africa higher economic damage from sea level rise was foreseen. Mozambique and South Africa were identified as countries in the region with the highest adaption costs (Brown and others, 2011). Nevertheless, more studies in the region are needed, to improve such estimates and examine other aspects of impact and adaptation in more detail.

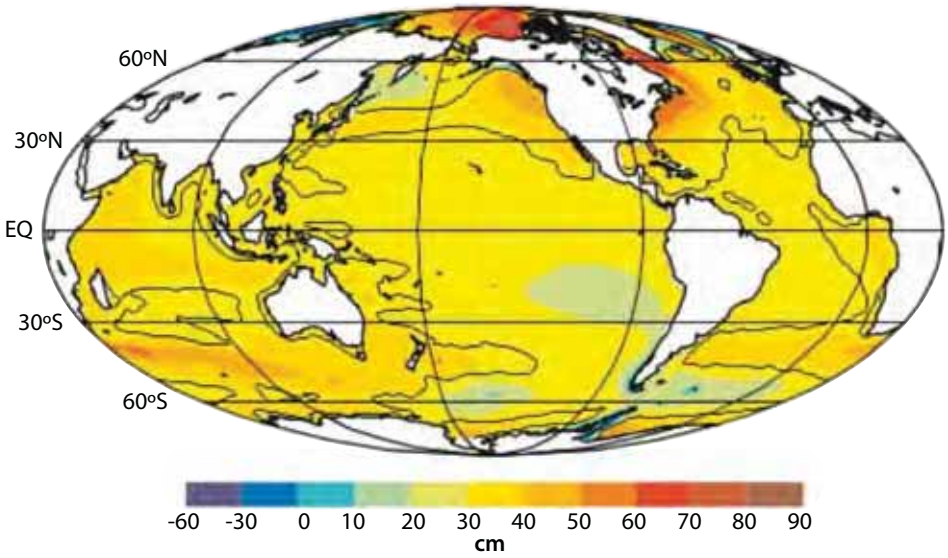


Figure 14.2. The regional distribution of the projections of sea level change for 2090 compared to 1990, combining global average sea level projections, dynamic ocean departure from the global average, and regional changes associated with the changing mass distribution in the cryosphere. The black contour is the "average" value at 2090 of 38 cm, dividing those regions with above and below-average sea level rise. (Figure source and caption taken from Church and others, 2011).

For Kenya, Awuor and others (2008) indicate that the impacts of sea level rise are likely to be felt beyond coastal and national boundaries. Activities such as infrastructure, tourism, aquaculture and agriculture are likely to be negatively affected due to rising sea level. For instance, with 0.3 m rise and without adaptation, an estimated 17 per cent of the Mombasa District will be submerged (Oyieke 2000). This rise would also affect 7 per cent of the population in the Tana Delta, and an area of about 481 km^2 could be lost between 2000 and 2050 (Ericson and others, 2006).

For Mauritius, the coastal zone is degrading at an accelerated rate due to sea level rise. The review by Brown and others (2011) mentions that with 1 m of rise, about 26 km of beach would disappear on the west coast, including flooding of local housing, tourism and infrastructure facilities. Inundation will also affect plantations and major coastal roads.

For the Seychelles islands, the impact of sea level rise will have also strong negative impacts on fishing and tourism, which are main sectors of socio-economic importance (Brown and others, 2011). The ports and airports which have been built on reclaimed low ground would also be severely affected (Brown and others, 2011). Furthermore the increasing sea level rise will lead to greater erosion which potentially will lead to an increased landslides, and beaches would be inundated, resulting in a severe damage to freshwater aquifers systems.

Anthropogenic and other changes on freshwater fluxes into the sea

Both natural and anthropogenic activities affect climate variability, with anthropogenic activities affecting the pace of their occurrence and severity. The African continent has been regarded as a region where human activities, associated with the use of freshwater systems (for construction of reservoirs, canals for irrigation and navigation and other uses), may cause severe changes to the hydrological system and river flow regimes (Shiklomanov 1998).

Indicators of climate change, such as unprecedented ocean warming, sea level rise, and changes on freshwater fluxes into the sea, will occur more frequently in future, and the largest number of people affected will be those in low-lying deltas in Asia and Africa (IPCC 2007, IPCC 2013). As an example, the UNEP (2002) report states that in Kenya, low reservoir levels resulting from drought and siltation have been linked to human deforestation and inappropriate management of land and water resources. This has led to reductions in hydropower generation, necessitating water and power rationing with severe social and economic consequences, which devastated the country's economy in 1999 and 2000. Losses from power rationing alone were estimated at US$ 2 million per day, and the cost of unmet electricity demand was estimated at US$ 400-630 million, equal to 3.8-6.5 per cent of GDP (UNEP 2002).

THE OCEANS' ROLE IN HEAT TRANSPORTATION

On the basis of a study of Mayotte Island corals (recent and fossil) over a long time series (1881 - 1994), Zinke and others (2008) showed evidence for hydrological changes that have taken place in the Western Indian Ocean. The balance P-E in the region has natural variations on timescales of 5 to 6 years and 18 to 25 years. The temporal changes on the P-E balance as well as on OLR in the region were anti-correlated with the SST, thus higher rainfall events induced cooler mean SST.

Recent analysis on the interannual variability of SST and circulation in the tropical Western Indian Ocean for the period 1980 to 2007 by Manyilizu and others (2014), in the oceanic environment around the Tanzanian coast, suggests that changes in the thermocline (which induces SST variability) are linked with anomalous short wave radiation, plus heat anomalies from the oceanic currents, namely the South Equatorial Current. In the offshore environment, the changes in the thermocline appeared to be linked to local Ekman pumping from the wind stress curl and Indian Ocean Dipole (IOD) and ENSO (Manyilizu and others, 2014). The IOD is a basin-wide mode of variability in the tropical Indian Ocean involving a strong ocean-atmosphere interaction. In its positive phase it is characterized by an anomalous cold temperature to the west of Sumatra, and warm temperatures in the tropical Western Indian Ocean.

The Indian Ocean gains heat to the north of 20°S and imports warm ITF water into the upper ocean near 12°S. For this ocean to find its equilibrium, a net of about 0.8 PW of this heat is transported southward, with less than half 0.3 PW, being mostly in the upper Indian Ocean subtropical gyre, and half 0.4 PW by the overturning cell from deep to intermediate (or thermocline), and 0.1 by the ITF (Talley 2008). As stated by Talley (2008), the deep upwelling is significant for the global heat budget, but insignificant for the freshwater balance. Important for the freshwater balance of the Indian Ocean is the upper branch of the subtropical gyre and the ITF that carries most of the northward transport of freshwater required balancing the net evaporation (Talley 2008).

In the northern Indian Ocean, the net heat gain is observed in the region of the warm pool tongue. This requires a balance, which is made through the southward export of heat across the equator and out of the tropics. Upwelling of deep to thermocline depth waters is thought to be responsible for a significant part of the heat export (Talley 2008). The coral study from Mayotte Island by Zinke and others (2008), referred to above, also concluded that warm ENSO events are associated with a negative freshwater balance in the southwest Indian Ocean. Therefore, the region south of 10°S exhibits an opposite ENSO response compared to the equatorial Indian Ocean region (Zinke and others, 2008).

ENVIRONMENTAL, ECONOMIC AND SOCIAL IMPLICATIONS OF CHANGES IN SALINITY AND NUTRIENTS

There is evidence for water vapour volumes increasing faster than precipitation, which will have far-reaching consequences (Held and Soden 2006). The residence time of water vapour in the atmosphere is also increasing, which implies that the exchange of mass between the boundary layer must decrease. This could result in fewer tropical cyclones in a warmer climate. In regions of net evaporation (eg Western Indian Ocean) salinity is increasing (Figure 14.1), leading to increased ocean vertical mixing. In the Intertropical Convergence Zone (ITCZ) and extra-tropical storm tracks, ocean salinity is decreasing due to high precipitation thus reducing ocean vertical mixing. The interaction between river discharges in the western Indian Ocean during the summer monsoon season is known to influence the surface salinity distribution over thousand of kilometres offshore.

Results from the Argo float observations from 2004 to 2013 indicate that seawater is becoming increasingly salty in the Western Indian Ocean and near the equator in the western and central Pacific Ocean. Such a change is indicative of changes in the hydrological cycle.

Amplification of strong contrast of surface salinity between the evaporative Arabian Sea and precipitation and runoff-dominated basin in the Bay of Bengal has been observed in a fifty-year linear trend data record from 1950 to 2008 (Durack and Wijffels 2010) (see Figure 14.1). The study suggests that in the Arabian Sea, a maximum salinity increase is found along the northeast with a magnitude of about 0.52 (+/- 0.26) at 13°N and 74°E (Figure 14.2). In contrast, the Bay of Bengal shows a strong surface freshening signal of -0.40 (+/-0.31) found in the northeastern regions of the Bay (19°N, 92°E). This freshening is constrained to the shallowest waters of the Bay (Figure 14.1) and extends southward and crosses the equator with maximum surface amplitude south of India. In general, the global averaged

surface salinity change is small, however at basin scale such change is large for Atlantic and Pacific Oceans, while near neutral for the Indian Ocean (-0.001+/- 0.061). Strong amplification of salinity contrast is indicative of an intensification of the hydrological cycle in response to a warmer climate (Held and Soden 2006).

Álvarez and others (2011) have investigated temporal changes in salinity and nutrients in the eastern and western subtropical gyre of the Indian Ocean, along a repeated hydrographic zonal transect that stretches from Australia to Africa, along 32ºS, for a period ranging from 1987 to 2002. With the aid of a numerical model running backwards, a simulation was made for the period from 1987 to 1960. During this period, salinity has shown an increasing trend, contrary to the period of 1987 – 2002. In the western Indian Ocean a decreasing trend in the transit time distribution indicates a faster delivery of Sub Antarctic Mode Water, thus less biogenic remineralisation. This explains the observed oxygen increase and nutrient decrease.

ENVIRONMENTAL, ECONOMIC AND SOCIAL IMPACTS OF CHANGES IN OCEAN TEMPERATURE

A direct link exists between changes to environmental oceanic conditions and economic and social impacts. Among many environmental parameters that could be inspected, here the influence of ocean temperature in the western Indian Ocean was considered. Major changes in ocean temperature can be associated with climate modes of variability such as El-Niño (La-Niña) phenomena for warmer (cooler) SST.

At great length, the impact of the sea level changes in the western Indian Ocean has been presented in this chapter. One must bear in mind that one important parameter associated with such changes is temperature, especially at the sea surface. While the general picture of the Indian Ocean's warm pool in the eastern and central portions is known to be increasing at a moderate rate in the last half-century, a more recent study based on both observational data and outputs from an ocean-atmosphere couple model by Roxy and others (2014), suggests a more drastic warming. Their study revealed a warming rate greater than was thought to be the case for the tropical western Indian Ocean, and one that has been developing for over a century (Figure 14.3). The rate of this warming is now classified as the fastest of any tropical global ocean regions, and is accountable for the largest contribution of the overall trend in the global mean sea surface temperature (Roxy and others, 2014), hence having a direct contribution to greenhouse warming.

For the period considered by Roxy and others (2014) from 1901 to 2012, it revealed an increasing rate of 0.7 ºC in the warm pool region, while the tropical western Indian Ocean has witnessed an anomalous sea surface temperature increase of 1.2 ºC during the summer season (Figure 14.3). Such significant changes on zonal SST gradients has the potential to change the Asian monsoonal circulation and rainfall patterns, as well as the productivity of the marine ecosystem in the western Indian Ocean (Roxy and others, 2014). Another important result from this study suggests that this long-term warming trend over the western Indian Ocean during summer is strongly dependent on the asymmetry in the ENSO teleconnections and positive SST skewness associated with ENSO during recent decades. Simply put, it is inferred that while major warming events such as ENSO induces a significant warming in the western Indian Ocean, a major cooling event such as La-Nina on the other hand fails to reverse such change accordingly (Roxy and others, 2014).

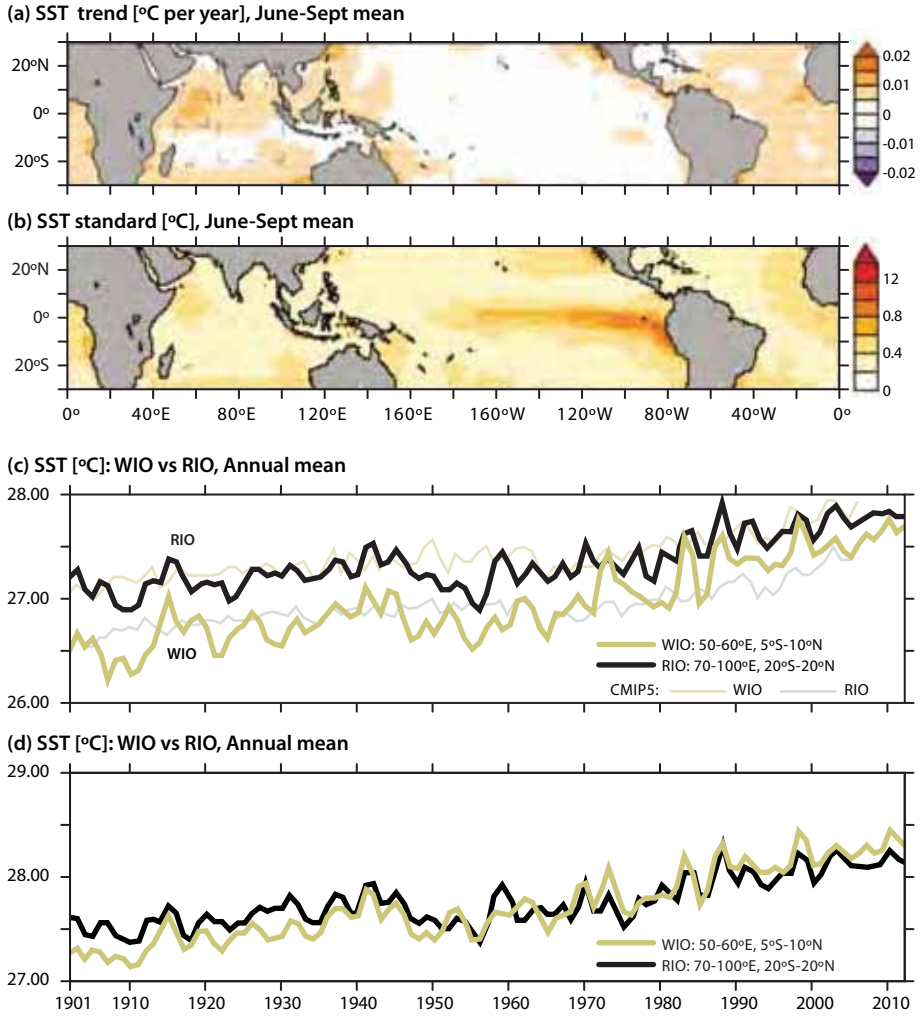


Figure 14.3. **(a)** Observed trend in mean summer (June to September) sea surface temperature (SST), units in °C year^{-1} over the global tropics from 1901 to 2012; **(b)** Interannual standard deviation of SST in °C for the same domain and time period; **(c)** Time series of mean summer SST in °C; **(d)** annual mean SST in °C over the western Indian Ocean (WIO [red: 5°S-10°N, 50-65°E]), with remaining Indian Ocean (RIO [black: 20°S-20°N, 70-100°E]). WIO and RIO are marked with inserted boxes in panel **(a)**. The CMIP5 ensemble means based on 25 climate models averaged over the WIO (light red) and RIO (light grey) are shown in panel **(c)**. (Figure source: Roxy and others, 2014).

References

Álvarez, M., Tanhua, T., Brix, H., Monaco, C.L., Metzl, N. and McDonagh, E.L. (2011). Decadal biogeochemical changes in the subtropical Indian Ocean associated with Subantarctic Mode Water. *J. Geosphys. Res. Oceans* 116, (C09)

Awuor, C.B., Orindi, V.A. and Adwere, A.O. (2008). Climate change and coastal cities: the case of Mombasa, Kenya. *Environ. Urban.* 20(1), 231–242

Beal, M.L., Chereskin, T.K., Lenn, Y.D. and Elipot S. (2006). The Sources and Mixing Characteristics of the Agulhas Current. *J. Phys. Oceanogr.* (36), 2060–2074

Bengtsson, L. (2010). The global atmospheric water cycle. *Environ. Res. Lett.* 5, 025001

Brown, S., Kebede, A. and Nicholls, R.J. (2011*). Sea-level Rise and Impacts in Africa, 2000 to 2100*. University of Southampton, UK

Church, J.A., White, J.N. and Hunter, R.J. (2006). Sea-level rise at tropical Pacific and Indian Ocean islands. *Glob. Planet. Change* 53(3), 155–168

Church, J.A., Gregory, J.M., White, N.J., Platten, S.M. and Mitrovica, J.X. (2011). Understanding and projecting sea level change. *Oceanography* 24(2), 130–143

Church, J.A., Clark, P.U., Cazenave, A., Gregory, J.M., Jevrejeva, S., Levermann, A., Merrifield, M.A., Milne,

G.A., Nerem, R.S., Nunn, P.D., Payne, A.J., Pfeffer, W.T., Stammer, D. and Unnikrishnan, A.S. (2013). Sea Level Change. In *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (eds. T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung,A. Nauels, Y. Xia, V. Bex and P.M. Midgley) Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Dai, A. and Trenberth, K.E. (2002). Estimates of Freshwater Discharge from Continents: Latitudinal and Seasonal Variations. *J. Hydromet,* 3, 660-687

Durack, P.J. and Wijffels, S.E. (2010). Fifty-Year Trends in Global Ocean Salinities and Their Relationship to Broad-Scale Warming, *J. Clim* 23, 4342-4362

Emery, W.J. (2003). Water Types and Water Masses. In *Encyclopedia of Ocean Sciences*. (eds. John Steele, Steve Thrope and Karl Turekain). Academic Press

Ericson, J.P., Vörösmarty, C.J., Dingman, S.L., Ward, L.G. and Meybeck, M. (2006). Effective sea-level rise and deltas: Causes of change and human dimension implications. *Glob. Planet. Change.* 50(1), 63-82

FAO (2001). FRA 2000 Main Report, FAO Forestry Paper 140. Rome

Held, I.M. and Soden, B.J. (2006). Robust Responses of the Hydrological Cycle to Global Warming. *J. Clim*. 19(21), 5686-5699

Han, W., Meehl, G., Rajagopalan, B., Fasullo, J., Hu, A, Lin, J., Large, W, Wang, J-W, Quan, X.-W., Trenary, L., Wallcraft, A., Shinoda, T. and Yeager, S. (2010). Patterns of Indian Ocean Sea-level change in a warming climate. *Nat. Geosci.* 3(8), 546-550

Hoguane, A.M. (2007). Diagnosis of Mozambique Coastal Zone. *Rev. Gestão Costeira Integrada* 7(1), 69-82

IPCC (2007). *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. (eds. M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson) Cambridge University Press. Cambridge, UK

IPCC (2013). *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (eds. Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung,A. Nauels, Y. Xia, V. Bex and P.M. Midgley) Cambridge University Press. Cambridge, United Kingdom and New York, NY, USA

Lagerloef, G., Schmitt, R., Schanze, J. and Kao, H.Y. (2010). The ocean and the global water cycle. *Oceanography* 23(4), 82–93

Linacre, E. and Geerts, B. (1997). *Climates and Weather Explained*. Routledge. New York, USA

Manyilizu M., Dufois, F., Penven, P. and Reason, C. (2014). Interannual variability of sea surface temperature and circulation in the tropical western Indian Ocean. *Afr. J. Mar. Sci.* 36(2), 233-252

McPhaden, M.J. (1999). El Niño and La Niña: Causes and Global Consequences. In *The Earth system: physical and chemical dimensions of global environmental change* (eds. M.C. MacCracken and J.S. Perry) vol.1, pp. 353–370. USA

Mukosa, C.F.G. and Mwiinga, P.C. (2008). *Transboundary issues on sustainable hydropower development in the Zambezi river basin in the eyes of the Zambezi river authority.* A ZRA Presentation at the Ministry of Energy and Water Development, Zambia. Hydropower Sustainability Assessment Forum Meeting: 4 September. Kafue Gorge Regional Training Centre

Mwaipopo, O.U. (2000). Implications of accelerated sea-level rise (ASLR) and climate change for Tanzania. In *Proceedings of the SURVAS Expert Workshop on "African Vulnerability and Adaptation to Impacts of Accelerated Sea-level Rise (ASLR)"* (eds. A.C. de la Vega-Leinert, R.J. Nicholls, A. Nasser Hassan and M. El-Raey) pp. 53-54. Cairo, Egypt

Oyieke, H. (2000). Implications of accelerated sealevel rise (ASLR) for Kenya. In *Proceedings of the SURVAS Expert Workshop on African Vulnerability and Adaptation to Impacts of Accelerated Sealevel Rise* (eds. A.C. De la Vega-Leinert, R. J. Nicholls, A. Nasser Hassan and M. El-Raey) pp. 55. Cairo, Egypt

Roxy, M.K., Ritika, K., Terray, P. and Masson, S. (2014). The Curious Case of Indian Ocean Warming. *J. Clim*. 27(22), 8501-8509

Schott, F.A., Shang-Ping, X. and McCreary, J.P. (2009). Indian Ocean circulation and Climate Variability. *Rev. Geophys.* 47, 1–46

Schwarzkopf, F.U., and Boning, C. W. (2011). Contribution of Pacific wind stress to multi-decadal variations in upper-ocean heat content and sealevel in the tropical south Indian Ocean. *Geophys. Res. Lett.* 38(12)

Shiklomanov, I.A. (1998). *World Water Resources: A new appraisal and assessment for the twenty-first century*. UNE-

SCO, UK

Siedler, G., Griffies, S.M., Gould, J. and Church, J.A. (2013). *Ocean Circulation and Climate, A 21st Century Perspective*. 2nd edition, vol. 103. International Geophysics Series, Academic Press: Oxford, Amsterdam

Stewart, R.H. (2008). *Introduction to Physical Oceanography*. Department of Oceanography. Texas A. and M. University

Talley, L.D. (2008). Freshwater transport estimates and the global overturning circulation: Shallow, deep and throughflow components, *Prog. Ocean*. 78, 257–303

Talley, L.D., Pickard, G.L., Emery, W.J. and Swift, J.H. (2011). *Descriptive Physical Oceanography: An Introduction*. 6th edition. Academic Press, Elsevier, Boston

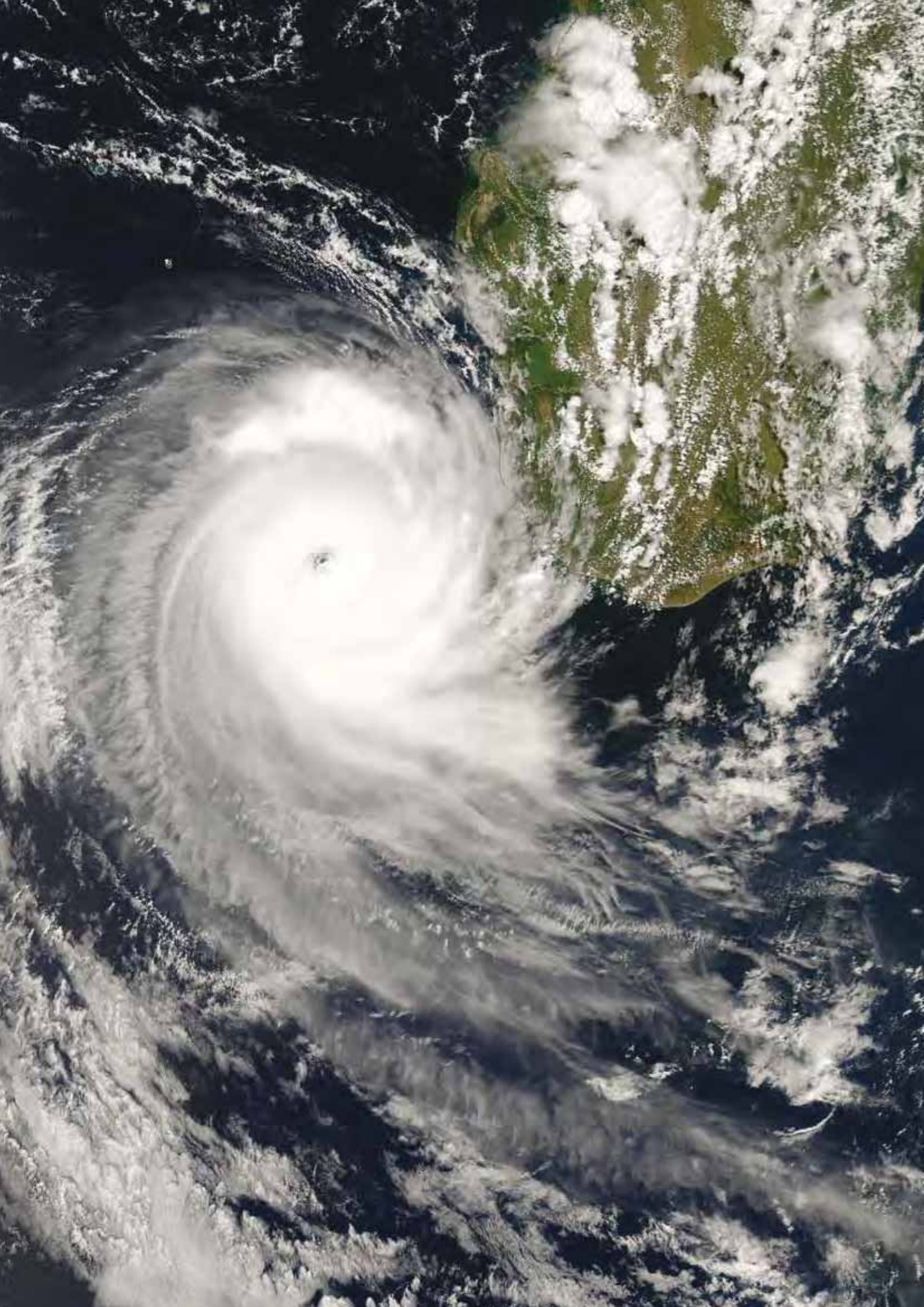
Tomczak, M. and Godfrey, J.S. (1994). *Regional Oceanography: An Introduction*. Pergamon Press, London

UNEP (2002). *State of the environment and policy retrospective: 1972–2002*. Earthscan Publications Ltd, London

Washington, R. and Preston, A. (2006). Extreme wet years over southern Africa: Role of Indian Ocean sea surface temperature. *J. Gephys. Res. Atmospheres* 111(D15)

Xie, S.-P., Annamalai, H., Schott, F.A. and McCreary Jr., J.P. (2002). Structure and mechanisms of South Indian Ocean climate variability. *J. Clim*. 15(8), 864-878

Zinke, J., Pfeiffer, M., Timm, O., Dullo, W.-C., Kroon, D. and Thomassin, B.A. (2008). Mayotte coral reveals hydrological changes in the western Indian Ocean between 1881 and 1994. *Geophys. Res. Lett*, 35(23)



15
Sea/Air Interaction

Shigalla Mahongo

Opposite page: Cyclone Favio entering the Mozambique Channel on 20 February 2007. © Nasa/Jeff Schmaltz/Goddard Space Flight Center.

INTRODUCTION

The atmosphere and the ocean form a coupled system, constantly exchanging mass (in the form of water, gas, spray, bubbles and particles) and energy at the interface between the seawater and air. This energy exchange occurs in the form of momentum (through wind stress) and heat. In other words, the atmosphere forces the ocean through exchange of momentum, net surface heat flux and freshwater flux. The exchanges at the sea/air interface are irregular, taking place at rates which are largely induced by the dynamics at the surface. The exchanges affect the biological, chemical and the physical properties of the ocean thus influencing its biogeochemical processes, weather and climate. Heat loss from the ocean to the atmosphere plays a vital role of regulating heat balance as well as moisture and energy budgets of the atmosphere. The mean climate of the Earth over long time scales is therefore partly shaped by the convergence/divergence of the oceanic heat exchanges, which act as sources and sinks of heat for the atmosphere (Lee and others, 2010).

An understanding of the extent to which the sea and the air influence each other is about large scale sea-air interactions. The biogeochemical interaction between the sea and the air that involve gas and chemical exchanges are important to life processes. This interaction is sustained by the mixing of the surface by wind and waves to keep a balance between the ocean and the atmosphere. About half the world's oxygen is produced by phytoplankton in the sea (Falkowski 2012), which are at the base of the marine food web. The phytoplankton, through the photosynthesis process, also extract carbon dioxide (CO_2), a greenhouse gas that contributes significantly to current global warming (Ciais and others, 2013). The oceans therefore act as major sinks for atmospheric CO_2. With the exception of the Indian Ocean, where the phytoplankton levels have remained relatively stable since the 1950s, the levels in the other oceans have generally declined by about 40 per cent (Boyce and others, 2010).

Whereas photosynthesis is one of the major biogeochemical processes which take the CO_2 from the atmosphere to the ocean, there are other biogeochemical processes which eventually lead to the removal of CO_2 from the sea. The dissolved CO_2 may either react with the sea water to form carbonic acid or with carbonates already in the water to form bicarbonates. Either of the two processes removes dissolved CO_2 from the sea water. Many marine plants and animals use the bicarbonate to form calcium carbonate skeletons (or shells). If the sea/air interaction processes remained unchanged, there would be a permanent balance between the concentrations of CO_2 in the atmosphere and the ocean. However, the levels of CO_2 in the atmosphere have been rising, so more of the gas is dissolving in the ocean and which is no longer able to absorb the increased concentration of CO_2 in the atmosphere without changes to the acidity levels (Singh and others, 2014).

The exchanges that involve more reactive gases such as dimethyl sulphide can alter cloud formation and hence albedo (Bigg and others, 2003). Particulate matter containing elements such as iron derived from continental land masses would tend to alter ocean primary productivity with impacts on other biogeochemical exchanges that might multiply. An iron deficit in sea water could be one of the major limiting factors for phytoplankton growth. However, wind borne dust from the deserts such as the Sahara plays a significant role in replenishing this important element in the sea (Bigg and others, 2003).

Every atmospheric gas is in equilibrium with its component that is dissolved in sea water, with dissolved oxygen and CO_2 being among the most important gases. Dissolved oxygen is critically important for respiration of aquatic animals, which releases energy from carbohydrates, releasing CO_2 and water as by-products. As for dissolved CO_2 this gas is very important for marine plants, which use dissolved CO_2 to manufacture carbohydrates through photosynthesis, releasing oxygen as a by-product (Karleskint and others, 2012). The main objective of this chapter is to review the status of the Western Indian Ocean (WIO) regional sea/air interactions and their associated environmental, economic and social implications.

CHANGES IN ATMOSPHERIC FLUXES AND CONCENTRATION LEVELS OF OXYGEN AND CARBON DIOXIDE

Changes in Atmospheric fluxes

The turbulent fluxes of heat, water and momentum through the sea surface constitute the principal coupling between the ocean and the atmosphere. The fluxes play an important role in driving both the ocean and atmospheric circulations, thereby redressing the heat imbalance. The air–sea fluxes also influence temperature and humidity in the atmosphere and, hence, the hydrological cycle (Rhein and others, 2013). Consequently, the exchange and transporting processes of these fluxes are essential components of global climate. The WIO region is strongly affected by external forcing, leading to interannual climatic variability such as the El Niño Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD), as well as seasonal climatic variability such as the monsoon circulation (Manyilizu and others, 2014).

Exchange of momentum through wind stress

The exchange of momentum between the atmosphere and the ocean, through wind stress, is the primary driver of ocean circulation, particularly the surface currents. Wind stress is a measure of momentum transferred from the atmosphere to the ocean (Collins and others, 2013). However, momentum exchange is complicated by the stratification or stability of the atmospheric boundary layer, the wave field near the surface, and a host of other processes. At the global level, there is evidence that the zonal mean wind stress at the sea-air interface has increased in strength since the early 1980s (Rhein and others, 2013).

In the WIO region, the trend of surface-wind stress pattern over the period 1966-2007 showed an enhanced convergence around 15°S due to anomalous north-westerly winds from the equator (Nidheesh and others, 2013). These wind changes resulted in a large negative wind stress curl anomaly around 10°S, dynamically consistent with the decrease in total steric sea level anomaly (SSLA) observed in the southwestern Indian Ocean region. The trend of wind stress in the western Equatorial Indian Ocean (WEIO) and Southwest Indian Ocean (SWIO) sub-regions with monthly NCEP data for the period 1982 to 1994 (May through September), showed very high values over the sub-region.

Heat flux

Information on sea-air heat fluxes over the WIO is generally scarce due to the relative paucity of data, making it difficult for one to make conclusive judgements on the general trends. At the global scale, the accuracy of the observations are also currently insufficient to permit direct assessment of changes in heat flux (Rhein and others, 2013). However, the net flux of heat at the sea surface in the tropical oceans, including the WIO region, is characterized by net gain due to incoming shortwave solar radiation, and net loss due to evaporation and heat fluxes (Jayakrishnan and Babu, 2013).

A study carried out in the east coast of Zanzibar Island, at Chwaka Bay, over a short period in January/February 1996 indicated a net gain to the bay of 275.5 W/m^2 due to incoming shortwave solar radiation (Mahongo 1997). The net heat loss was due to the sum of the fluxes of evaporation (157.8 W/m^2), long-wave back radiation (38.1 W/m^2) and sensible heat (17.8 W/m^2), respectively (Mahongo 1999, Mahongo 2000). The net heat gain to the

sea was therefore 61.8 W/m^2 which could be accounted for by advection flux to the offshore (Mahongo 1997). Similar quantities of evaporation and sensible heat fluxes in the offshore around the same latitude and season are slightly lower, being estimated at 92 W/m^2 and 11 W/m^2 (Ramesh Kumar and Gangadhara Rao 1989).

Over recent decades, trends have been recorded in many of the parameters that affect heat transfer at the sea-air interface. These include: definitive increase in sea surface temperature (SST) (Roxy and others, 2014), in surface air temperature (Vincent and others, 2011) and in wind speed (Mahongo and others, 2012, Shaghude and others, 2013). For instance, during the period 1901-2012, the tropical WIO, which is generally cool, has experienced an anomalous warming of 1.2 °C in summer SST, at a rate that is greater than recorded in any tropical ocean region (Roxy and others, 2014). The observed ocean warming could potentially change the monsoon circulation and precipitation patterns over the WIO region with impacts on the marine food webs that would multiply due to reductions in the productive diatoms which are the basis of the food chain. This will result in relatively less energy available to support high-level marine vertebrates such as fish and marine mammals.

Upper Ocean Heat Content

The ocean's large mass and high heat capacity allow it to store huge amounts of energy. However, due to increasing concentrations of greenhouse gases, heat radiated from the earth's surface does not escape freely into space. Most of the excess heat is therefore stored in the upper ocean, leading to the rising of the upper ocean heat content (Levitus and others, 2009). During the last four decades (1971-2010), estimates from global ocean temperature measurements indicate that the upper ocean (0 to 700 m depth) has absorbed about 137 TW of heat (1 TW = 10^{12} watts), equivalent to 93 per cent of the combined heat stored by warmed air, sea, land and melted ice (Rhein and others, 2013).

In the Indian Ocean, in-situ and satellite observations, ocean-atmosphere re-analysis products and re-constructed datasets show basin-scale decadal warming trends in the upper ocean heat content for the period 1955 to 2008, which were attributed to anthropogenic forcing (Levitus and others, 2009). More recently, Chu (2011) used monthly synoptic temperature and salinity datasets for the Indian Ocean between 1990 and 2009 to study the upper ocean heat content. The results indicated that the first two Empirical Orthogonal Function (EOF) modes accounted for between 24.27 and 20.94 per cent of the variance, representing basin-scale cooling/warming (EOF-1) and Indian Ocean Dipole (EOF-2) events, respectively. The observed trends in ocean heat content may therefore lead to rising sea levels and significant stress to some marine ecosystems.

Fresh water exchange

The ocean salinity, which is a proxy indicator of freshwater fluxes to the oceans (Bingham and others, 2012), increased from 1987 to 2002 in the upper thermocline of the WIO along 32°S (Álvarez and others, 2011), reversing the freshening trend which previously occurred from 1962-1987 (Bindoff and McDougall 2000). After the recent advent of the use of Argo floats, tracking of surface ocean salinity achieved near-global coverage in 2004. The data showed an increasing trend of ocean salinity in the WIO region between 2004 and 2013. Diagnosis and understanding of trends in ocean surface salinity is important because changes in salinity affect circulation, water column stratification as well as changes in regional sea level (Rhein and others, 2013). For instance, historical salinity measurements in the WIO show strengthening of the South Equatorial Current (SEC) in the 1950–1975 interval compared with the early 2000s due to excess of evaporation over precipitation (Zinke and others, 2005). This in turn affects biological productivity, the capacity of the ocean to store heat and carbon and, therefore, the carbon cycle.

Changes in concentration levels of oxygen and carbon dioxide

Available records from the Indian Ocean (including the WIO region) between 1962 and 2002 indicate that oxygen concentration at a mean latitudinal section of 32°S has undergone two major changes. The first change involved a pronounced decreasing trend in concentration levels between 1962 and 1987 (Bindoff and McDougall 2000). The second phase occurred between 1987 and 2002, where the concentration levels reversed to reveal an increasing trend (McDonagh and others, 2005). Bindoff and McDougall (2000) attributed the decrease during the first phase to the slowing down of the subtropical gyre circulation in the south Indian Ocean, implying that the gyre circulation may have accelerated during the second phase.

Changes in the concentration levels of oxygen may have important implications for marine ecosystems and socio-economic livelihoods of coastal communities. In view

of this, Körtzinger and others (2006) have proposed oxygen to be used as one of the climate change indicators. Furthermore, measurements of oxygen generally have relatively high precision and accuracy, making oxygen suitable for being used as a target tracer on large-scale observing programs for detection of decadal changes (Gruber and others, 2007).

In the upper thermocline, subtropical, subsurface water of the Indian Ocean along 20°S (which includes the southwestern Indian Ocean), anthropogenic CO_2 storage over an 8-year period (between 1995–2003/2004) is reported to have increased at an average rate of 7.1 mol/m^2 (Murata and others, 2010). The observed change is almost two times higher than that reported during the previous decade (between 1978 and 1995), which was 13.6 mol/m^2 (Sabine and others, 1999).

The world's oceans play a significant role as sinks for anthropogenic carbon, sequestrating roughly one-third of the cumulative human CO_2 emitted from the atmosphere over the industrial period (Khatiwala and others, 2013). Other studies note that the oceanic anthropogenic carbon inventory has increased between the period spanning from 1994 and 2010 (Christensen and others, 2013). Although the carbon sequestration concept has recently triggered global concerns, very few studies have been undertaken in the WIO region. Among the outstanding studies on carbon sequestration concept conducted in the WIO region include Sengul and others (2007), Alemayehu and others (2014) and Jones and others (2014).

METEOROLOGICAL PHENOMENA OF THE WESTERN INDIAN OCEAN

Monsoon winds

The WIO exhibits more pronounced seasonal wind reversals than the rest of the Indian Ocean and is an important region of air–sea interaction (Benny 2002). Two types of seasonal wind systems have been documented, namely the northeast (NE) and southeast (SE) trade winds, leading to the NE and SE monsoon seasons. Both trade wind systems are influenced by seasonal shifts in the Inter-Tropical Convergence Zone (ITCZ). The most important factor that determines the generation of the monsoon seasonal wind pattern is the geographical orientation of the Indian Ocean. It is bounded to the north by the Asian continent, which largely influences the meteorology of the region. The other factor is the presence of the East African Highlands, which play an important role in establishing the upper air flow, in particular the Somali Jet, which has a considerable impact on WIO weather patterns (Slingo and others, 2005).

The SE trade winds (April-October) originate from the semi-permanent South Indian Ocean anticyclone (Mascarene High). Conversely, the NE trades (November-March) originate from the semi-permanent high pressure system centred in the Arabian Gulf (Arabian High), also related to pressure build-up over Siberia (Siberian High). The shifting of the ITCZ northwards and then southwards gives the coast of East Africa its marked biannual rainy seasons with the long rains in March-April-May and the short rains in October-November-December. Due to the effect of the Coriolis force, the NE winds veer to the northwest in the south of the equator, whereas the SE winds veer to the west in the north of the equator. An important wind-driven feature in WIO is the upwelling phenomena off the coast of Somalia. During the SE monsoon season, an upwelling of cold water mass is established in this area, characterized by lowering of SST to about 22°C on average (Mafimbo and Reason 2010).

Over the last three decades, both the mean and maximum speeds of the monsoon winds have generally strengthened in some parts of the region such as in Tanzania (Mahongo and others, 2012). While these changes could be attributed to the global climate changes, they could also be related to natural decadal cycles of the climate system, including the 22-year Hale solar cycle (Mahongo 2014). Therefore, a longer time series dataset is needed to ascertain whether the increasing trend will persist. Dunne and others (2012) have found no evidence of changes in the wind regime in the region (at Diego Garcia) during the recent past. A global assessment by the Intergovernmental Panel on Climate Change (IPCC) also noted a low confidence in changes of surface wind speeds due to uncertainties in datasets and measures used (Hartmann and others, 2013).

Tropical cyclones

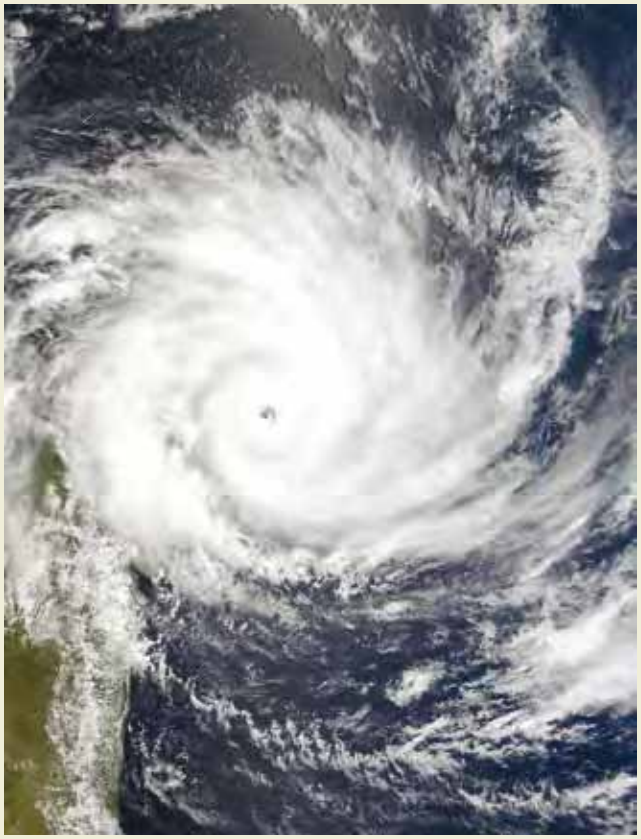
As part of planet's Warm Pool, tropical cyclones are an important feature of the meteorology of the WIO region, particularly over the southwest Indian Ocean. Cyclone activity in the WIO region is strongly influenced by anomalously warm SSTs in the tropical South Indian Ocean, which is a critical factor in their formation. Most of the cyclones originate from the east of Madagascar (50°–100°E, 5°– 15°S) and some from the Mozambique Channel during

Austral summer (Ho and others, 2006). The tropical cyclone season extends from October to May, and about 11-12 cyclones (tropical storms and hurricanes) occur annually (Bowditch 2002). In each season, about four cyclones reach hurricane intensity. The islands of Comoros, Mauritius and Madagascar lie within the region of tropical cyclone activity, while Réunion, Mayotte, Comoros, and Mozambique are also prone to direct landfall (Figure 15.1). On rare occasions, some parts of southern Tanzania and South Africa can also be affected.

Webster and others (2005) observed an increase in the annual frequency of cyclones in the South Indian Ocean within the period 1970 and 2004. The number of intense tropical cyclones also increased from 36 during 1980-1993 to 56 during 1994-2007, parallel to a simultaneous but smaller decrease in the number of tropical storms (Mavume and others, 2009). Globally however, the current datasets do not indicate any significant trends in tropical cyclone frequency over the past century (Christensen and others, 2013). It also remains uncertain whether any reported long-term increases in tropical cyclone frequency are robust, after accounting for past changes in observing capabilities (Christensen and others, 2013). Incidentally, no significant trends were observed in the annual numbers of tropical cyclones in the South Indian Ocean between the period 1981–1982 to 2006–2007 (Kuleshov and others, 2010).

Apparently, one of the challenges in tracking changes in the frequency and intensity of cyclones is that the record of past events is heterogeneous. This is due to changes in observational capabilities and how cyclones have been measured and recorded. It is thus difficult to draw firm con-

BOX 15.1. TROPICAL CYCLONE GAFILO AND ITS IMPACT IN MADAGASCAR



Cyclone Gafilo approaching Madagascar on 6 March 2004. © Nasa/Jeff Schmaltz/Goddard Space Flight Center.

The Tropical Cyclone Gafilo, which struck the northeast coast of Madagascar early on the morning of 7 March 2004, was the most intense and devastating tropical cyclone ever recorded in the Southwest Indian Ocean. The cyclone was unusually large and violent, with wind speeds of about 250 km/h, and gusts of up to 330 km/h. Gafilo was the deadliest and most destructive cyclone of the 2003/2004 cyclone season.

Gafilo originated from south of Diego Garcia, and intensified into a moderate tropical storm on 3 March 2004. Gafilo became a tropical cyclone on 4 March 2004, and ultimately intensified into a very intense tropical cyclone on 6 March 2004, prior to making landfall over Madagascar early on 7 March 2004. After crossing Madagascar, Gafilo emerged into the Mozambique Channel and made landfall over Madagascar again on 9 March 2004. After a three-day loop overland, the system arrived back over the southern Indian Ocean on 13 March 2004, and transitioned into a subtropical depression on 14 March 2004.

The cyclone caused a massive destruction of property and 85 per cent of the city of Antalaha was destroyed. The cyclone claimed 237 lives, with 181 missing persons and 879 injured, and caused a property loss of about US$ 250 million in Madagascar. More than 304 000 people were displaced by the storm and more than 6 000 hectares of agricultural land were flooded, resulting in major crop losses. Total rainfall for the period 3–10 March 2004 reached values of up to 500 mm in an area from the central Mozambique Channel eastward along the northwest coastline of Madagascar.

clusions on the observed trends prior to the satellite era and in ocean basins such as the South Indian Ocean (Christensen and others, 2013). According to Christensen and others (2013), tropical cyclone numbers are unlikely to increase, but cyclone maximum intensity is likely to increase on the global average, meaning increased maximum precipitation and winds.

Monsoon rains

Coastal rainfall in the western Indian Ocean is mostly seasonal, with the heaviest and most prolonged rains occurring during the months of March to June. Most parts of the region experience annual rainfall of between 1 000 to 2 000 mm, but local variations are common (Ngusaru 2002). Generally, the effect of rainfall and river runoff on salinity is restricted to narrow coastal fringes.

The trends in precipitation indices in the western Indian Ocean are generally weak and show less spatial coherence. Vincent and others (2011) found a significant decrease in the total annual rainfall during the period 1961-2008. Their results also indicate some increase in consecutive dry days, no change in daily intensity and consecutive wet days, and a decrease in extreme precipitation events. Weak correlations were found between precipitation indices and surface air temperature. The IPCC regional climate projections for the 21st century indicate an increase in the annual mean rainfall over East Africa (Collins and others, 2013).

Sea Surface Temperature (SST)

The WIO region's meteorology is dominated by the seasonal reversal of the monsoon wind systems, leading to the largest annual variations in SSTs found in any of the tropical oceans. On the inter-annual timescale, the SST in the WIO region is primarily influenced by the El Niño Southern Oscillation and the Indian Ocean Dipole (IOD). Manyilizu and others (2014), using NCEP Reanalysis data stretching from 1980 to 2007, observed these two signals in the region that were prominent at periods of 5 and 2.7 years, respectively. According to the IPCC Fifth Assessment Report (AR5), the WIO region's SST trend over the period 1950–2009, computed using monthly SST data extracted from the Hadley Centre HadISST1.1 data set (Rayner and others, 2003), indicate an increase of 0.60°C (Hoegh-Guldberg and others, 2014). In the Somali Current surface waters, the same dataset indicated an increase of 0.26°Cover the period between 1982 and 2006 (Hoegh-Guldberg and others, 2014).

During 1901-2012, the tropical western Indian Ocean (50-65°E, 5°S-10°N) experienced anomalous warming of 1.2°C in austral summer SSTs, surpassing that of the Indian Ocean warm pool which increased by only about 0.7°C (Roxy and others, 2014). The increase in temperature of the generally cool WIO against the rest of the tropical warm pool region affects zonal SST gradients, and could potentially change the monsoon circulation pattern, with impacts on rainfall patterns as well as changes on the marine food webs in the region. This is due to the fact that warming causes the air over the ocean to expand and lower the atmospheric pressure consequently unsettling the wind pattern which, in turn, may lead to the changes on monsoon flow pattern.

Besides anthropogenic global warming, the natural long-term warming trend of the Indian Ocean during the period 1901-2012 was influenced by the asymmetry in the El Niño Southern Oscillation (ENSO) teleconnection, whereby El Niño events induced anomalous warming over the WIO and La Niña events failed to do the reverse (Roxy and others, 2014). The period between 1950 and 2012 was characterized by strong and frequent occurrences of positive El Niño events (Roxy and others, 2014), consistent with the period 1960-2004 (Ihara and others, 2008). The warming in the region has also been attributed to positive SST skewness associated with ENSO, as the frequency of El Niño events have increased during recent decades (Roxy and others, 2014).

ENVIRONMENTAL, ECONOMIC AND SOCIAL IMPLICATIONS OF TRENDS IN METEOROLOGICAL PHENOMENA

Abrupt cyclogenesis is known to increase the risk of marine environmental hazards and coastline erosion particularly for island states such as Mauritius, Reunion and Madagascar (Chang-Seng and Jury 2010). The cyclones may bring severe flooding to coastal areas of Africa, as exemplified in Mozambique in February 2000 (Box 15.1). In some parts of the region, cyclones had been associated with heavy swells which created significant rises in sea levels that affected coastal infrastructure such as roads and settlements, as well as beach stability (Ragoonaden 1997). Considering the vulnerability of the coastal communities of the WIO region to tropical cyclone activity, especially the island states and low-lying areas of Mozambique, developing better monitoring and forecast tools for such sporadic weather events should be given high priority.

Anthropogenic ocean acidification

Ocean acidification is a relatively new field of research, with most of the research conducted to-date being short-term and laboratory based. Acidification is a direct consequence of increased atmospheric CO_2 emissions to the atmosphere. A proportion of the emitted gas stays in the atmosphere as greenhouse gas, while some of it leaves the atmosphere to either become sequestered in trees and plants or become absorbed in the oceans. Ocean acidification alters the chemical speciation and biogeochemical cycles of many elements and compounds in sea water, creating repercussions throughout marine food chains. The chemical changes caused by the uptake of CO_2 cause many calcifying species to exhibit reduced calcification and growth rates, and an increase in carbon fixation rates in some photosynthetic organisms. Acidification is also known to increase erosion of carbonate rocks, degradation of coral reef habitats and alteration of the otoliths of pantropical fish species with implications for sensory function (Bignami and others, 2013).

There is a financial barrier in pursuing research on ocean acidification in developing countries, including the WIO region, due to the high costs associated with the nature of the research. Currently, a few monitoring studies on seawater pH are undertaken, but no long-term observational studies have yet been embarked on (Sumaila and others, 2014). Recently, however, some initiatives have begun to address these shortcomings through collaboration with international research institutions by studying some aspects of ocean acidification. In Tanzania for instance, the UK Ocean Acidification Research Programme is currently investigating a variety of geological records of a newly recovered borehole through marine sediments to study the response of the carbon cycle during the rapid onset of the Paleocene / Eocene thermal maximum (PETM) using new computer models (Aze and others, 2014).

In Kenya, the International Atomic Energy Agency (IAEA) is collaborating with CORDIO-East Africa through the Coordinated Research Project (CRP) to: identify and describe pathways of impact of ocean acidification, improve understanding of the vulnerability of regions and markets to ocean acidification, and quantify economic impacts of biological effects of ocean acidification to assist natural resource management and policy decisions on regional and local scales.

ENVIRONMENTAL, ECONOMIC AND SOCIAL IMPLICATIONS OF TRENDS IN OCEAN ACIDIFICATION

Ocean acidification has only recently been recognized as a global threat, with potentially adverse environmental, economic and social implications. Being a complex phenomenon, isolating it from other factors affecting the ocean such as surface warming and coastal pollution is very challenging. Furthermore, it takes time to observe developments that impact the environment, economy and human society. The adverse effects of rising acidity include an alteration of the health of many marine species such as plankton, molluscs, and other shellfish (Table 15.1). In particular, corals can be very sensitive to increased acidity, which may lead to alteration to the reef-fish habitat.

Most of the coastal communities in the region are small-scale artisanal fishers who are highly dependent upon fishing for their livelihoods (Kimani and others, 2009). Changes to harvest could therefore be a threat to food security. Aquaculture in the region is increasing and has promising potential. A shift toward new production methods and cultured species may provide benefits to household livelihoods and small and medium enterprise development. More information is therefore needed on carbon chemistry and fisheries in the region.

Although the impacts of long-term changes in ocean acidification on marine organisms and their ecosystems are much less certain, due to the fact that the physiological attributes of marine ecosystems is highly variable, the effects among organisms will generally also be variable. Considering the generation spans of the different species, it is possible that the impact of acidification and the degree to which species adapt to their changing environment can take years or decades to observe. In the WIO region, no observational or direct experimental data or studies on trends in ocean acidification impacts have been undertaken. However, areas such as the monsoon-induced upwelling zones as well as the coastal and estuarine waters in the region are natural hotspots of special concern. These areas support lucrative fisheries, but the upwelled waters with high CO_2 content make them particularly sensitive to increased ocean acidification.

In view of the on-going changes in global climate and the associated alterations in ocean acidification, coastal communities in the WIO region need to have a clear understanding of the possible scale of potential impacts based on assessment of exposure, sensitivity and adaptive

capacity. Case studies need to be undertaken on the environmental, economic and social impacts on ecosystems and aquatic organisms, especially for the species most vulnerable to ocean acidification. Comprehensive risk assessments should also be designed and implemented to prioritize adaptive responses.

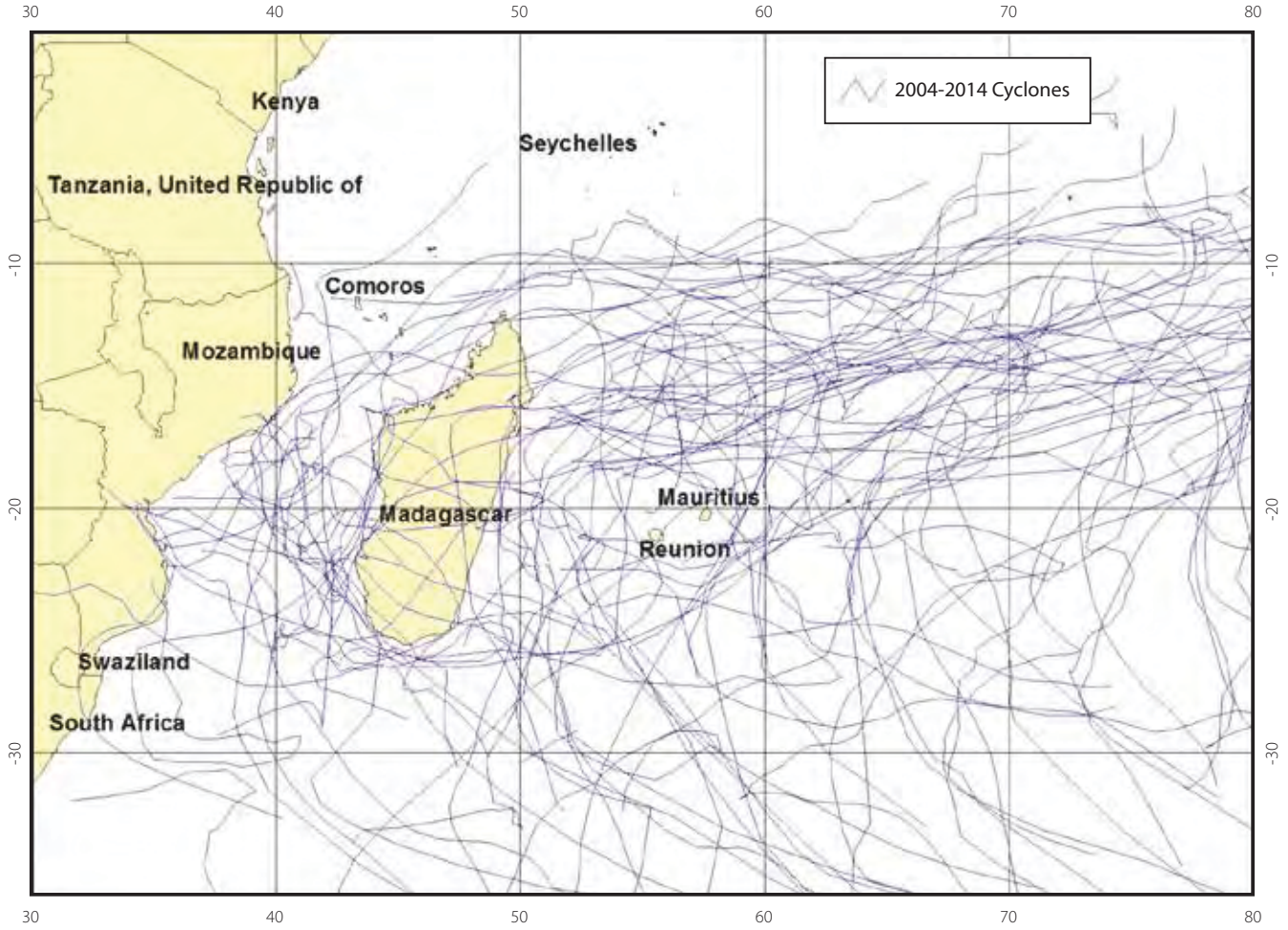


Figure 15.1. WIO Tropical Cyclone Trackline (2004-2014).

Table 15.1. Summary of the anticipated future effects of ocean acidification on different groups of marine organisms, mostly based on experimental studies from around the world. Note that none of the data is from this region. Table adopted from Sumaila and others (2014).

Group	Main acidification impacts
Warm water corals	A relatively well-studied group. The great majority of experiments show that increasing seawater CO_2 decreases adult coral calcification and growth, and suppresses larval metabolism and metamorphosis. Although most warm water coral reefs will remain in saturated waters by 2100, saturation levels are predicted to decline rapidly and substantially; thus coral calcification is unlikely to keep up with natural bioerosion. Interactions with other climatic and anthropogenic pressures give cause for concern.
Molluscs	Significant effects on growth, immune response and larval survival of some, although with high inter-specific. Pteropods seem particularly sensitive and are a key component of high latitude food webs. Molluscs are important in aquaculture, and provide a small yet significant protein contribution to human diet.
Echinoderms	Juvenile life stages, egg fertilization and early development can be highly vulnerable, resulting in much reduced survival Adult echinoderms may increase growth and calcification; such responses are, however, highly species specific.

Group	Main acidification impacts
Crustaceans	The relative insensitivity of crustaceans to ocean acidification has been ascribed to well-developed ion transport regulation and high biogenic content of their exoskeletons. Nevertheless, spider crabs show a narrowing of their range of thermal tolerance by ~2˚C under high CO_2 conditions.
Foraminifera	Shell weight sensitive to CO_3^{2-} decrease in the laboratory with field evidence for recent shell-thinning.
Fish	Adult marine fish are generally tolerant of high CO_2 conditions. Responses by juveniles and larvae include diminished olfactory ability, affecting predator detection and homing ability in coral reef fish and enhanced otolith growth in sea bass.
Coralline algae	Meta-analysis showed significant reductions in photosynthesis and growth due to ocean acidification treatments. Elevated temperatures (+3°C) may greatly increase negative impacts. Field data at natural CO_2 vents show sensitivity of epibiont coralline algae.
Non-calcified macro-algae; sea grasses	Both groups show capability for increased growth. At a natural CO_2 enrichment site, sea grass production was highest at mean pH of 7.6.
Coccolitho-phores	Nearly all studies have shown reduced calcification in higher CO_2 seawater. However, the opposite effect has also been reported, and ocean acidification impacts on coccolithophore photosynthesis and growth are equivocal, even within the same species. This variability may be due to the use of different strains and/or experimental conditions.
Bacteria	Most cyanobacteria (including Trichodesmium, a nitrogen-fixer) show enhanced photosynthesis and growth under increased CO_2 and decreased pH conditions. Heterotrophic bacteria show a range of responses with potential biogeochemical significance, including decreased nitrification and increased production of transparent exopolymer particles (affecting aggregation of other biogenic material and its sinking rate). Adaptation by bacteria to a high CO_2 world may be more rapid than by other groups.



Figure15.2. Floods in Mozambique in January 2013. © Phil Hay/UN/World Bank.

References

Alemayehu, F., Richard, O., James, K.M., and Wasonga, O. (2014). Assessment of Mangrove Covers Change and Biomass in Mida Creek, Kenya. *Open Journal of Forestry* 4, 398-413

Álvarez, M., Tanhua, T., Brix, H., Lo Monaco, C., Metzl, N., McDonagh, E.L. and Bryden, H.L. (2011). Decadal biogeochemical changes in the subtropical Indian Ocean associated with Subantarctic Mode Water. *J. Geophy. Res., Oceans* 116(C9)

Aze, T. , Barry, J. , Bellerby, R.G. , Brander, L. , Byrne, M. , Dupont, S. , Gattuso, J.P. , Gibbs, S. , Hansson, L. , Hattam, C. , Hauton, C. , Havenhand, J. , Fosså, J.H. , Kavanagh, C. , Kurihara, H. , Matear, R.J. , Mark, F.C. , Melzner, F. , Munday, P. , Niehoff, B. , Pearson, P. , Rehdanz, K. , Tambutte, S. , Turley, C.M. , Venn, A. , Warnau, M. and Young, J.R. (2014). An Updated Synthesis of the Impacts of Ocean Acidification on Marine Biodiversity. *CBD Technical Series* No 75 Montreal, Québec, Canada, Secretariat of the Convention on Biological Diversity

Benny, P.N. (2002). Variability of western Indian Ocean currents. *Western Indian Ocean J. Mar. Sci.* 1(1), 81-90

Bigg, G.R., Jickells, T.D., Liss, P.S. and Osborn, T.J. (2003). The role of the oceans in climate. *Int. J. Climatol.* 23(10), 1127-1159

Bignami, S., Enochs, I.C., Manzello, D.P., Sponaugle, S. and Cowen, R.K. (2013). Ocean acidification alters the otoliths of a pantropical fish species with implications for sensory function, *Proc. Natl. Acad. Sci. U.S.A.* 110(18), 7366-7370

Bindoff, N.L. and McDougall, T.J. (2000). Decadal Changes along an Indian Ocean Section at 32°S and Their Interpretation. *J. Phys. Ocean.* 30(6), 1207-1222

Bingham, F.M., Foltz, G.R. and M.J. McPhaden (2012), Characteristics of the seasonal cycle of surface layer salinity in the global ocean. *Ocean Sci. Discuss*, 8, 2377–2415

Bowditch, N. (2002). *The American practical navigator: an epitome of navigation*, 2002 Bicentennial Edition. Paradise Cay Publications

Boyce, D.G., Lewis, M.R. and Worm, B. (2010). Global phytoplankton decline over the past century. *Nature* 466(7306), 591-596

Chang-Seng, D.S. and Jury, M.R. (2010). Tropical cyclones in the SW Indian Ocean. Part 1: inter-annual variability and statistical prediction. *Meteorol. Atmos. Phys.* 106, 149-162

Christensen, J.H., Krishna Kumar, K., Aldrian, E., An, S.-I., Cavalcanti, I.F.A., de Castro, M., Dong, W., Goswami, P., Hall, A., Kanyanga, J.K., Kitoh, A., Kossin, J., Lau, N.-C., Renwick, J., Stephenson, D.B., Xie, S.-P. and Zhou, T. (2013). Climate Phenomena and their Relevance for Future Regional Climate Change. In *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the IPCC.* (eds. Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley) pp. 1217-1308 Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Chu, P.C. (2011). Global upper ocean heat content and climate variability. *Ocean Dynam.* 61(8), 1189-1204

Ciais, P., Sabine, C., Bala, G., Bopp, L., Brovkin, V., Canadell, J., Chhabra, A,. DeFries, R., Galloway, J., Heimann, M., Jones, C., Le Quéré, C., Myneni, R.B., Piao, S. and Thornton, P. (2013). Carbon and Other Biogeochemical Cycles. In *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the IPCC.* (eds. Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley) pp. 465-570. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Collins, M., Knutti, R., Arblaster, J., Dufresne, J.-L., Fichefet, T., Friedlingstein, P., Gao, X., Gutowski, W.J., Johns, T., Krinner, G., Shongwe, M., Tebaldi, C., Weaver A.J. and Wehner, M. (2013). Long-term Climate Change: Projections, Commitments and Irreversibility. In *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the IPCC.* (eds. Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley) pp. 1029-1136. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Dunne, R.P., Barbosa, S.M. and Woodworth, P.L. (2012). Contemporary sea level in the Chagos Archipelago, central Indian Ocean. *Glob. Planet. Chang.* 82-83, 25-37

Falkowski, P. (2012). Ocean Science: The power of plankton. *Nature* 483(7387), S17-S20

Gruber, N., Doney, S.C., Emerson, S.T., Gilbert, G., Kobayashi, T., Kortzinger, A., Johnson, G.C., Johnson, K.S., Riser, S.C. and Ulloa, O. (2007). *The Argo-Oxygen Program: A white paper to promote the addition of oxygen sensors to the international Argo Float program*. Version 5-1, Report, Argo Steering Comm.

Hartmann, D.L., Klein Tank, A.M.G., Rusticucci, M., Alexander, L.V., Brönnimann, S., Charabi, Y., Dentener, F.J., Dlugokencky, E.J., Easterling, D.R., Kaplan, A., Soden, B.J., Thorne, P.W., Wild, M. and Zhai, P.M. (2013). Observations: Atmosphere and Surface. In *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the IPCC*. (eds. Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley) pp. 159-254 Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Ho, C.-H., Kim, J.-H., Jeong, J.-H., Kim, H.-S. and Chen, D. (2006). Variation of tropical cyclone activity in the South Indian Ocean: El Niño–Southern Oscillation and Madden-Julian Oscillation effects. *J. Geophys. Res.-Atmos.* 111(D12)

Hoegh-Guldberg, O., Cai, R., Poloczanska, E.S., Brewer, P.G., Sundby, S., Hilmi, K., Fabry, V.J. and Jung, S. (2014). The Ocean. In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the IPCC* (eds. V.R. Barros, C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White) pp. 1655-1731. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Ihara, C., Kushnir, Y. and Cane, M.A. (2008). Warming trend of the Indian Ocean SST and Indian Ocean Dipole from 1880 to 2004. *J. Clim.* 21, 2035-2046

Jayakrishnan, P.R. and Babu, C.A. (2013). Study of the Oceanic Heat Budget Components over the Arabian Sea during the Formation and Evolution of Super Cyclone, Gonu. *Atm. Clim. Sci.* 3, 282-290

Jones, T.G., Ratsimba, H.R., Ravaoarinorotsihoarana, L., Cripps, G., and Bey, A. (2014). Ecological variability and carbon stock estimates of mangrove ecosystems in northwestern Madagascar. *Forests* 5(1), 177-205

Karleskint, G., Turner, R. and Small, J. (2012). *Introduction to Marine Biology*. Cengage Learning

Khatiwala, S., Tanhua, T., Mikaloff Fletcher, S., Gerber, M., Doney, S.C., Graven, H.D., Gruber, N., McKinley, G.A., Murata, A., Ríos, A.F. and Sabine, C.L. (2013). Global ocean storage of anthropogenic carbon. *Biogeosciences* 10(4), 2169-2191

Kimani, E.N., Okemwa, G.M. and Kazungu, J.M. (2009). Fisheries in the Southwest Indian Ocean: Trends and governance challenges. In *The Indian Ocean: Resource, Governance Challenges* (eds. Laipson, E. and Pandya, A.) pp. 3-16. The Henry L. Stimson Centre. Washington, D.C.

Körtzinger, A., Riser, S. C. and Gruber, N. (2006). Oceanic oxygen: The oceanographer's canary bird of climate change. *ARGO Newsletter* 7, 2-3

Kuleshov, Y., Fawcett, R., Qi, L., Trewin, B., Jones, D., McBride, J. and Ramsay, H. (2010). Trends in tropical cyclones in the South Indian Ocean and the South Pacific Ocean. *J. Geophys. Res.-Atmos.* 115(D1)

Lee, H.S., Takao Yamashita, T. and Seol Shim, J.-S. (2010). Wave-current interaction process in sea surface boundary layer considering wave breaking in deep and shallow water. *Geophys. Res. Abstr.* 12, 7750

Levitus, S., Antonov, J.I., Boyer, T.P., Locarnini, R.A., Garcia, H.E. and Mishonov, A.V. (2009). Global ocean heat content 1955-2008 in light of recently revealed instrumentation problems. *Geophy. Res. Lett.* 36(7), L07608

Mafimbo, A.J. and Reason, C.J.C. (2010). Air-sea interaction over the upwelling region of the Somali coast. *J. Geophy. Res., Oceans (1978-2012)* 115(C1)

Mahongo, S.B. (1997). *Sea surface heat exchange and bottom reflection in a tidal, shallow tropical lagoon: Chwaka Bay, Zanzibar*. MS thesis, Department of Oceanography. Gothenburg University, Sweden

Mahongo, S.B. (1999). Turbulent heat energy exchange in a tropical bay. *Tanz. J. Sci.* 25, 1-15

Mahongo, S.B. (2000). Radiative heat exchange in a tropical bay, east coast of Zanzibar. *Indian J. Mar. Sci.* 29, 12-18

Mahongo, S.B. (2014). *Analysis of met-ocean processes in relation to changes in large scale climatic systems in Tanzania and the western Indian Ocean*. PhD Thesis, University of Dar es Salaam

Mahongo, S.B., Francis, J. and Osima, S.E. (2012). Wind Patterns of Coastal Tanzania: Their Variability and Trends. *Western Indian Ocean J. Mar. Sci.* 10, 107-120

Manyilizu, M., Dufois, F., Penven, P. and Reason, C. (2014). Interannual variability of sea surface temperature and

circulation in the tropical western Indian Ocean. *Afri. J. Mar. Sci.* 36(2), 233-252

Mavume, A.F., Rydberg, L., Rouault, M. and Lutjeharms, J.R.E. (2009). Climatology and landfall of tropical cyclones in the south-west Indian Ocean. *Western Indian Ocean J. Mar. Sci.* 8(1), 15-36

McDonagh, E.L., Bryden, H.L., King, B.A., Sanders, R.J., Cunningham, S.A. and Marsh, R. (2005). Decadal Changes in the South Indian Ocean Thermocline. *J. Clim.* 18(10), 1575-1590

Murata, A., Kumamoto, Y., Sasaki, K., Watanabe, S. and Fukasawa, M. (2010). Decadal increases in anthropogenic CO2 along 20°S in the South Indian Ocean. *J. Geophy. Res., Oceans* 115(C12)

Ngusaru, A. (2002). Climate and oceanography. In *A field-guide to the seashores of Eastern Africa and the Western Indian Ocean Islands* (ed. Richmond, M. D.) pp. 12-16 Sida/SAREC

Nidheesh, A.G., Lengaigne, M., Vialard, J., Unnikrishnan, A.S. and Dayan, H. (2013). Decadal and long-term sea level variability in the tropical Indo-Pacific Ocean. *Clim. Dynam.* 41, 381-402

Ragoonaden, S. (1997). Impact of sea-level rise on Mauritius. *J. Coastal Res. (*Special Issue*)* 24, 206-223

Ramesh Kumar, M. R. and Gangadhara Rao, L. V. (1989). Latitudinal variation of air sea fluxes in the western Indian Ocean during Austral summer and fall. *Bound.-Layer Met.* 48, 99-107

Rayner, N.A., Parker, D.E., Horton, E.B., Folland, C.K., Alexander, L.V., Rowell, D.P., Kent, E.C. and Kaplan, A. (2003). Global analyses of sea surface temperature, sea ice, and night marine air temperature since the late nineteenth century. *J. Geophys. Res.-Atmos. (1984-2012)*, 108(D14)

Rhein, M., Rintoul, S.R., Aoki, S., Campos, E., Chambers, D., Feely, R.A., Gulev, S., Johnson, G.C., Josey, S.A., Kostianoy, A., Mauritzen, C., Roemmich, D. and Talley, L.D. (2013). Observations: Ocean. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the IPCC.* (eds. Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley) pp. 255-315. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Roxy, M.K., Ritika, K., Terray, P. and Masson, S. (2014). The Curious Case of Indian Ocean Warming. *J. Clim.* 27(22), 8501-8509

Sabine, C.L., Key, R.M., Johnson, K.M., Millero, F.J., Poisson, A., Sarmiento, J.L., Wallace, D.W. R. and Winn, C.D. (1999). Anthropogenic CO2 inventory of the Indian Ocean. *Glob. Biogeochem. Cycles* 13(1), 179-198

Sengul, M., Pillay, A.E., Francis, C.G., and Elkadi, M. (2007). Climate change and carbon dioxide (CO2) sequestration: an African perspective. *Int. J. Env. Studies* 64(5), 543-554

Shaghude,Y.W, Mburu, J., Uku, J., Ochiewo, J., Nyandwi, N., Ong'anda, H., Magori, C., Sanga, I. and Arthurton, R.S. (2013). Beach sand supply and transport at Kunduchi, Tanzania and Bamburi, Kenya. *Western Indian Ocean J. Mar. Sci.* 11, 135-154

Singh, S. K., Sundaram, S. and Kishor, K. (2014). *Photosynthetic Microorganisms: Mechanism for Carbon Concentration*. Springer

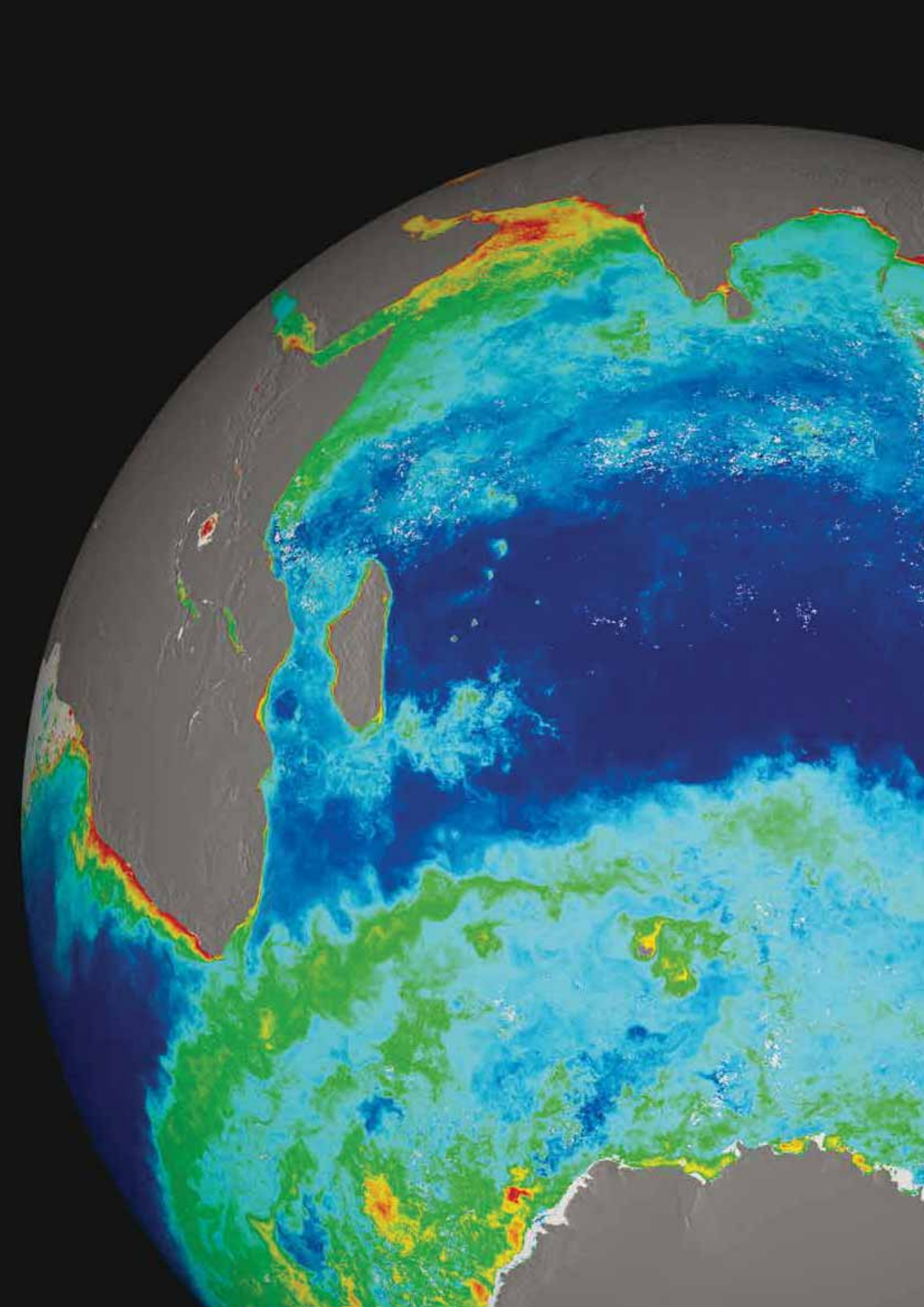
Slingo, J., Spencer, H., Hoskins, B., Berrisford, P. and Black, E. (2005). The meteorology of the Western Indian Ocean, and the influence of the East African Highlands. *Philos. Trans. R. Soc. Lond. A*, 363(1826), 25-42

Sumaila, U. R., Samoilys, M., Allison, E., Cinner, J., DeYoung, C. and Kavanagh, C. (2014). Economic Impacts of Ocean Acidification on Fisheries and Aquaculture in the Western Indian Ocean: Current Knowledge and Recommendations. *Indian Ocean and Red Sea (FAO 51, 57) DRAFT*

Vincent, L.A., Aguilar, E., Saindou, M., Hassane, A.F., Jumaux, G., Roy, D., Booneeady, P., Virasami, R., Randriamarolaza, L.Y.A., Faniriantsoa, F.R., Amelie, V., Seeward, H. and Montfraix, B. (2011). Observed trends in indices of daily and extreme temperature and precipitation for the countries of the western Indian Ocean, 1961–2008. *J. Geophys. Res.-Atmos.* 116(D10)

Webster, P.J., Holland, G.J., Curry, J.A. and Chang, H.R. (2005). Changes in Tropical Cyclone Number, Duration, and Intensity in a Warming Environment. *Science* 309(5742), 1844-1846

Zinke, J., Pfeiffer, M., Timm, O., Dullo, W.C. and Davies, G.R. (2005). Atmosphere-ocean dynamics in the Western Indian Ocean recorded in corals. *Phil. Trans. R. Soc. A* 363(1826), 121-142



16
Phytoplankton Primary Production

Margareth Kyewalyanga

Opposite page: Chlorophyll concentration in the WIO during the austral summer (Dec 2011-Mar 2012). © Nasa/Suomi NPP/Norman Kuring

INTRODUCTION

The plankton

Primary productivity may be defined as the amount of organic material produced per unit area per unit time; or simply as the product of phytoplankton biomass times phytoplankton growth rate (Cloern and others, 2014). Marine primary production plays an important role in food web dynamics, in biogeochemical cycles and in marine fisheries (Chassot and others, 2010, Passow and Carlson 2012). The term plankton, which means wandering or drifting, generally encompasses three groups: the phytoplankton, the photosynthetic (plant) component; the zooplankton, which is the animal component and the ichthyoplankton which comprise the fish larvae. However, this chapter will concentrate on the plant component, the phytoplankton. Phytoplankton is the foundation of the aquatic food web, meaning that they are the primary producers (Vargas and others, 2006). A common feature to all phytoplankton is that they contain chlorophyll-*a*; but there are other accessory pigments such as chlorophyll-*b* and chlorophyll-*c*, as well as photosynthetic carotenoids (Kirk 1994, Barlow and others, 2008). These pigments absorb solar energy and convert carbon dioxide and water into high-energy organic carbon compounds that fuels growth by synthesizing vital required components such as amino acids, lipids, protein, polysaccharides, pigments and nucleic acids. The photosynthetic process produces gross primary production; and the difference between gross primary production and respiration gives net primary production. Respiration is the release of carbon dioxide by photosynthetic organisms; leaving a net photosynthetic fixation of inorganic carbon into autotrophic biomass. Phytoplankton in the ocean contributes to roughly half of the planetary net primary production (Field and others, 1998). Through sinking of the fixed organic matter, primary production acts as a biological pump that removes carbon from the surface ocean, thereby playing a global role in climate change (ASCLME/SWIOFP 2012).

The main types of phytoplankton are cyanobacteria, diatoms, dinoflagellates, green algae and coccolithophores. In addition to phytoplankton, other primary producers contribute to ocean primary production, especially in the coastal areas. These include mangroves, seagrasses, macroalgae and salt marshes (Oliveira and others, 2005, Duarte and others, 2005). Furthermore, symbiotic algae, some epiphytes and benthic microalgae are also producers. However, phytoplankton contributes to more than 90 per cent of total marine primary production (Duarte and Cebrian 1996). In the group of cyanobacteria, some genera such as *Trichodesmium*, *Nostoc and Richelia*, are able to fix nitrogen from the atmosphere, thereby increasing sources of nutrients (Lyimo and Hamis 2008, Poulton and others, 2009). Under increased nutrient concentration, other genera from among the dinoflagellages such as *Dinophysis* can form blooms that could be harmful (harmful algal blooms – HABs or red tides) or be a nuisance to

other aquatic organisms like fish and shellfish, the environment, as well as humans, and could cause serious economic losses in aquaculture, fisheries and tourism-based activities (Babin and others, 2008).

A general classification of microalgae is illustrated in Table 16.1. The table gives a total of 13 divisions/classes. Size-wise, phytoplankton can be sub-divided into three groups, namely: pico-phytoplankton (0.2 – 2.0 µm), nano-phytoplankton (2.0 – 20 µm) and micro-phytoplankton (20 – 200 µm), see Table 16.1. The primary consumers, zooplankton, also play an important role in the transfer of energy from one trophic level to another in the marine food web, thereby acting as a link between producers and higher consumers. Zooplankton is sub-divided into two groups, namely, the protozoa zooplankton with two phyla and Eumetozoan zooplankton with about 14 phyla. In zooplankton, the size ranges from 0.01 mm to several centimeters, although most of them do not exceed 5 mm (Conway and others, 2003). Herbivorous zooplankton feed on phytoplankton, and these feed carnivorous zooplankton, which in turn are eaten by other larger animals (see schematic illustration in Figure 16.1), thus playing a very important role in supporting the productivity of marine/coastal fisheries. Zooplankton is the basic food for most fish larvae and some adult fishes as well as cetaceans. As such, its distribution is considered as a proxy for ocean fertility, providing information on potential fishing zones (Reid and others, 2000).

The Western Indian Ocean (WIO) region

The WIO region could be sub-divided into two large marine ecosystems, namely: the Somali Current Large Marine Ecosystem (SCLME) and the Agulhas Current Large Marine Ecosystem (ACLME); the region also covers areas that are outside the two LMEs (ASCLME/SWIOFP 2012). The ACLME is located in the southwestern Indian Ocean, encompassing the continental shelves and coastal waters of mainland states of Mozambique and eastern South Africa, as well as the archipelagos of the Comoros, the Seychelles, Mauritius and La Reunion-France (Heileman and others, 2008). At the northeastern end of the ACLME is Madagascar, the world's fourth largest island with extensive coastline of more than 5 000 km (McKenna and Allen 2005). The SCLME extends from the Comoro Island and the northern tip of Madagascar in the south to the Horn of Africa in the north, bordered by Somalia, Kenya and Tanzania.

In the WIO region, circulation pattern differs between the southern and the northern parts of the region. In the south, circulation is persistent throughout the year, being wind driven anti-cyclonically, whereas in the north circulation is forced by the monsoon winds that reverse seasonally (Mengesha and others, 1999, Lutjeharms 2006). According to Lutjeharms (2006), the flow during the north-east monsoon is directed southwards along the East African coast and during the southwest monsoon it is directed northwards, becoming the East African Coastal

Table 16.1. Classification of phytoplankton algal types (adopted from Jeffrey and Vesk 1997)

Algal Division/Class	Microplankton 20 – 200+ µm	Nanoplankton 2 – 20 µm	Picoplankton 0.2 – 2 µm
Bacillariophyta	+	+	+
Chlorophyta	+	+	+
Chrysophyceae	+	+	+
Cryptophyta	+	+	-
Cyanophyta	+	+	+
Dinophyta	+	-	-
Euglenophyta	-	+	-
Eustigmatophyta	+	+	-
Prasinophyta	+	+	+
Prochlorophyta	-	+	-
Prymnesiophyceae	+	-	-
Rhodophyta	-	+	-

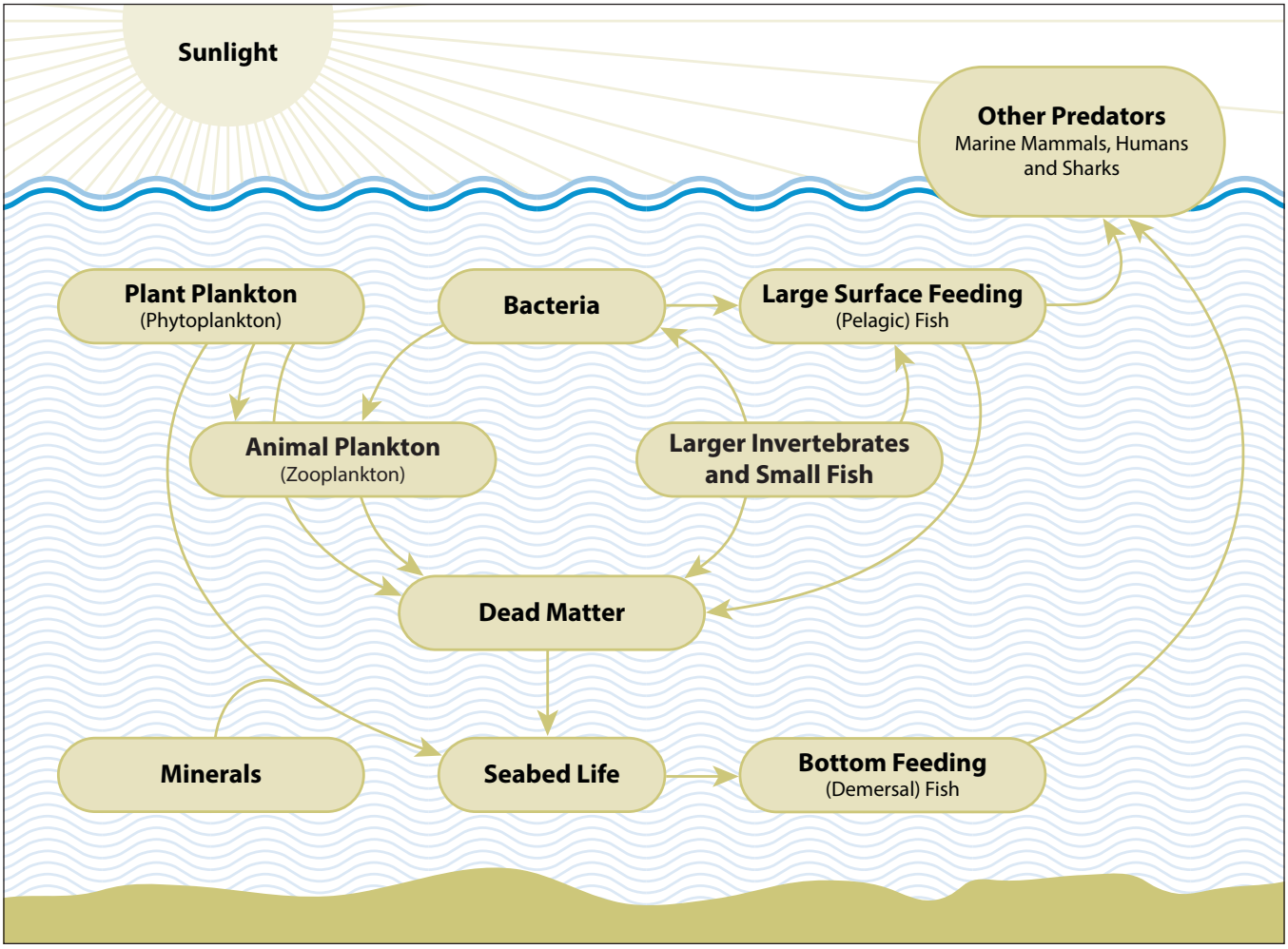


Figure 16.1. Simplified illustration of the marine food chain. In the real sense, the marine food web is very complex with interactions between organisms in the ecosystem, composed of detritus, numerous organisms such as bacteria, phytoplankton, zooplankton, fish, birds, marine mammals and humans. (Source: adapted from http://www.goldridge08.com).

Current. This current originates from the bifurcation of the East Madagascar Current, at the African coast around 10^0S.

Both LMEs are moderately productive with an average production ranging between 150 and 300 g C m^{-2} a^{-1} (Heileman and Scott 2008, Heileman and others, 2008). For the ACLME, primary production is largely driven by the Mozambique Channel eddies and localized eddies or topography-driven upwelling (Quartly and others, 2005, Kyewalyanga and others, 2007, Barlow and others, 2013). Relative to other parts of the Indian Ocean and the Atlantic Ocean that borders western Africa that seem to be more productive (Figure 16.2), productivity in the WIO region is between low and moderate levels, although there are some highly productive areas, especially along the coasts. In summary, the WIO waters are characterized by warm temperatures and low nutrients, low biomass and relatively low-moderate primary production (Karl and others, 1999). The phytoplankton communities are usually dominated by pico-phytoplankton and nano-phytoplankton (Barlow and others, 1999, Barlow and others, 2007, Goericke and others, 2000, Sá and others, 2013).

Factors affecting productivity and the distribution of primary producers

Primary production, phytoplankton distribution and abundance are influenced by several factors, thus they vary both seasonally and spatially. Primarily, phytoplankton depends on carbon dioxide, sunlight and nutrients for growth, but some other factors such as water depth, water temperature, wind and grazers also play a significant role. The South and Western Indian Ocean are probably the least studied areas. Research has so far focused on the Arabian Sea (northwestern Indian Ocean) while extensive regions of oceanic waters remain unknown. Therefore, in the WIO region, information on primary production and phytoplankton

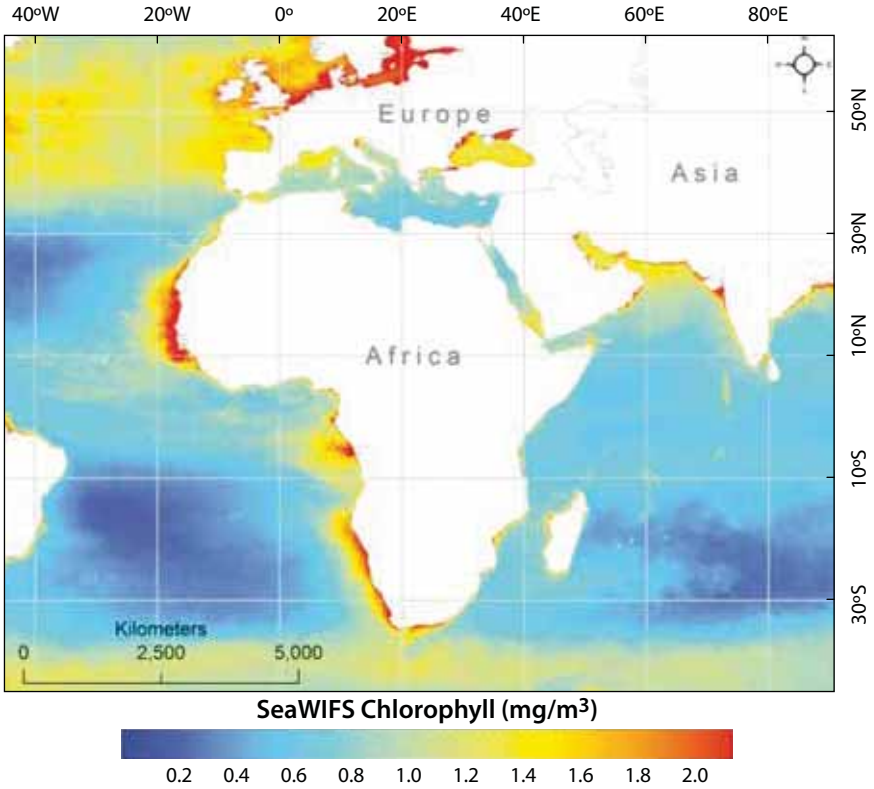


Figure 16.2. Calculated annual average (year 2009) of chlorophyll-*a* concentration (mg m^{-3}) extracted from satellite data (SeaWIFS) for the Indian Ocean and the Eastern Atlantic Ocean. It clearly shows how oligotrophic the waters of the Western Indian Ocean are in comparison to other adjacent waters that border the African continent (Arabia Sea, Mediterranean Sea and the Atlantic Ocean). Data downloaded from NASA (National Aeronautics and Space Administration) – GIOVANNI Ocean Colour Radiometry online visualization and analysis – Global monthly products (http://www.gdata.sci.gsfc.nasa.gov/).

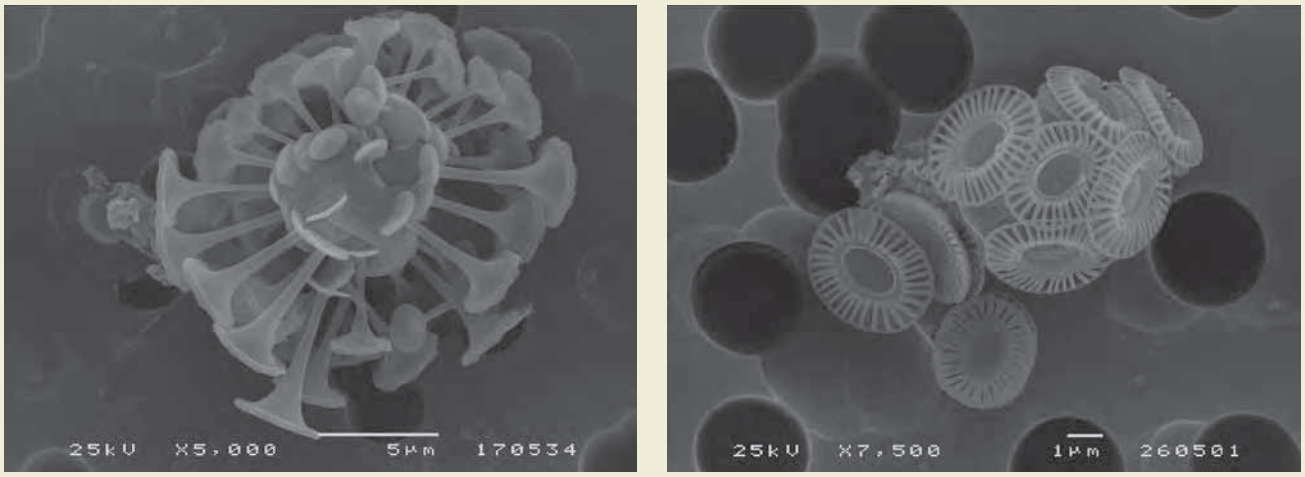
communities' distribution and abundance is sparse and less homogeneous (Sá and others, 2013). Comparing the two LMEs for primary production studies, the waters of the Somali Current LME are less studied relative to the ACLME (in the South Western Indian Ocean region), which has received much more attention (Meyer and others, 2002, Barlow and others, 2008, Barlow and others, 2010, Barlow and others, 2011, Barlow and others, 2013, Barlow and others, 2014, Kyewalyanga and others, 2007, Sá and others, 2013, Lamont and others, 2010, Lamont and Barlow 2014). The following two paragraphs looks at the drivers of primary production and the rates in the region.

Some of the main drivers of productivity include monsoon seasons (Kromkamp and others, 1997, McClanahan 1998), circulation, upwelling and eddies (Meyer and others, 2002, Quartly and Srokosz 2004), nutrients (Kyewalyanga and others, 2007, Leal and others, 2009, Tew-Kai and Marsac 2009, Koné and others, 2009, Sá and others, 2013, Sadally and others, 2004), irradiance and temperature (Bowman and others, 2003, Lamont and Barlow 2015), bottom topography that might cause upwelling (Galliene and Smythe-Wright 2005), growth rates (Cloern and others, 2014), grazing (Calbet 2008, Loebl and Van Beusekom 2008, Ward and others, 2012, Lee and others, 2012) and water column stability (Barlow and others, 2007). The levels of ultra-violet radiation (UVR) can also affect primary production. The enhanced level of radiation, ultra-violet B (UV-B; 280-315 nm) is more harmful than the normal level known as ultra-violet A (UV-A; 315-400 nm). UVR causes harm by inhibiting photosynthesis, photo-protection and affects the DNA molecule (Smith and others, 1992, Helbling and others, 2005). In temperate regions with strong seasonality and close proximity to the ozone "hole", Helbling and others (2005) found that strong levels of UVR result in phytoplankton being dominated by small sized cells (pre- and post-bloom conditions), whereas during the winter bloom with less UVR, micro-phytoplankton dominate.

Rates of primary production in the region vary significantly both in space and time. For values measured *in-situ*, primary production has been shown to range from less than 0.1 g C m^{-2} d^{-1} (Steeman-Nielsen and Jensen 1957, Mitchell-Innes 1967) to more than 3.0 g C m^{-2} d^{-1} especially in coastal embayments and along productive continental

shelves such as the Natal and Delagoa Bights (Ryther and others, 1996, Barlow and others, 2010, Barlow and others, 2011). However, these are the extreme cases. Most of the values determined in the WIO region fall in the range between 0.5 and 2.0 g C m^{-2} d^{-1}. For example, in Tanzanian waters, Ryther and others (1966) found rates ranging from about 0.3 to 1.00 g C m^{-2} d^{-1} while Barlow and others (2011) observed rates in primary production ranging from 0.79–1.89 g C m^{-2} d^{-1} in Pemba and Zanzibar Channels. In the Delagoa Bight, primary production rates have been shown to range from 0.6 to 0.85 g C m^{-2} d^{-1} (Mitchell-Innes 1967, Kyewalyanga and others, 2007). In the Natal Bight however, maximum values are > 2.0 g C m^{-2} d^{-1} (Burchall 1968a, Burchall 1968b, Barlow and others, 2010). In the northern part of the WIO region, the Arabia Sea, a comprehensive study during the Joint Global Ocean Flux Studies (JGOFS) was conducted between 1994 and 1996. The various data collected, both *in-situ* and remotely-sensed have revolutionised the understanding of the Arabian Sea and uncovered new findings on the effects of the monsoons and on

BOX 16.1 INFLUENCE OF PRODUCTIVITY DRIVERS ON THE VARIATION OF PHYTOPLANKTON ASSEMBLAGES ALONG THE MOZAMBIQUE COAST



The species *Discosphaera tubifera* (left) and *Emiliana huxleyi* (right). © Carolina Sá.

Drivers of phytoplankton distribution, abundance and productivity could vary significantly, even within the coastal waters of a given country. A good example is Mozambique, which has a long coastline, about 2 500 km in length, influenced by different water masses and other factors such as tides, river flow and upwelling due to eddies. These influence nutrient concentrations as well as exposure of phytoplankton to varying degrees of photosynthetically available irradiance (PAR), temperature and salinity, thereby having a direct impact on phytoplankton abundance, distribution and community composition. A recent study carried out along the entire coast of Mozambique assessed pigment and microscopic analysis of phytoplankton (Sá and others, 2013). At each station, sampling took place in surface waters as well as at the sub-surface chlorophyll maximum (SSM). A north-south gradient in temperature and salinity was observed in which the northern coast had higher surface temperature but relatively low salinity, while the southern coast had the reverse conditions (Sá and others, 2013). There were notable patterns of phytoplankton distribution and community composition that changed between regions; such that the Delagoa Bight, Angoche and the Sofala Bank in the southern part of the coast were found to be the most productive regions. Micro-phytoplankon were associated with the cooler water masses off the southern coast, whereas pico-phytoplankton were found to be associated with the warmer water masses off the northern coast. In the water column, the relatively large phytoplankton (micro), contributed significant biomass both at the surface and at the SSM; the smallest proportion (pico-phytoplankton) contributed mostly at the surface while the medium-sized ones (nano-phytoplankton) were more abundant at the SSM. On composition, nano-sized phytoplankton were dominated by *Discosphaera tubifera* and *Emiliania huxleyi*, while the most abundant micro-phytoplankton were mostly diatoms of the species: *Cylindrotheca closterium, Hemiaulus haukii, Proboscia alata, Pseudo-nitzschia* spp. and *Chaetoceros* spp.

phytoplankton and their productivity (Watts and Sathyendranath 2002). The entire dataset on carbon assimilation showed that rates of primary production ranged from 0.12 to 3.0 g C m^{-2} d^{-1} (Owens and others, 1993, Madhupratap and others, 1996, Marra and others, 1998, Savidge and Gillpin 1999, Barber and others, 2001).

Irradiance and temperature

Irradiance is a major driving force for photosynthesis; it warms the surface waters of the oceans, thereby regulating the water temperature. Both temperature and irradiance vary with the seasons of the year. Temperature is an important environmental parameter that influences biological processes in the ocean, and various studies have demonstrated that phytoplankton community structure varies in a regular, predictable pattern with temperature, especially in temperate regions (Boumann and others, 2005, Platt and others, 2005). To be able to utilize irradiance efficiently, phytoplankton has evolved taxon specific suites of pigments in their pigment–protein complexes for light absorption in the visible spectral range of 400-700 nm (Porra and others, 1997). Phytoplankton cells quickly adapt to changes in light quantity and quality and have developed different suites of pigments to deal with varying light regimes in different ecosystems (Falkowski and La Roche 1991, Kirk 1994, Barlow and others, 2007).

For example, they can do this by regulating the proportion of their photosynthetic or photo-protective carotenoids to total carotenoids or by a shift in phytoplankton communities (Barlow and others, 2002, Barlow and others, 2011, Barlow and others, 2013, Barlow and others, 2014). In the tropical Zanzibar waters, Barlow and others (2011) showed that phytoplankton do maximize their photosynthesis in the upper waters with high irradiance and low nutrients. However, in deeper waters where irradiance is low, phytoplankton tend to adapt to this condition by increasing their quantum yield of photochemistry. This is done by increasing their accessory pigments such as chlorophyll-*b*, chlorophyll-*c* and photosynthetic carotenoids (Barlow and others, 2011). Along the Mozambique coast, Sá and others (2013) found that different size classes of phytoplankton dominated different water masses (see Box 16.1). The warmer (nutrient poor) northern water masses were dominated by the small pico-phytoplankton while the southern water masses, cooler and rich in nutrients were dominated by micro-phytoplankton, especially diatoms.

Nutrients

Nutrient availability (especially nitrogen and phosphorus) is one of the primary factors that control the distribution of phytoplankton communities in the WIO region, while silicate was shown not to be limiting for this region (Barlow and others, 2007, Kyewalyanga and others, 2007, Leal and others, 2009, Sá and others, 2013). Nutrients distribution vary both horizontally and vertically in the water column. Most nutrient profiles show low values in surface (euphotic) layer, and the concentration increases with depth. This is because the presence of enough irradiance in the surface waters stimulates productivity, which consumes the nutrients. A general assessment of nutrient distribution in some of the areas of the WIO region, based on recent studies also revealed significant spatial variations. Along the Mozambique coast, Sá and others (2013) observed that nitrogen-nutrients concentration was below detection limit; while silicate ranged from between 6 and 10 µmol l^{-1} and in some areas was as high as 17 µmol l^{-1}. In the Delagoa Bight region (southern coast of Mozambique) from onshore to offshore, vertical profiles of nitrate presented values that ranged from below detection limit to 0.95 µmol l^{-1}; those of phosphate concentrations had values that ranged from 0.1 to 1.05 µmol l^{-1}; while for silicate concentrations values ranged from 0.1 to 4.4 µmol l^{-1}. With such nutrient concentrations, primary production values of the water column for the entire sampling area were found to range from low to medium values, namely 0.22 – 0.85 g C m^{-2} d^{-1} (Kyewalyanga and others, 2007).

In Mauritius' surface waters around Flic-en-Flac and Belle Mare, nutrient concentrations were relatively low and ranged as follows: highest values of nitrate ranged from 0.1 to 25 µmol l^{-1}; phosphate ranged from about 0.1 to 6 µmol l^{-1}; while silicate ranged from 0.1 to 23 µmol l^{-1} (Sadally and others, 2014). In the vicinity of Unguja and Pemba Islands, along the Tanzanian coast, Barlow and others (2011) determined nutrient concentrations at selected depths, between 2 and 125 m, and found nitrate concentration to be less than 0.25 µmol l^{-1} in the upper mixed layer, while in deeper waters concentration of nitrate reached as high as 8.5 µmol/l. A study across the tropical Indian Ocean (Barlow and others, 2007) revealed that nitrite+nitrate and phosphates in surface waters were very low. The concentration for nitrate+nitrite was less than 0.1 µmol l^{-1} and ranged from 0.06 to 0.14 µmol l^{-1} for phosphate. Although silicate levels were relatively higher that those of other nutrients, the observed levels (of up to 2.0 µmol l^{-1}) remain in the low range.

A recent regional-wide assessment of nutrient concentrations was conducted during a project designed to address land-based activities in the Western Indian Ocean (WIO-LaB). All WIO countries, with exception of Reunion and Somalia, participated in the sampling that was conducted from 2006-2008 at selected control and potential hotspots - test sites (UNEP/Nairobi Convention Secretariat, CSIR and WIOMSA, 2009). At the test stations, ammonium levels ranged from 0.001 – 13.44 µmol l^{-1}, nitrate-nitrogen from 0.002 – 31.38 µmol l^{-1}; nitrite-nitrogen from 0.002 – 0.43 µmol l^{-1}; and phosphate-phosphorus from 0.0002 – 0.65 µmol l^{-1}. All the highest values were observed off Madagascar, with exception of the highest phosphate concentration, which was recorded off Mauritius (UNEP/Nairobi Convention Secretariat, CSIR and WIOMSA, 2009). Since these values were taken from known hotspots, it is possible that the site off Madagascar (Nosy-By) is more polluted relative to other hotspots in the rest of the WIO countries. This area is characterised by bays where major land-based activities are situated, such that it receives discharges from the port, industries, petroleum product depot and domestic wastewaters. Fish mortality has also been occurring in the area. In the open ocean waters of the WIO region, nutrients seem to be relatively low and primary production is between low to medium. However, fish catch seems to be relatively high. Notwithstanding artisanal fisheries, it has been shown that the WIO region generates more than 4 million tonnes of fish per year, which contributes about 4 per cent of the global industrialised fish catch (SWIOPF 2012).

Ocean currents and circulation

Ocean currents are important features that strongly influence the availability of nutrients and the distribution of phytoplankton. Lutjeharms (2006) provided description of the oceanography and hydrography of the coastal oceans off southeastern Africa and their influence on biological productivity and biota. The dominant large-scale oceanographic feature of the LME is the Agulhas Current, a swift warm western boundary current that forms part of the anticyclonic gyre of the south Indian Ocean. This LME is influenced by mixed climate conditions, with the upper layers being composed of both tropical and subtropical surface waters (Beckley 1998). Large parts of the system are characterized by high levels of mesoscale variability, particularly in the Mozambique Channel and south of Madagascar. Eddy formation was also observed in the southwest side of the Mascarene Plateau, being caused by a current moving in clockwise direction with high velocities (Badal and others, 2009). In Mozambican waters, Sá and others (2013) found that micro-phytoplankton (diatoms) dominated both the surface and the sub-surface chlorophyll maxima, being associated with cooler southern water masses whereas the pico-phytoplankton was associated with the warmer northern water masses.

In the mesoscale eddies of the Mozambique Channel, Barlow and others (2014) found that in surface waters, prokaryotes were of primary importance, followed by small flagellates, while flagellates dominated the deep chlorophyll maximum layer. Diatoms were found to dominate shelf and frontal stations. To get the best from such environments, diatom-dominated communities and prokaryotes-dominated communities regulated their chlorophyll-specific absorption, proportion of photosynthetic pigments, proportion of total chlorophyll-*a* to total pigments and the proportion of photo-protective pigments in an inverse direction. For example, diatom-dominated communities showed low chlorophyll-specific absorption, high total chlorophyll-*a* proportion and high proportions of photosynthetic carotenoids and chlorophyll-*c*. The flagellates were somewhere in the middle (Barlow and others, 2014).

Upwelling and freshwater input

Both these processes bring new nutrients into the surface layer of the ocean. Upwelling is the process through which deep nutrient-rich waters are brought up into the surface layer (vertical movement upwards), while freshwater input, horizontally, is mainly through rivers or surface runoffs during heavy rains (Ramessur 2011). This increases the nutrient concentrations, resulting in enhanced biomass concentration and productivity. In the WIO region, upwelling is known to occur along the Somali coast (McClanahan 1998), off the northern Kenya coast, Mascarene Plateau through obstruction of the South Equatorial Current (Galliene and others, 2004, Galliene and Smythe-Wright 2005), at specific offsets of the coastline in the Mozambique Channel, off the southeastern tip of Madagascar (Lutjehams 2006) and at the Madagascar Ridge (Poulton and others, 2009). In the Delagoa Bight, passing anticyclonic eddies influences water masses in the Bight, resulting in upwelling in the shelf area (Lutjeharms and Da Silva 1988, Kyewalyanga and others, 2007, Barlow and others, 2008, Sá and others, 2013, Fennessy and others,

2013); but also the inshore northward-flowing coastal current causes frequent upwelling due to interaction with the bottom topography (Lamont and others, 2010). For the Natal Bight, the Agulhas Current has been observed to result in a kinematically driven upwelling cell bringing cooler nutrient-rich waters into the shelf.

The WIO region is endowed with major rivers, which add nutrients to coastal areas, especially during the heavy rain season. Some of the main rivers from the mainland states that empty into the Indian Ocean include: Juba and Shabelle (in Somalia), Tana and Sabaki (Kenya), Pangani, Wami, Ruvu, Rufiji and Ruvuma (Tanzania), Zambezi, Maputo, Incomati and Limpopo Rivers (Mozambique) and Thukela, Great Brak, Breede, Klein, Mngeni, and Umfolozi Rivers (in South Africa). In waters very close to the shore, availability of nutrients due to anthropogenic input, surface runoffs and river input especially during the rainy season, results in high concentrations of phytoplankton. As such, phytoplankton tends to decrease from coastal waters towards deeper waters (Figure 16.3, Peter 2013, Ezekiel 2014, Sadally and others, in press). This implies that the coastal strip is richer than the open ocean in terms of productivity thereby supporting considerable number of food chains and food webs (Cloern and others, 2014). The coastal areas, especially in mangrove ecosystems and seagrass beds, act as nursery grounds and feeding areas for a number of marine organisms both benthic and pelagic.

Monsoon circulation

Primary productivity in the WIO region is subjected to two alternating and distinctive seasons, the southern and northern monsoons, which have a marked effect on air and water temperature, wind, rainfall and phytoplankton biomass (Figure 16.3). The prevailing winds during the monsoons are a particularly important influencing factor on water circulation, especially in the northern part of the WIO region. They affect the distribution of nutrients and marine organisms as well as biological processes, changing wave action, and affecting a wide range of human activities (Richmond 2011). From November to March, the prevailing trade wind is from the northeast, but more northwesterly in direction to the south of the equator. From June to September, the stronger southwest monsoon wind prevails. South of the equator, this wind is more southeasterly in direction (Richmond 2011). In Tanzanian waters, recent studies have shown that monsoon seasonality has a great influence on phytoplankton distribution and abundance (Peter 2013, Ezekiel 2014). Similarly, off the Kenyan coast, both primary and secondary productivity are strongly influenced by the monsoon seasons (McClanahan 1998). The

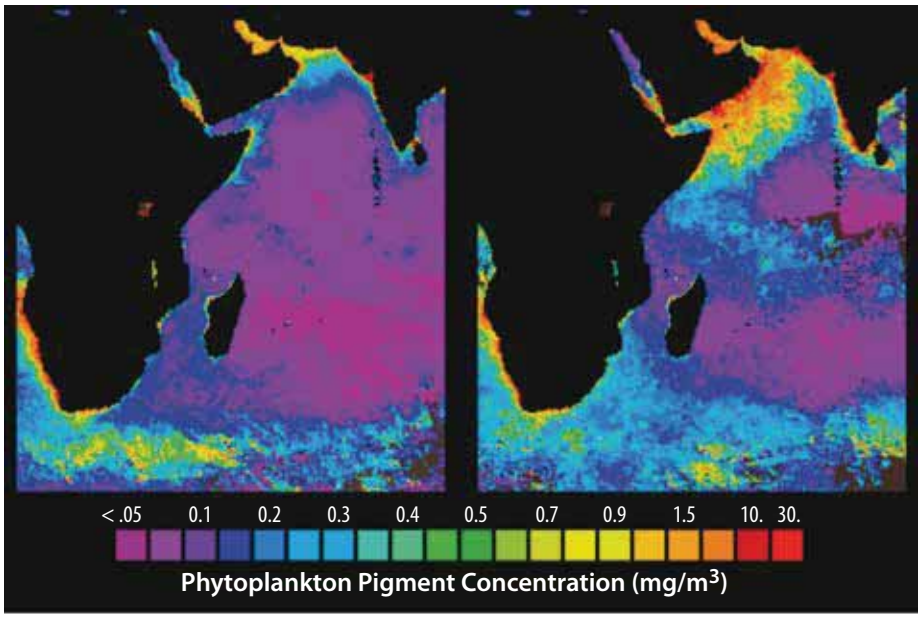


Figure 16.3. Monsoonal changes in the Indian Ocean directly affect phytoplankton biomass (Chl-*a* mg m^{-3}). Left panel shows a period of pre-monsoon calm (May-June composite); while the right panel shows strong summer southwesterly conditions with strong winds that generated upwelling of nutrient-rich waters, leading to the development of bloom conditions (September-October composite). (Source: http://disc.sci.gsfc.nasa.gov/education-and-outreach/additional/images/Monsoon.GIF).

southwest monsoons are characterized by heavy rainfall, strong wind energy, low temperatures and high clouds; the reverse is true for the northeast monsoon. Both primary and secondary plankton productivity are higher at the continental shelf compared to offshore as well as during the northeast monsoon over the southwest monsoon. This high production is caused by nutrient enrichment of the coastal waters by heavy surface runoff during the southwest monsoons from major rivers, Tana and Sabaki, and upwelling off northern Kenya. During the northeast monsoon the lower current speeds and higher salinities provide a comparatively stable environment for enhancing production at the shelf (Government of Kenya 2009).

ENVIRONMENTAL, ECONOMIC AND SOCIAL IMPLICATIONS OF TRENDS IN PRIMARY PRODUCTION

The trend

Primary production for the WIO region is not consistent, as it tends to vary from year to year driven by a number of factors (see above) that operate synergistically or antagonistically. For example, phytoplankton abundance (Chl-*a*), could be positively correlated with one factor (such as nitrate concentration) but at the same time negatively correlated to another such as temperature or salinity due to seasonality or input of surface runoff from terrestrial sources that might bring nutrients into the coastal areas (Peter 2013). Figure 16.4 shows average chlorophyll-*a* concentration for the WIO region, derived from satellite data over the last 12 years. The general trend has been to decrease with time, but it also shows a significant inter-annual variability. The general decrease is in agreement with the global trend in primary production, which appears to be decreasing and in doing so constraining fisheries catches (Chassot and others, 2010). Moreover, productivity in the WIO region is a bit low in the central part, but relatively higher in the northern (the Arabian Sea) and south-western part of the region (Figures 16.2 and 16.3). Although the general trend for WIO region primary production is to decrease, there are some exceptional areas that have high productivity from influence of nutrient input via land-based sources and upwelling (see above). Therefore, it is somehow difficult to predict changes and trends in production for the entire region. The impact of climate change exacerbates any change that occurs due to other factors. Globally, primary production has been shown to increase in upwelling zones and sub-polar regions, while in the sub-tropical gyres the trend is to decrease (Behrenfeld and others, 2006, Chavez and others, 2010). In the following

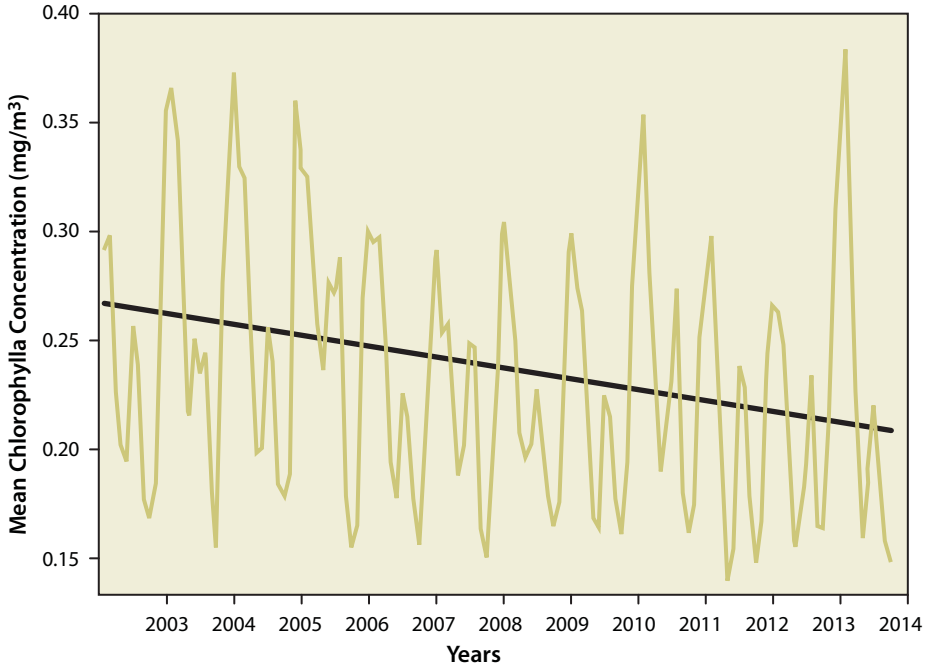


Figure 16.4. Monthly averages of chlorophyll-*a* concentration (mg m^{-3}) calculated for the Western Indian Ocean region covering a period from July 2002 to April 2014 The blue line shows monthly variations due to seasonal changes, but more importantly the red line shows a decreasing trend in the concentration with time. Data downloaded from NASA (National Aeronautics and Space Administration) – GIOVANNI Ocean Colour Radiometry online visualization and analysis – Global monthly products (http://www.gdata.sci.gsfc.nasa.gov/).

sub-sections, the environmental, economic and social factors that might have an impact on the trend in primary productivity of the WIO region are briefly discussed.

Environmental implications

The primary producers are linked to fisheries because they are at the base of the marine food webs. Furthermore, some fishes like parrot fish are herbivorous, thus feeding directly on marine plants (seagrasses, seaweeds). This implies that a change in the trend of primary production will also affect fish spawning, growth and/or reproduction. In temperate regions, the survival of fish larvae was clearly shown to depend on the timing of the phytoplankton spring bloom (Platt and others, 2003). In tropical regions, like the WIO region, coral reef ecosystems support a large number of fish and other marine organisms. Any impact to corals, such as bleaching events, will impact organisms that depend on the reef for food and shelter. Bleaching affects the survival and productivity of the symbiotic micro-algae (the zooxanthllae), which can lead to coral death. The death of the coral will have a direct impact on the corallivores (the fish who feed on corals, such as the orange-spotted filefish (*Oxymonacanthus longirostris*)) and others that depend on the health of the ecosystem. As a result, fisheries catch, especially artisanal fisheries, will be impacted. Considering a bottom-up approach, any factor that influences the base of the food web will have implications for higher trophic levels extending to the top predators (Cury and others, 2003). At the scale of LMEs, primary production was shown to limit average and maximum fisheries catches over both short (up to 5 years) and long (about 50 years) time scales (Chassot and others, 2010).

At smaller scales, especially in areas with high nutrient input, eutrophication (characterized by high growth of phytoplankton and macroalgae) may occur. The major causes of eutrophication is waste water input, which contain high levels of inorganic nutrients such as nitrogen and phosphate, or with high organic content, ie, high biological and chemical oxygen demand (UNEP/Nairobi Convention Secretariat, CSIR and WIOMSA, 2009, Chislock and others, 2013). In the WIO region, eutrophication at a large scale hasn't been shown. However, harmful or nuisance algal blooms have been identified in pollution hotspots of the WIO countries (UNEP/Nairobi Convention Secretariat, CSIR and WIOMSA, 2009). The only significant HAB events in the region have been reported in Kenya, Mauritius, Somalia, South Africa and Tanzania, and for each of these countries a good summary of the causes of HABs or nuisance algal blooms, the effect to the environment, to tourism and or to communities has been given, where Mauritius seems to have the biggest impact (ASCLME/SWIOFP 2012).

A simultaneous regional survey was conducted between 1998 and 2000 by the IOC-UNESCO HAB Programme in Kenya, Madagascar, Mauritius, Reunion and Tanzania. The results identified 60 potential HAB species, representing four different classes (ASCLME/SWIOFP 2012). The known environmental impacts of algal blooms include: reduced water clarity (by reducing light penetration) that is vital to light-dependent benthic species, effect on aesthetics and biodiversity, increased pH due to reduction of dissolved inorganic carbon because of increased photosynthesis, smothering of benthic communities during die-offs of algal blooms, modification of species composition and creation of anoxic conditions due to decomposition of organic matter, resulting in mortalities of marine species due to hypoxia (UNEP/Nairobi Convention Secretariat, CSIR and WIOMSA, 2009, ASCLME/SWIOFP 2012, Chislock and others, 2013).

Socio-economic implications

For coastal communities of the WIO region who depend mostly on coastal resources for their food and livelihoods, a decreasing trend in the regional primary production with direct impact on fisheries catches is not good news. In general, a global decreasing trend in primary production (Chassot and others, 2010) and the observed decrease in phytoplankton biomass in the WIO region in the last 12 years in particular (Figure 16.4), will have a significant impact in fisheries catches, which in turn will exacerbate the already existing problem of overfishing. Overfishing, which causes fish depletion has a direct impact on food security and livelihoods of coastal societies. Added to that, elevated levels of primary production resulting in algal blooms that include harmful and or the nuisance species would worsen an already worrying situation.

The HABs exist in both marine and fresh waters, and they do produce toxins which could poison domestic animals, wildlife, fish, benthic organisms and humans. The impact of HABs on coastal communities and their economy may be by loss of aesthetic values that greatly affect tourism and its associated benefits; loss of artisanal fisheries and aquaculture (see Box 16.2) and effects on seafood quality (Babin and others, 2008, Asplund and others, 2013).

BOX 16.2 HARMFUL ALGAL BLOOMS AFFECTING SEAWEED FARMS AND FARMERS IN ZANZIBAR



The algal farming in Paje, east coast of Unguja Island, Zanzibar. © José Paula.

Recently in Zanzibar waters, incidents of algal blooms have been observed and they are affecting areas where seaweed is being farmed – in Paje, the east coast and in Bweleo the southwest coast of Unguja Island. The farmers experienced irritation of the skin and mortality of the farmed seaweed *Eucheuma denticulatum* (Msuya 2013, Kyewalyanga Pers. observation). On the east coast, a toxic cyanobacterium *Lyngbya* spp. was identified as the cause, while on the southwest coast the identified alga was *Sarconema*, which was covered by microalgae film containing different species of microalgae and *Lyngbya* spp. The other microalgae included*: Nitzschia longissima, Licmophora abbreviate, Grammatophora marine and Podocystis spathulata* (Msuya 2013). The causes of this condition, which was not observed before 2011 are suggested to be nutrients load due to pollution (probably the primary cause) but the effect of climate change (increased surface temperature and erosion) might also be playing a significant role. The occurrence of these blooms affects the health of the environment (seaweed mortality) and public health (irritation of the seaweed farmers' skin). In addition, the mortality of the farmed seaweeds causes economic loss and impact on the livelihood of the surrounding village community. However, impact on other marine organisms especially benthic communities are yet to be identified.

The implication is the effect on food safety, food security and income-generating activities; and risk to human health from recreational contact with HABS and consumption of contaminated seafood that might even result into loss of life (UNEP/Nairobi Convention Secretariat, CSIR and WIOMSA, 2009).

Potential conflict between different sectors is another socio-economic factor associated with the formation of harmful algal blooms. For example, when establishments discharge untreated waste water, creating ideal conditions for development of harmful algal blooms that affect the environment as well as the surrounding communities. This would result in contravention of environmental regulations besides compromising food safety as well as public health of coastal communities.

Other factors affecting resilience at the base of the food web

Climate change is associated with increased irradiance, causing warming, which raises sea-surface temperature. Increased temperature causes stable water-column, resulting in stratification that might limit nutrient injection into the euphotic zone, needed for primary production. A large-scale study of primary production through remote sensing has shown that increase in sea surface temperature triggered a reduction in the global production of ocean phytoplankton since the early 1980s (Behrenfeld and others, 2006). Because an impact on the base of the food web will also affect higher trophic levels (Cury and others, 2003, Platt and others, 2003), a reduction in primary production would reduce fisheries catches and lead to overfishing in order to satisfy protein demand (Chassot and others, 2010). Another angle for which climate change impacts on ocean primary production is through ocean acidification (Cooley and others, 2009). Increased acidity in the ocean will impact on phytoplankton, especially those with calcareous shells such as coccolithophores (like *Emiliania huxleyi*) as well as macro-algae with similar structures, such as *Halimeda* sp. However, a direct link between ocean acidification and fisheries catch hasn't been shown for the WIO region. Besides climate change, anthropogenic activities such as increased coastal development to accommodate increased tourism (Sadally and others, 2014) as well as destruction of habitats and damming of the rivers, increases sedimentation in coastal waters thereby reducing light availability for photosynthesis to both phytoplankton and macro-algae.

BOX 16.3 THE USE OF SYSTEMS FOR MUNICIPAL WATER TREATMENT IN THE WIO REGION

There is a number of ways in which pollution from wastewater, which could lead to HABs, could be reduced in the WIO region. One of the assessments in the region (UNEP/Nairobi Convention Secretariat, CSIR and WIOMSA, 2009) revealed that four main municipal water treatment systems exist, though used differently in different countries, most likely dependent on the status of economic development of each country. These include central sewer systems, septic tanks and soak away, pit latrines and other systems. The distribution of the population in each of the WIO countries using the different systems can be summarized as (UNEP/Nairobi Convention Secretariat, CSIR and WIOMSA, 2009):

Percentage of the population on a central sewer systems ranges from a minimum of 0.3 per cent in Comoros to a maximum of 47 per cent in South Africa.

The percentage of the population with septic tanks and soak aways ranges from a minimum of 4 per cent in South Africa to a maximum of 87.6 per cent in the Seychelles.

Populations with pit latrines range from a minimum of 3.6 per cent in the Seychelles to a maximum of 94.4 per cent in the Comoros.

The percentage population on other systems (such as dry and chemical toilets) ranges from non-existence in Comoros, Kenya and Mozambique to a maximum of 31 per cent in South Africa.

This indicates that attempts to contain the municipal wastes do exist in each country in the region though the level of usage of particular systems vary depending on costs.

ACTIONS THAT COULD BE TAKEN FOR A MORE SUSTAINABLE FUTURE (RESPONSE)

The primary producers do adapt to natural changes in the environment, especially light, nutrients and temperature. They have various mechanisms such as varying proportions of chlorophyll-*a* and carotenoids, as described above. However, anthropogenic activities tend to exacerbate the natural factors/changes. Thus, we need to look at the human side to answer the question "What is being done and how effective is it?"

Eutrophication and harmful algal blooms (HABs)

To combat the effect of eutrophication, that causes HABs and other nuisance blooms, the countries of the WIO region are trying to reduce the input of wastewaters into the ocean or by treating the water to reduce contaminants and nutrients before its release into the environment. The estimated amount of municipal waste water (potentially entering the coastal zone of the WIO region) range from a minimum of 168 m^3 d^{-1} in the Comoros to a maximum of 255 000 m^3 d^{-1} in South Africa, other countries being somewhere in between (UNEP/Nairobi Convention Secretariat, CSIR and WIOMSA, 2009).

On HABs, it is known that potentially harmful algae exist throughout the region, and their effects (some acute) have been observed. Yet, only two countries have on-going monitoring programs; South Africa's west coast and Reunion Island (ASCLME/SWIOFP 2012). Other countries need to initiate similar monitoring programmes. For example, there was a public outcry in Seychelles' capital city of Victoria, when nutrient caused discolouration of the water surrounding the port, due to phytoplankton bloom (UNEP/Nairobi Convention 2014a). The Director General for Wildlife, Enforcement and Permits of Seychelles commented that the eutrophication was due to lots of nutrients that cause rapid algae growth and that this condition has been observed in previous years, occurring at the same time when it is hot and the ocean is calm. In a different case, as recent as March 2015, a discolouration of the water in Pemba Island (Tanzania) has been reported. The waters were red in colour and fish were dying. All activities in the sea (fishing, recreational, seaweed farming) hade to be altered until a study was conducted to identify the cause(s). These cases and that of Zanzibar (see Box 16.3) are strong evidence to prompt countries of the WIO region to initiate HAB monitoring programmes.

In other areas, nutrient input originates from mariculture activities. Effluents from mariculture farms may contribute significant nutrient loading into coastal waters, resulting in unwanted nuisance or harmful blooms. What is needed is to conduct sustainable aquaculture in which the effluent water is treated before being released into the ocean. Alternatively, mariculture systems considering integration of finfish, shellfish and seaweed (Mmochi and Mwandya 2003), are examples of good mariculture prac-

tices, in which both the solid and dissolved wastes are utilized within the closed system.

Climate change

For the WIO region, to combat the effect of climate change on primary production and other processes that affect marine resources on which human beings depend on (such as fisheries), scientists are directing research towards understanding mechanisms underlying ecosystem dynamics and fisheries dynamics "Ecosystem based management of fisheries". Research in the region is now multi-disciplinary and of trans-boundary nature, geared towards providing answers to managers and policy makers on how to conserve biodiversity and sustainable conservation, utilization and exploitation of coastal and marine resources (UNEP/Nairobi Convention Secretariat, CSIR and WIOMSA, 2009, ASCLME/SWIOPF 2012, SWIOFP 2012). Processes in the coastal zone, both natural and anthropogenic, are interlinked and complex, while some of them are trans-boundary. Nature takes care of itself, but human activities need to be regulated. Lack of political willingness in some cases and inadequate awareness complicate decision making in the management of coastal resources. There is need to take factors like climate change seriously and come up with adaptive and mitigation strategies. One good example is that of Mauritius, whereby the Ministry of Environment and Sustainable Development, together with other partners, have launched a sensitization campaign on climate change adaptation in the coastal zone of Mauritius (UNEP/ Nairobi Convention 2014b). The main strategic objectives of the campaign are to increase public access to information on climate change and to increase public awareness raising and education on climate change. This is a good strategy, which should be replicated by other WIO countries, especially Small Islands Developing States (SIDS), in order to reduce human impacts.

CONCLUSION

A considerable effort by the WIO states has also been put into designation of coastal and marine protected, conserved and reserved areas. A comprehensive list of existing parks, reserves or conservation areas of the WIO Countries, showing the name, designation, designation type (national, international), IUCN category, status (designated or proposed), year of status and management authority is presented in the SWIOFP report (SWIOFP 2012). The list shows that all countries (with the exception of Comoros, which has only one) have established a good number of marine reserves. Kenya has 15, Madagascar 14, Mozambique has 7, Mauritius 22, Reunion 18, Seychelles 13, Tanzania 25 and South Africa has 15. This is a good number of reserves in the region, totaling 129, and what is important is to make sure that each one has a good management plan and that rules and regulations are being enforced.

Although individual countries' efforts are commendable, oceanic primary production itself and its impacts (as discussed above) know no boarders. Therefore, integrated initiatives for the entire region are called for. The regional-wide, Strategic Action Plan (WIO SAP), with the vision '*People of the region prospering from a heathy Western Indian Ocean*' formulated three main quality environmental objectives, which are intended to be achieved by the year 2035 (UNEP/Nairobi Convention Secretariat 2009):

- Critical WIO habitats will be protected, restored and managed for sustainable use;
- Water quality will meet international standards; and
- River flows will be wisely and sustainably managed.

These environmental quality objectives are intended to ensure that the marine and coastal ecosystem will function well and that goods and services will be assured for sustainable socio-economic development in the WIO region. The vision has five principles, namely i) equity, ii) sharing responsibility and management, iii) harmony between resource users and nature, iv) an informed society and v) life style adjusted to sustainability (UNEP/Nairobi Convention Secretariat 2009). If all the countries of the region, regardless of the stage of development, would abide to the principles and also participate in implementing the agreed management targets and actions for each of the above objectives, uncertainties in the future of decreasing fish catch due to decreasing primary producers would be highly reduced.

RECOMMENDATIONS

The States of the WIO region need to honour their commitment in many signed protocols related to conservation and management of coastal and marine environment, such as the Nairobi Convention Protocols (www.unep.org/NairobiConvention/The_Convention/index.asp): Protocol for the Protection of the Marine and Coastal Environment of the Western Indian Ocean from Land-Based Sources and Activities (adopted: Nairobi, 31 March, 2010); Protocol Concerning Protected Areas and Wild Fauna and Flora in

the Eastern African Region (adopted: Nairobi, 21 June 1985) and the Protocol Concerning Co-operation in Combating Marine Pollution in Cases of Emergency in the Eastern African Region (adopted: 1985). In addition, a new protocol on Integrated Coastal Zone Management is in preparation and is nearing completion.

Initiatives in dealing with changing environments should not be dealt with at national or regional scales only; they need to start at community (village) levels. Knowledge and awareness are important; people should be empowered and allowed to play an active role in effective governance and management of natural resources. All these require financial resources. Governments should strive to set aside appropriate finances to allow implementation and enforcement of technologies and practices that will minimize impact of human activities in the marine environments of the WIO region.

On the scientific side there are gaps in the knowledge in primary production in the WIO region. Most scientific work has concentrated in the Agulhas LME area – South Western Indian Ocean region. Significant efforts need to concentrate in the northern part of the region as well, in the Somali Current LME area. Furthermore, of the available regional literature on primary production, more work has been done in understanding their distribution, abundance, physiology and related subjects. There is inadequate literature relating to the variation or trends of primary production to the environmental, social and economic implications to the societies of the WIO region. Thus, studies like these need to be conducted to better understand the impact of variation in primary production on the well-being of coastal communities.

References

ASCLME/SWIOFP (2012). *Transboundary Diagnostic Analysis for the Western Indian Ocean*. vol. 1: Baseline. South Africa

Asplund, M., Mushi, G., Lugomela, C., Lyimo, T. and Granberg, M. (2013). *Variation in community composition of* Vibrio *spp. along a salinity gradient from Ruvu mangrove creek to the coastal sea in Bagamoyo, Tanzania*. 8th WIOMSA Scientific Symposium Book of Abstract, page 26.

Babin, M., Roesler, C.S. and Cullen, J.J. (eds.) (2008). *Real-time coastal observing systems for marine ecosystem dynamics and Harmful Algal Blooms*. Monographs on Oceanographic Methodology Series. UNESCO. Paris

Badal, M.R., Rughooputh, S.D.D.V., Rydberg, L., Robinson, I.S. and Pattiaratchi, C. (2009). Eddy formation around South West Mascarene Plateau (Indian Ocean) as evidenced by satellite 'global ocean colour' data. *Western Indian Ocean J. Mar. Sci*. 8(2), 139-145

Barber, R.T., Marra, J., Bidigare, R.R., Codispoti, L.A., Halpern, D., Johnson, Z., Latasa, M.,Barlow, R. G., Aiken, J., Holligan, P. M., Cummings, D. G., Maritorena, S. and Hooker, S. (2002). Phytoplankton pigment and absorption characteristics along meridional transects in the Atlantic Ocean. *Deep Sea Res. Part I Oceanogr. Res. Pap*. 49(4), 637–660

Barlow, R., Kyewalyanga, M., Sessions, H., van den Berg, M. and Morris, T. (2008). Phytoplankton pigments, functional types, and absorption properties in the Delagoa and Natal Bights of the Agulhas ecosystem. *Estuar. Coast. Shelf S.* 80, 201–211

Barlow, R., Lamont, T., Britz, K. and Sessions, H. (2013). Mechanisms of phytoplankton adaptation to environmental variability in a shelf ecosystem. *Estuar. Coast. Shelf S.* 133, 45-57

Barlow, R., Lamont, T., Kyewalyanga, M., Sessions, H., van den Berg, M. and Duncan, F. (2011). Phytoplankton production and adaptation in the vicinity of Pemba and Zanzibar Islands, Tanzania. *Afr. J. Marine Sci.* 33(2), 283—295

Barlow, R., Lamont, T., Morris, T., Sessions, H. and van den Berg, M. (2014). Adaptation of phytoplankton communities to mesoscale eddies in the Mozambique Channel. *Deep Sea Res. Part II Top. Stud. Oceanogr.* 100, 106–118

Barlow, R., Stuart, V., Lutz, V., Sessions, H., Sathyendranath, S., Platt, T., Kyewalyanga, M., Clementson, L., Fukasawa, M., Watanabe, S. and Devred, E. (2007). Seasonal pigment patterns of surface phytoplankton in the subtropical southern hemisphere. *Deep Sea Res. Part I Oceanogr. Res. Pap*. 54(10), 1687–1703

Barlow, R.G., Lamont, T., Kyewalyanga, M., Sessions, H. and Morris, T. (2010). Phytoplankton production and

physiological adaptation on the southeastern shelf of the Agulhas ecosystem. *Cont. Shelf Res.*30, 1472–1486

Barlow, R.G., Mantoura, R.F.C. and Cummings, D.G. (1999). Monsoonal influence on the distribution of phytoplankton pigments in the Arabian Sea. *Deep Sea Res. Part II Top. Stud. Oceanogr.* 46(3), 677–699

Beckley, L.E. (1998). The Agulhas Current Ecosystem with particular reference to dispersal of fish larvae. In *Large Marine Ecosystems of the Indian Ocean: Assessment, Sustainability and Management* (eds. K. Sherman, E. N. Okemwa and M. J. Ntiba) pp. 255-276. Blackwell Science, Inc. Malden, M.A.

Behrenfeld, M.J., O'Malley, R.T., Siegel, D.A. and McClain, C.R. (2006). Climate-driven trend in contemporary ocean productivity. *Nature* 444, 752-755

Bouman, H., Platt, T., Sathyendranath, S., and Stuart, V. (2005). Dependence of light-saturated photosynthesis on temperature and community structure. *Deep Sea Res. Part I Oceanogr. Res. Pap.* 52(7), 1284-1299

Bowman, H., Platt, T., Sathyendranath, S., Li, W.K.W., Stuart, V., Fuentes-Yaco, C., Maass, H., Horne, E.P.W., Ulloa, O., Lutz, V. and Kyewalyanga, M. (2003). Temperature as indicator of optical properties and community structure of marine phytoplankton: implications for remote sensing. *Mar. Ecol. Prog. Ser.* 258, 19-30

Burchall, J. (1968a). *Primary production studies in the Agulhas current region off Natal—June 1965.* Investigational Report, 20. Oceanographic Research Institute, Durban

Burchall, J. (1968b). *An evaluation of primary productivity studies in the continental shelf region of the Agulhas current near Durban (1961-1966).* Investigational report, 21. Oceanographic Research Institute, Durban

Calbet, A. (2008). The trophic roles of microzooplankton in marine systems. *ICES J. Mar. Sci.* 65, 325-331

Chassot, E., Bonhommeau, S., Dulvy, N.K., Melin, F., Watson, R., Gascuel, D. and Le Pape, O. (2010). Global marine primary production constrains fisheries catches. *Ecol. Lett.*13, 495–505

Chavez, F P., Messié, M. and Pennington, J.T. (2010). Marine primary production in relation to climate change variability. *Ann. Rev. Mar. Sci.* 3, 227-260

Chislock, M.F., Doster, E., Zitomer, R.A. and Wilson, A.E. (2013). Eutrophication: causes, consequences, and controls in aquatic ecosystems. *Nat. Educ. Knowl.* 4(4), 10

Cloern, J.E., Foster, S.Q. and Kleckner, A.E. (2014). Phytoplankton primary production in the world's estuarine-coastal ecosystem. *Biogeosciences* 11, 2477–2501

Conway, D.V.P., White, R.G., Hugues-Dit-Ciles, J., Gallienne, C.P. and Robins, D.B. (2003). *Guide to the coastal and surface zooplankton of the south-western Indian Ocean.* Occasional Publication of the Marine Biological Association of the United Kingdom. No 15. Plymouth, UK

Cooley, S.R., Kite-Powell, H.L. and Doney, S.C. (2009). Ocean acidification's potential to alter global marine ecosystem services. *Oceanography 22*, 172-181

Cury, P., Shannon, L. and Shin, Y.J. (2003). The functioning of the marine ecosystems: a fisheries perspective. In *Responsible fisheries in the marine ecosystem* (eds. M. Sinclair and G. Valdimarsson) pp. 103-123. FAO and CAB International. Rome, Italy, and Wallingford, UK

Duarte, C.M. and Cebrian, J. (1996). The fate of marine autotrophic production. *Limnol. Oceanogr.* 41, 1758–1766

Duarte, C.M., Middelburg, J.J. and Caraco, N. (2005). Major role of marine vegetation on the oceanic carbon cycle. *Biogeosc. 2*, 1-8

Ezekiel, J. (2014). *Temporal and spatial variation of phytoplankton in Rufiji Delta/Mafia Channel, Southern Tanzania.* MSc. Thesis, University of Dar es Salaam, Dar es Salaam, Tanzania

Falkowski, P.G. and La Roche, J. (1991). Acclimation to spectral irradiance in algae. *J.Phycol.* 27, 8–14

Fennessy, S. T., Ayers, M., Barlow, R., Kunnen, T., De Lecea, A. M., De Charmoy, L., Guastella, L., Hein, L., Huggett, J., Lamont, T., Mackay, F., Meyer, A., Mkhize, N., Muir, D., Nieuwenhys, C., Omarjee, A., Ovechkina, M. N., Pretorius, M., Robert, M., Scharler, U., Smit, A. J., Taljaard, S., Untiedt, C. B., Uken, R., van Ballegooyen, R. and van de Molen, J. (2013). *Ecosystem processes in a river-influenced Bight: linking geological, biological and physical processes to understand ecosystem functioning.* 8th WIOMSA Scientific Symposium Book of Abstract, page 64

Field, C.B., Behrenfeld, M.J., Randerson, J.T., and Falkowski, P. (1998). Primary production of the biosphere: integrating terrestrial and oceanic components. *Science 281*(5374), 237-240

Gallienne, C.P. and Smythe-Wright, D. (2005). Epipelagic mesozooplankton dynamics around the Mascarene Plateau and Basin, Southwestern Indian Ocean. *Phil. Trans. R. Soc. A.* 363, 191–202

Gallienne, C.P., Conway, D.V.P., Robinson, J., Naya, N., S, William, J.S., Lynch, T. and Meunier, S. (2004). Epipelagic mesozooplankton distribution and abundance

over the Mascarene Plateau and Basin, south-western Indian Ocean. *J. Mar. Biol. Ass. U.K.* 84(1), 1-8

Goericke, R., and Smith, S.L. (2001). Primary productivity and its regulation in the Arabian Sea during 1995. *Deep Sea Res. Part II Top. Stud. Oceanogr.* 48, 1127-1172

Goericke, R., Olson, R.J. and Shalapyonok, A. (2000). A novel niche for *Prochlorococcus* sp. in low-light suboxic environments in the Arabian Sea and the Eastern Tropical North Pacific. *Deep Sea Res. Part I Oceanogr. Res. Pap.* 47, 1183–1205

Government of Kenya (2009). *State of the coast report: Towards integrated management of coastal and marine resources in Kenya*. National Environment Management Authority (NEMA), Nairobi

Heileman, S. and Scott L.E.P. (2008). The Somali Current Large Marine Ecosystem. In *The UNEP Large Marine Ecosystem Report: A Perspective on Changing Conditions in LMEs of the World's Regional Seas (*eds. K. Sherman and G. Hempel) UNEP, United States

Heileman, S., Lutjeharms J.R.E. and Scott L.E.P. (2008). The Agulhas Current Large Marine Ecosystem. In *The UNEP Large Marine Ecosystem Report: A Perspective on Changing Conditions in LMEs of the World's Regional Seas* (eds. K. Sherman and G. Hempel) pp. 2-18. UNEP, United States

Helbling, E.W., Barbieri, E.S., Marcoval, M.A., Gonçalves, R.J. and Villafañe, V.E. (2005). Impact of solar ultraviolet radiation on marine phytoplankton of Patagonia, Argentina. *Photochem. Photobiol.* 81(4), 807-818

Jeffrey, S.W. and Vesk, M. (1997). Introduction to marine phytoplankton and their pigment signatures. In *Phytoplankton pigments in oceanography.* (eds. Jeffrey, S.W., Mantoura, R.F.C. and Wright, S.W.) pp. 37–84. UNESCO Publishing, Paris

Karl, D.M., Christian, J.R., Dore, S.E., Hebel, D.V., Letelier, R.M., Tupas, L.M. and Winn, C.D. (1999). Seasonal and interannual variability in primary production and particle flux at Station ALOHA. *Deep Sea Res. Part II Top. Stud. Oceanogr.* 43, 239–268

Kirk, J.T.O. (1994). *Light and Photosynthesis in Aquatic Ecosystems*. 2nd edition. Cambridge University Press, Cambridge

Koné, V., Aumont, O., Levy, M. and Resplandy, L. (2009). Physical and biogeochemical controls of the phytoplankton seasonal cycle in the Indian Ocean: A modeling study. In *Indian Ocean Biogeochemical Processes and Ecological Variability*. (eds. Wiggert, J. D., Hood, R. R., Naqvi, S. W. A., Brink, K. H., and Smith, S. L.) vol. 185, pp. 147-166. Geophysical Monograph Series

Kromkamp, J., De Bie, M., Goosen, N., Peene, J., Van Rijswijk, P., Sinke, J. and Duineveldt, G.C.A. (1997). Primary production by phytoplankton along the Kenyan coast during the SE monsoon and November intermonsoon 1992, and the occurrence of *Trichodesmium*. *Deep Sea Res. Part II Top. Stud. Oceanogr.* 44 (167), 1195-1212

Kyewalyanga, M., Naik, R., Hegde, S., Raman, M., Barlow, R. and Roberts, M. (2007). Phytoplankton biomass and primary production in Delagoa Bight Mozambique: Application of remote sensing. *Estuar. Coast. Shelf S.* 74, 429-436

Lamont, T. and Barlow, R.G. (2015). Phytoplankton production and physiology during mid-summer 2010 on the KwaZulu-Natal Bight, South Africa. *Afr. J. Marine Sci.*

Lamont, T., Barlow, R., Morris, T. and van den Berg, M.A. (2014). Characterisation of mesoscale features and phytoplankton variability in the Mozambique Channel. *Deep Sea Res. Part II Top. Stud. Oceanogr.* 100, 94-105

Lamont, T., Roberts, M.J., Barlow, R.G., Morris, T. and van den Berg, M.A. (2010). Circulation patterns in the Delagoa Bight, Mozambique, and the influence of deep ocean eddies. *Afr. J. Marine Sci.* 32(3), 553–562

Leal, M.C., Sá, C., Nordez, S., Brotas, V. and Paula, J. (2009). Distribution and vertical dynamics of planktonic communities at Sofala Bank, Mozambique. *Estuar. Coast. Shelf S.* 84, 605–616

Lee, D.B., Song, H.Y., Park, C. and Choi, K.H. (2012). Copepod feeding in a coastal area of active tidal mixing: diel and monthly variations of grazing impacts on phytoplankton biomass. *Mar. Ecol.* 33, 88–105

Loebl, M. and Van Beusekom, J.E.E. (2008). Seasonality of microzooplankton grazing in the northern Wadden Sea. *J. Sea Res.* 59, 203-216

Lutjeharms, J.R.E. (ed.) (2006). *The Agulhas Current*. Springer, Berlin

Lutjeharms, J.R.E. and Da Silva, A.J. (1988). The Delagoa Bight eddy. *Deep Sea Res. Part I Oceanogr. Res. Pap.* 35, 619–634

Lyimo, T. and Hamisi, M. (2008). Cyanobacteria occurrence and nitrogen fixation rates in the seagrass meadows of the East Coast of Zanzibar: Comparisons of sites with and without seaweed farm. *Western Indian Ocean J. Mar. Sci.* 7(1), 45-55

Madhupratap, M., Kumar, S.P., Bhattathiri, P.M.A., Kumar, M.D., Raghukumar, S., Nair, K.K.C., and Ramaiah, N. (1996). Mechanisms of the biological response to winter cooling in the northeastern Arabian Sea. *Nature* 384, 549-552

Marra J., Dickey, T.D., Kinkade, C.S., Ho. C., Sigurdson, D.E., Weller, R. and Barber, R.T. (1998). Variability in primary production as observed from moored sensors in the central Arabian Sea in 1995. *Deep Sea Res. Part II Top. Stud. Oceanogr.* 45, 2253-2268

McClanahan, T. (1998). Seasonality in East Africa's coastal waters. *Mar. Ecol. Prog. Ser.* 44, 191-199

McKenna, S.A. and Allen, G.R. (2005). *A Rapid marine biodiversity assessment of northwest Madagascar. Bulletin of the Rapid Assessment Programme 31*. Center for Applied Biodiversity Science, Conservation International, Conservation International. Washington, D.C.

Mengesha, S., Dehairs, F., Elskens, M. and Goeyens, L. (1999). Phytoplankton nitrogen nutrition in the Western Indian Ocean: Ecophysiological adaptations of neritic and oceanic assemblages to ammonium supply. *Estuar. Coast. Shelf S.* 48, 589–598

Meyer, A.A., Lutjeharms, J.R.E. and de Villiers, S. (2002). The nutrient characteristics of the Natal Bight, South Africa. *J .Mar. Syst.* 35, 11-37

Mitchell-Innes, B.A. (1967). *Primary production studies in the South-West Indian Ocean, 1961–1963*. Investigational Report No 14. Oceanographic Research Institute, Durban, Republic of South Africa

Mmochi, A.J. and Mwandya, A.W. (2003). Water quality in the Integrated Mariculture Pond Systems (IMPS) at Makoba Bay, Zanzibar, Tanzania. *Western Indian Ocean J. Mar. Sci.* 2(1), 15-24

Msuya, F.E. (2013). *Recent occurrence of algal blooms affecting seaweed farms in Zanzibar – a sign of climate change impact.* 8th WIOMSA Scientific Symposium Book of Abstract, page 143

Oliveira, E.C., Osterlund, K. and Mtolera, M.S.P. (2005). *Marine Plants of Tanzania: A guide to the seaweeds and seagrasses*. Botany Department, Stockholm University, Sweden

Owens, N.J.P., Burkill, P.H., Mantoura, R.F.C., Woodward, E.M.S., Bellan, I.E., Aiken, J., and Llewellyn, R.J.M. (1993). Size-fractionated primary production and nitrogen assimilation in the northwestern Indian Ocean. *Deep Sea Res. Part II Top. Stud. Oceanogr.* 40, 711-736

Passow, U. and Carlson, C.A. (2012). The biological pump in a high CO_2 world. *Mar. Ecol. Prog. Ser.* 470, 249-271

Peter, N. (2013*). Phytoplankton distribution and abundance along Zanzibar and Pemba Channels*. M.Sc. Thesis, University of Dar es Salaam, Dar es Salaam, Tanzania

Platt, T., Bouman, H., Devred, E., Fuentes-Yaco, C. and Sathyendranath, S. (2005). Physical forcing and phytoplankton distributions. *Sci. Mar.* 69, 55–73

Platt, T., Fuentes-Yaco, C. and Frank, K. (2003). Spring algal bloom and larval fish survival. *Nature* 423, 398-399

Porra, R.J., Pfündel, E.E. and Engel, N. (1997). Metabolism and function of photosynthetic pigments. In *Phytoplankton Pigments in Oceanography*. (eds. S.W. Jeffrey, R.F.C. Mantoura and S.W. Wright) pp. 85–126, UNESCO Publishing, Paris

Poulton, A.J., Stinchcombe, M.C. and Quartly, G.D. (2009). High numbers of *Trichodesmium* and diazotrophic diatoms in the southwest Indian Ocean. *Geophys. Res. Lett.* 36(15)

Quartly, G.D. and Srokosz, M.A. (2004). Eddies in the southern Mozambique Channel. *Deep Sea Res. Part II Top. Stud. Oceanogr.* 51, 69–83

Quartly, G.D., Buck, J.J.H. and Srokosz, M.A. (2005). Eddy Variability East of Madagascar. *Phil. Trans. R. Soc. A* 363, 77-79

Ramessur, R.T. (2011). Dissolved nutrients from submarine groundwater discharge in Flic en Flac Lagoon, Mauritius. *Western Indian Ocean J. Mar. Sci.* 10(2), 121-127

Reid, P.C., Battle, E.J.V., Batten, S.D. and Brander, K.M. (2000). Impact of fisheries on plankton community structure. *ICES J. Mar. Sci.* 57, 495-502

Richmond, M.D. (ed.) (2011). *A field guide to the seashores of Eastern Africa and Western Indian Ocean Islands*. Sida/WIOMSA

Ryther, J.H., Hall, J.R., Pease, A.K., Bakun, A. and Jones, M.M. (1966). Primary organic production in relation to the chemistry and hydrography of the western Indian Ocean. *Limnol. Oceanogr.* 11, 371–380

Sá, C., Leal, M.C., Silva, A., Nordez, S., André, E., Paula, J. and Brotas, V. (2013). Variation of phytoplankton assemblages along the Mozambique coast as revealed by HPLC and microscopy. *J. Sea Res.* 79, 1–11

Sadally, S.B., Taleb-Hossenkhan, N. and Bhagooli, R. (2014). Spatial and temporal variations of micro-phytoplankton diversity and biomass in two tropical coral reefs. *Afr. J. Marine Sci.* 36(4), 423-438

Savidge, G. and Gilpin, L. (1999). Seasonal influences on

size-fractionated chlorophyll *a* concentrations and primary production in the northwest Indian Ocean. *Deep Sea Res. Part II Top. Stud. Oceanogr.* 46, 701-723

Smith, R.C., Prezelin, B.B., Baker, K.S., Bidigare, R.R., Boucher, N.P., Coley, T., Karentz, D., MacIntyre, S., Matlick, H.A. and Menzies, D. (1992). Ozone depletion: ultraviolet radiation and phytoplankton biology in antarctic waters. *Science* 255(5047), 952-959

Steemann-Nielsen, E. and Jensen, E.A. (1957). Primary organic production. The autotrophic production of organic matter in the oceans. *Galathea Rep.* 1, 49-136

SWIOFP (2012). *Mainstreaming biodiversity in fisheries management: a retrospective analysis of existing data on vulnerable organisms in the South West Indian Ocean*. A specialist report. A SWIOFP Retrospective Analysis. Durban, South Africa

Tew-Kai, E. and Marsac, F. (2009). Patterns of variability of sea surface chlorophyll in the Mozambique Channel: a quantitative approach. *J. Mar. Syst.* 77, 77–88

UNEP/Nairobi Convention (2014a). "Possible algal bloom caused by nutrient excess at Port Victoria". In *Marine and coastal news round-up in the Western Indian Ocean (WIO) Region*. 23rd May. http://www.unep.org/NairobiConvention/

UNEP/Nairobi Convention (2014b). "Mauritius: Sensitising the public and stakeholders on climate change adaptation". In *Marine and coastal news round-up in the Western Indian Ocean (WIO) Region*. 15th August. http://www.unep.org/NairobiConvention/

UNEP/Nairobi Convention Secretariat (2009). *Strategic Action Programme for the Protection of the Coastal and Marine Environment of the Western Indian Ocean from Land-based Sources and Activities*. Nairobi, Kenya

UNEP/Nairobi Convention Secretariat, CSIR and WIOMSA (2009). *Regional Synthesis Report on the Status of Pollution in the Western Indian Ocean Region*. UNEP. Nairobi, Kenya

UNEP/Nairobi Convention Secretariat. http://www.unep.org/Nairobi Convention/The Convention/index.asp.

Vargas. C.A., Escribano, R. and Poulet, S. (2006). Phytoplankton food quality determines time windows for successful zooplankton reproductive pulses. *Ecology* 8, 2992-2999

Ward, B.A., Dutkiewicz, S., Jahn, O. and Follows, M.J. (2012). A size-structured food-web model for the global ocean. *Limnol. Oceanogr.* 57(6), 1877-1891

Watts, L. and Sathyendranath, S. (2002). Report sensing of ocean colour in the Arabian Sea. Report of the Indian Ocean synthesis group on the Arabian Sea process study. *JGOFS Report* 35, 30-35



17
Ocean-sourced Carbonate Production

Jacqueline Uku

Opposite page: Biogenic rocks and sediments at Ibo Island, Mozambique. © José Paula.

INTRODUCTION

Globally, atmospheric carbon dioxide (CO_2) is exchanged with the surface ocean through a gas exchange mechanism which is driven by the partial pressure differences in carbon dioxide between the air and the sea (Ciais and others, 2013). Once in the ocean, the production of carbonates is a process that is governed by a series of chemical reactions as described by Doney and others (2009). Carbon dioxide dissolves in sea water (H_2O) to form carbonic acid (H_2CO_3). This then dissociates to form bicarbonate ions (HCO_3), hydrogen ions (H^+) and carbonate ions (CO_3). These reactions are reversible and are in an equilibrium state in seawater which has a pH of around 8.1 (Doney and others, 2009). At this pH, approximately 90 per cent of the inorganic carbon is in the form of bicarbonate, 9 per cent exists as carbonate and 1 per cent is in the form of dissolved carbon dioxide (Doney and others, 2009).

Calcification is the process in which calcium (Ca) combines with carbonate ions to form the mineral calcium carbonate ($CaCO_3$) (Andersson and Gledhill 2013). Most of the calcium carbonate production in the sea is attributed to corals, calcifying algae, foraminifera, echinoderms, molluscs and bryozoans (Andersson and Gledhill 2013) and in these organisms the calcification process involves the formation of calcium carbonate deposits in shells and other skeletal parts (Doney and others, 2009, Lobban and Harrison 1994).

In the open ocean, the carbonate producers are microscopic foraminifera (microscopic animals) and coccolithophores (microscopic algae) which are carried around in the oceanic systems and once they die their calcareous skeletons sink to the bottom of the ocean and form part of the oceanic bed (Langer 2008, Shutler and others, 2013).

THE IMPORTANCE OF CARBONATE PRODUCERS TO THE MARINE AND COASTAL ENVIRONMENT

Langer (2008) indicates that benthic and planktonic foraminifera currently produce approximately 1.4 billion tonnes of of calcium carbonate per year, which ends up buried in oceanic sediments, representing approximately 25 per cent of the global ocean carbonate production. Foraminifera have also been shown to contribute to the cementation and stability of coral reefs (Langer 2008).In addition to the foraminifera, coccolithophores are widely distributed in the world's oceans and play a major role in the oceanic carbon cycles (Shutler and others, 2013).

Among coastal systems, coral reefs form one of the most diverse environments of the ocean and are estimated to host one third of all marine species (Veron and others, 2009) and they are the most visible carbonate producers. They are found in over 110 countries and contribute 900 million tonnes of global carbonate production (Langer 2008). Coral reefs in the WIO region shield the coastline from wave action and erosion and the effects of sea level rise, thus protecting lagoons and mangroves and helping to maintain habitats for a variety of commercial and non-com-

mercial species (Veron and others, 2009, McClanahan and others, 2011).

The calcification process is an important process in the building of coral reefs and for the supply of carbonate sands to coastal lagoons (Kangwe and others, 2012). Calcium carbonate from corals and calcifying algae is the greatest source of sediment in the oceans (Milliman and Droxler 1995, Freely and others, 2004) and the contribution of carbonates to the sedimentary composition of the marine environment in the WIO region is significant (Rees and others, 2005, Kangwe and others, 2012). It has been estimated that approximately 50 per cent of all calcium carbonate that accumulates in marine sediments is stored in shallow coastal and shelf environments as well as in coral reef environments (Andersson and Gledhill 2013).

Individual corals have been documented to deposit between 0.5 – 3.0 g $CaCO_3/cm^2/yr$ while estimates of larger reef areas show that calcification by corals and algae together contributes between 1.5 – 10.0 kg $CaCO_3/m^2/yr$ (Andersson and Gledhill 2013). For example, the shallow-water green alga *Halimeda* sp. generates between 2.0 and 4.0 kg $CaCO_3/m^2/ar$ (Andersson and Gledhill 2013).

Calcium carbonate deposits function as deterrents to predators and therefore protect the soft tissues of the organism from predation (Doney and others, 2009, Lobban

BOX 17.1. SOURCES OF SAND ON BAMBURI BEACH, KENYA



Bamburi beach, Kenya. © Jared Bosire.

In the WIO region, beach profiling in the Bamburi area, close to Mombasa, revealed that beach sediments comprise a combination of coralline, algal and siliciclastic sands. In some areas of the Bamburi beach, large-sized coral debris can be found whilst in others the debris has been broken down by wave action to contribute finer fragments of coral to the beach sands. At least 50 per cent of the beach sand is derived from a carbonate source, the contributors being corals and calcareous green algae (*Halimeda* spp.) as well as molluscs and foraminifera. Beaches that are located close to creeks generally contain a greater percentage of siliciclastic sands, whose origin is terrestrial, whilst those located further from the creeks contain a greater amount of carbonates. The carbonate sands also contribute to lagoon sediments to form a substrate for seagrasses and *Halimeda* spp., which are a critical fishery habitat in the WIO region (Shaghude and others, 2013).

and Harrison 1994). Other benefits include structural support, increased surface area and the elevation of calcifying organisms above the sediment level to enable them to maintain proximity to high light levels and to keep up with the rise in sea levels (Andersson and Gledhill 2013) as is the case with corals.

In the WIO region, the sediment found on beaches is comprised of carbonates from various sources including coral fragments, calcareous green algae, shells of molluscs and spines of sea urchins (echinoderms) (Shaghude and others, 2013), as described in more details in Boxes 17.1 and 17.2.

BOX 17.2. CONTRIBUTION OF CALCAREOUS ALGAE TO THE CHWAKA BAY ECOSYSTEM, ZANZIBAR



Halimeda sp. in Cabo Delgado, North Mozambique. © José Paula.

Chwaka Bay, in Zanzibar, Tanzania, is characterized by large meadows of the green calcareous algae (*Halimeda* spp.) as well as rhodoliths (red coralline algae). The calcareous green algae are estimated to cover up to 35 per cent of the bay. The key contribution of the *Halimeda* spp. in this bay has been observed to be the production of carbonate sand. The calcium carbonate production by *Halimeda opuntia* in Chwaka Bay has been estimated to reach 17. 6 kg $CaCO_3/m^2$/yr which is higher than estimates for this species from other parts of the world.

Rhodoliths are free living nodules that are common in Chwaka Bay. They provide food, shelter and nursery grounds to fish and molluscs. In some parts of the world, rhodoliths are extracted for use as soil conditioners and fertilizers.

In Chwaka Bay, as in other parts of the WIO region, *Halimeda* spp. and other calcifying algae are found within seagrass environments. It has been thought that there is a coupling between seagrasses and calcareous macroalgae. This is because the photosynthetic process by seagrasses leads to the creation of a high pH environment which increases the saturation state of calcium carbonate ($CaCO_3$) in the surrounding water. This in turn causes high calcification rates in *Halimeda* spp. and other coralline algae (Kangwe and others, 2012). (Source: Shagude et al. 2013)

ECONOMIC CONTRIBUTION OF CARBONATE PRODUCERS TO ECONOMIES OF THE WIO COUNTRIES

In the WIO region, coral reefs are a major carbonate producer. They extend from southern Somalia to the coast of KwaZulu-Natal, South Africa. The most common form is the fringing reef. In addition, the WIO region is characterized by barrier reefs, found in Madagascar and Mayotte, atolls found in the Seychelles and patch reefs found in South Africa (ASCLME/SWIOFP 2012).

Coastal and marine ecosystems, including coral reefs, support the provision of food and income for approximately 30 million people as well as goods and services that are important to national economies (McClanahan and others, 2011). More specifically, tourism is the largest direct source of income that is directly linked to the coastal and marine environment; the region's beautiful sandy beaches, mangrove forests, lagoons and coral reefs attract over 20 million tourists from all over the world every year, injecting more than US$ 6 000 million per year into the economies of the WIO region (UNEP/Nairobi Convention Secretariat 2009). Tourism to the coastal regions of the WIO surpasses the contribution of fisheries to these economies thus making the integrity of carbonate-based habitats such as reefs and beaches a critical part of the coastal economies of the region (UNEP/Nairobi Convention Secretariat 2009).

The integrity of these habitats also contributes to the fishing economy of the coastal countries as fish and other valuable marine species such as molluscs and crustaceans find shelter within coral reef and associated seagrass habitats (UNEP/Nairobi Convention Secretariat 2009). Therefore any negative impact on these key habitats would extend to the livelihoods of coastal populations who depend on tourism, fisheries and other marine resources.

PRESSURES ON CARBONATE PRODUCERS

Ocean acidification

The most significant pressure on carbonate producers is the increase in atmospheric carbon dioxide. This is due to the combustion of fossil fuels as well as the production of cement, both key features of industrial development. Carbon dioxide has been documented to have increased from 278 ppm in about the year 1750 to 390.5 ppm in the year 2011, equivalent to about a 40 per cent rise (Ciais and others, 2013). Much of this increase has occurred in the recent past, with carbon emissions from fossil fuel combustion and cement production increasing faster during the 2000–2011 period than during the 1990–1999 period (Feely and others, 2009, Ciais and others, 2013). In the WIO region, the exploitation of oil and gas has been on the increase (ASCLME/SWIOFP 2012), and the drive towards industrialization will eventually make this region a net contributor to the increase in atmospheric carbon dioxide. Worldwide, it has been postulated that carbon dioxide levels are due to increase up to 450 ppm by 2040, if the current rate of increase persists, which is believed will cause rapid decline of coral reefs due to acidification, mass bleaching and other environmental impacts (Veron and others, 2009).

The absorption of the excess carbon by seawater causes chemical reactions that result in the reduction in the pH of seawater. The increase of carbon dioxide increases the amounts of bicarbonate and hydrogen ions resulting in the lowering of the pH which in turn lowers the concentration of carbonate ions (Feely and others, 2009, Borges and Gypens 2010, Rhein and others, 2013) thus making them less available for the formation of calcium carbonate in marine organisms. The mean pH of surface waters in the open ocean ranges from 7.8 to 8.4, thus the ocean remains mildly basic (pH >7) at present (Rhein and others, 2013). It has been estimated that the pH of the ocean surface will drop by 0.3 – 0.4 units by the end of this century (Feely and others, 2009, Rhein and others, 2013). Though the consequences of changes in pH and the saturation state of carbonate ions for marine organisms and ecosystems are just beginning to be understood, and it is expected that the calcification rates of most marine pelagic and benthic calcifying organisms will decrease (Borges and Gypens 2010, Rhein and others, 2013).

Changes in pH have been documented in cold oceans of the high latitudes where carbon dioxide is more soluble and it is projected that the impact in the tropics will begin to be seen between 2030 and 2050 (Veron and others, 2009). Further to this, Veron and others (2009) indicate that when carbon dioxide levels reach 450 ppm, calcification of coralline algae will be inhibited whilst that of corals will be reduced by half with shallow water branching corals becoming brittle and susceptible to breakage leading to habitat deterioration.

Experimental work has contributed a greater understanding of the anticipated responses to ocean acidification. Findings of laboratory experiments, which are usually short-term in nature, spanning over a period of a few hours

to weeks, show that the typical response in most organisms has been the loss of the carbonate skeletons in low pH environments (Doney and others, 2009). In some organisms, reduced fertilization success and developmental rates have been documented (Doney and others, 2009). Therefore impacts on food chains are anticipated (Trilbollet and Golubic 2011). Associated organisms that feed on corals (known as bioeroders) such as boring bivalves, grazers, such as urchins and fish, are expected to show reduced grazing impacts as these organisms also have calcified parts such as shells and mouth parts which would similarly be affected by the low pH environment (Trilbollet and Golubic 2011).

Several planktonic species have demonstrated resilience to increased carbon dioxide under experimental conditions (Doney and others, 2009). From experimental work undertaken in different parts of the world, it is clear that there could be species of calcifying organisms in the WIO that could survive the pH changes that are anticipated to occur, due to genetic diversity (Veron and others, 2009).

The spatial variability of impact responses by coral reef habitats to climate warming have varied over geographical scales (Graham and others, 2008). For the WIO region it can be implied that similar variations may occur as a result of ocean acidification. In addition to this, some calcifying organisms may shift their distribution ranges to more carbonate rich environments (Doney and others, 2009).

Eutrophication and its impacts on carbonate producers

Runoff from terrestrial sources due to urban development, agriculture and deforestation form a crucial link to lowered water quality of coastal areas (Veron and others, 2009). Sewage contributes to nutrient enrichment through the enhanced amounts of phosphates, ammonium and nitrates that flow into the sea water. Bjork and others (1995) documented a 60 per cent decrease in the cover of coralline algae that were close to sewage sources in Zanzibar. Further to this, a decline in growth rates of coralline algae was also documented at high phosphate concentrations while increased ammonium and nitrate levels did not have significant effects (Bjork and others, 1995).

The effects of eutrophication can also have far reaching consequences on seagrass habitats as high nutrient levels impact negatively on seagrasses, changing habitat structure (Deegan and others, 2002). As the seagrass environment plays a critical role in supporting the calcification of associated coralline algae (Kangwe and others, 2012) the implications of the loss of seagrasses due to eutrophication would also impact the calcification process and cause a decline in the abundance of associated carbonate producers.

Impact of (rising) ocean temperature

In many parts of the Western Indian Ocean region 45 per cent of the living corals were killed through bleaching during the warm temperature events of 1998 (McClanahan and others, 2011). Since the first occurrence in the late 1970s bleaching events linked to the El Niño cycles have occurred at intervals of every 4 – 7 years and are expected to occur more frequently in the future as ocean temperatures rise (Veron and others, 2009). Small increases in sea temperature of 1 – 2 ^{o}C destabilize the relationship between corals and their symbiotic algae (zooxanthellae) on which they rely on for energy and growth (Veron and others, 2009). In corals, the symbiotic relationship between the corals and zooxanthellae is critical as the zooxanthellae enhance coral calcification by providing a favorable environment for the deposition of calcium carbonate (Pearse and Muscatine 1971). The high temperatures result in the loss of the zooxanthellae from the coral tissues leaving them bleached or white in color (Veron and others, 2009). The consequences are the physical breakdown of coral structures as well as enhanced chemical breakdown in the event of ocean acidification (Andersson and Gledhill 2013).

Studies in the WIO region documented a decline in the richness of fish species in response to the loss of coral cover due to bleaching due to the loss of the physical structure of the reef (Graham and others, 2008). Live coral has been found to be important for the settlement of fish larvae therefore bleaching events lead to diverse impacts across the food chains associated with the coral reef ecosystem (McClanahan and others, 2011).

Further to this, Graham and others (2008) noted that in areas where corals extend to a depth of 50 m such as in atoll environments, the deeper waters could provide a refuge from temperature fluctuations for broodstock of corals which enable faster recovery of corals in shallow areas of these regions. Such areas would be important for integration into monitoring and experimental studies that provide greater insights into the role of uninhabited atolls in the management of climate change impacts (Knowlton and Jackson 2008).

Bioerosion and its impacts on carbonate producers

Coral reefs are governed by constructive forces such as calcification which lead to their growth as well as destructive forces that cause degradation, which include physical, chemical and biological erosion (Trilbollet and Golubic 2011, Andersson and Gledhill 2013). The erosion of reefs internally is through organisms such as cyanobacteria, fungi, sponges and polychaetes which excavate into the carbonate structures as they search for shelter and food (Trilbollet and Golubic 2011). External bioeroders include grazers, such as echinoderms and fishes, that graze on carbonate surfaces with their teeth (Trilbollet and Golubic 2011). The process of bioerosion causes the breakdown of corals into fine sediment that is deposited on the seabed (Trilbollet and Golubic 2011). Corals are continually being eroded through these processes and bioeroders constitute a food source for fish (Stromberg 2004).

Trilbollet and Golubic (2011) have postulated that ocean acidification combined with eutrophication, increasing temperatures and high irradiance will have impacts on bioerosion rates. The lower pH caused by acidification is expected to reduce calcification rates of corals which presents an opportunity for the increase of bioerosion by internally boring organisms (Trilbollet and Golubic 2011). Under normal situations, corals are able to control the rate of intrusion by internal bioeroders however this control may breakdown under acidification scenarios. The scenario of high bioerosion and poorly developed reefs has been documented in the eastern tropical Pacific where carbon dioxide levels are naturally high and the seawater pH is low and high nutrient levels exist (Andersson and Gledhill 2013).

Climate change-related sea level rise

The variation in sea levels is due to the transfer of water between the ocean, continents, ice sheets and the re-distribution of water within the ocean due to tidal changes and changes in the oceanic and atmospheric circulation (Rhein and others, 2013). It has been estimated that globally the average sea level has risen over the 20th century, with a mean rate of 1.7 mm/a between 1900 and 2010 and of 3.2 mm/a and between 1993 and 2010 (Rhein and others, 2013). Normal reef growth has been estimated to be approximately 6 mm/a and reefs have been able to grow upwards and keep up with the rate of the rising sea level (Veron and others, 2009). However, higher rates of sea level rise will have implications on the ability of coral reefs to keep up growth, which, when combined with other stressors such as acidification and high impact weather events, degradation of the coral reef environment could be significant (Veron and others, 2009).

Extractive use of carbonate producers

The reef environments of the WIO region provide habitats for many tropical fish species that are important for commercial and artisanal fisheries. They also provide materials such as shells for sale and coral rock used in the construction industry. As a result, many coral reefs around the WIO region are under threat from over-utilization as well as from visible anthropogenic influences such as pollution, sedimentation, nitrification and the damaging effects of fishing (ASCLME/SWIOFP 2012).

CONCLUSIONS

The WIO region is still considered to be relatively pristine compared to other regions of the world, however it is increasingly being threatened with signs of degradation seen due to natural climate change variability as well as anthropogenic impacts (UNEP/Nairobi Convention Secretariat 2009). The coastal zone of the WIO region supports over 60 million people (UNEP/Nairobi Convention Secretariat 2009). This has led to pressures associated with urbanization, most significant in mainland states where urban centres such as Mombasa (Kenya), Dar es Salaam (Tanzania), Maputo (Mozambique) and Durban (South Africa) support populations of between 2 and 4 million (UNEP/Nairobi Convention Secretariat 2009).This has led to localized pollution from domestic, industrial and agricultural sources leading to the degradation of coastal waters and sediments, resulting in a loss of biological diversity, human health problems and a reduction in fish stocks and catches (UNEP/Nairobi Convention Secretariat 2009).

There is an expanding pool of knowledge about the carbonate producers in the WIO and the few studies available provide a glimpse into the critical role that these organisms play in a world of increasing carbon (Kangwe and others, 2012, Semesi 2009).

Inferences can be made from the experimental work documented by Doney and others (2009) that due to the highly diverse marine flora and fauna that characterizes the WIO region, the responses to increased acidification and eutrophication of the ocean will be varied with some species expected to be resilient to these changes.

RECOMMENDATIONS

McClanahan and others (2011) stress the importance of identifying areas where reefs have exhibited resilience to the current climate stresses and establishing management regimes in such areas to ensure that there will be a pool of genetic material that can survive the increasing climatic impacts. In their study, they identified the region from southern Kenya to northern Mozambique as critical for the focus of regional management initiatives aimed at maintaining high diversity of reef habitats by reducing fishing impacts and pollution.

Further to this, Maina and others (2013), stress the fact that human impacts such as deforestation which leads to sedimentation, overfishing, coral destruction through physical means and sewage outflows present a greater threat to carbonate producers. They argue that land use changes have a far greater impact than climate change in their study of Madagascar which faces a decline in forest cover due to increased demand for land for agriculture and mining. This has led to a high sediment load and changes in evapotranspiration, ground water discharge and sediment loading into the marine environment. For the survival of reefs in Madagascar they argue that regional land-use management is more important than mediating climate change (Maina and others, 2013).

There is a need for focused studies, that track impacts through food webs, to understand the specific responses of the carbonate producers. As described by Doney and others (2009), programmes that provide for systematic, cost-effective monitoring of surface water chemistry and long-term laboratory manipulative experiments are critical in understanding the responses of carbonate producers in a fast changing world.

References

Andersson, A.J. and Gledhill, D. (2012). Ocean acidification and coral reefs: Effects on breakdown, dissolution, and net ecosystem calcification. *Annu. Rev. Mar. Sci. 5*, 321-348

ASCLME/SWIOFP (2012). Transboundary Diagnostic Analysis for the Western Indian Ocean. Volume 1: Baseline. South Africa

Bjork, M., Mohammed, S., Bjorklund, M. and Semesi, A. (1995). Coralline algae, important coral-reef builders threatened by Pollution. *Ambio* 24 (7-8), 502-505

Borges, A. and Gypens, N. (2010). Carbonate chemistry in the coastal zone responds more strongly to eutrophication than to ocean acidification. *Limnol. Oceanogr.* 55(1), 346–353

Ciais, P., Sabine, C., Bala, G., Bopp, L., Brovkin, V., Canadell, J., Chhabra, A,. DeFries, R., Galloway, J., Heimann, M., Jones, C., Le Quéré, C., Myneni, R.B., Piao, S. and Thornton, P. (2013). Carbon and Other Biogeochemical Cycles. In *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the IPCC*. (eds. Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley) pp. 465-570. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Deegan, L., Wright, A., Ayvazian, S., Finn, J., Golden, H., Merso, R. and Harrison, J. (2002). *Aquatic Conserv: Mar. Freshw. Ecosyst.* 12, 193–212

Doney, S., Fabry, V., Feely, R. and Kleypas, J. (2009). Ocean Acidification: The other CO_2 problem. *Annu. Rev. Mar. Sci.* 1, 69–92

Feely, R.A., Sabine, C., Lee, K., Berelson, W., Kleypas, J., Fabry, V. and Millero, F. (2004). Impact of anthropogenic CO2 on the CaCO3 system in the oceans. *Science* 305(5682), 362-366

Feely, R., Scott, C. and Cooley, S. (2009). Ocean acidification: Present conditions and future changes in a high CO_2 world. *Oceanography* 22(4), 37–47

Graham, N. McClanahan, T., MacNeil, M., Wilson, S., Polunin, N., Jennings, S., Chabanet, P., Clark, S., Spalding, M., Letourneur, Y., Bigot, L., Galzin, R., Ohman, M., Garpe, K., Edwards, A. and Sheppard, C. (2008). Climate Warming, Marine Protected Areas and the Ocean-Scale Integrity of Coral Reef Ecosystems. *PLoS ONE* 3(8): e3039

Kangwe, J., Semesi, S., Beer, S., Mtolera, M. and Bjork, M. (2012). Carbonate production by calcareous algae in a seagrass dominated system: The example of Chwaka Bay. In *People, Nature and Research in Chwaka Bay, Zanzibar, Tanzania* (eds. De la Torre Castro, M. and Lyimo,

T.) pp. 143–156

Knowlton, N, and Jackson, J. (2008). Shifting baselines, local impacts, and global change on coral reefs. *PLoS Biol* 6(2), e54

Langer, M. (2008). Assessing the contribution of foraminiferan protists to Global Ocean carbonate production *J. Eukaryot. Microbiol*. 55(3), 163–169

Lobban, C. and Harrison, J. (1994). *Seaweed ecology and physiology*. Cambridge University Press.

Maina, J., Moel, H., Zinke, J., Madin, J., McClanahan, T. and Vermaat, J. (2013). Human deforestation outweighs future climate change impacts of sedimentation on coral reefs. *Nat. Commun*. 4, 1986

McClanahan, T.I.M., Maina, J.M. and Muthiga, N.A. (2011). Associations between climate stress and coral reef diversity in the western Indian Ocean. *Glob. Change Biol*. 17(6), 2023–2032

Milliman, J. and Droxler, A. (1995). Calcium Carbonate Sedimentation in the global ocean: Linkages between the neritic and pelagic environments. *Oceanography* 8(3), 92–94

Pearse, V. and Muscatine, L. (1971) Role of symbiotic algae (zooxanthellae) in coral calcification. *Biol. Bull*. 141, 350–363

Rees, S., Opdycke, B., Wilson, P. and Fifield, L. (2005). Coral reef sedimentation on Rodrigues and the Western Indian Ocean and its impact on the carbon cycle. *Phil. Trans. R. Soc. A*. 363, 101–120

Rhein, M., Rintoul, S.R., Aoki, S., Campos, E., Chambers, D., Feely, R.A., Gulev, S., Johnson, G.C., Josey, S.A., Kostianoy, A., Mauritzen, C., Roemmich, D. and Talley, L.D. (2013). Observations: Ocean. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the IPCC*. (eds. Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley) pp. 255-315. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Semesi, I. (2009). *Seawater pH as a controlling factor in macroalgal calcification and photosynthesis*. PhD Thesis. Stockholm University

Shaghude Y, Mburu, J., Uku, J., Ochiewo, J., Nyandwi, N. , Onganda, H., Magori, C. Sanga, I. and Arthurton, R. (2013). Beach Sand Supply and Transport at Kunduchi in Tanzania and Bamburi in Kenya. *Western Indian Ocean J. Mar. Sci*. 11(2), 135-154

Shutler, J., Land, P.E., Brown, C.W., Findlay, H.S., Donlon, C.J., Medland, M., Snooke, R., and Blackford, J.C., (2013). Coccolithophore surface distributions in the North Atlantic and their modulation of the air-sea flux of CO2 from 10 years of satellite Earth observation data. *Biogeosciences* 10, 1-11

Stromberg, H. (2004). *Benthic cryptofauna and internal bioeroders on coral reefs*. PhD Thesis. Stockholm University

Trilbollet , A. and Golubic, S. (2011). Reef Bioerosion: Agents and Processes. In *Coral Reefs: An Ecosystem in Transition* (eds. Dubinsky, Z. and Stambler, N.) pp. 435–449. Sprigner.

UNEP/Nairobi Convention Secretariat (2009). *Strategic Action Programme for the Protection of the Coastal and Marine Environment of the Western Indian Ocean from Land-based Sources and Activities*. Nairobi, Kenya

Veron, J.E.N., Hoegh-Guldberg, O., Lenton, T.M., Lough, J.M., Obura, D.O., Pearce-Kelly, P., Sheppard, C.R.C., Spalding, M., Stafford-Smith, M.G. and Rogers, A.D. (2009). The coral reef crisis: The critical importance of <350 ppm CO2. *Mar. Pollut. Bull*. 58, 1428–1436



18

Aesthetic, Cultural and Spiritual Services from Coastal and Marine Environments

Rosemarie Mwaipopo and Mwanahija Shalli

Opposite page: Fort Jesus in Mombasa Island, built in the XVI century, a UNESCO World Heritage Site. © Alex Wafula.

INTRODUCTION

The interaction between human culture and the coastal and marine environment in the Western Indian Ocean (WIO) region has over time produced unique cultural products, practices and cultural influences. Several historical and archaeological sites exist, some attached to the region's rich maritime history, with slave trade as an important component. Evolution of cultures over the years (Seland 2014) provide people with a range of heritage values, cultural identities and certain forms of spiritual services (UNESCO 2003). Some of these landscapes have also attracted significant tourism due to their aesthetic and historical value. Equally important are traditional knowledge systems and institutions, some of which are given anecdotal or mythical reference, yet which illustrate existence of customary systems of resource management and local people's understanding as well as appreciation of ecosystem functioning (Cinner and Aswani 2007, Masalu and others, 2010). Marine resources, either used for cultural transactions or for direct consumption, are also part of the cultural heritage associated with the ecosystem, providing a range of benefits for the sustenance of coastal livelihoods. Certain historical sites and landscapes have however suffered from poor management (Duarte 2012), owing to factors that include changing value systems and physical intrusion, calling for concerted management efforts. At the same time, while some of the intangible heritage in the WIO region remains quite vibrant and dynamic, others are declining in cultural significance (Cinner 2007, Sunde 2013). Integration of customary systems in the management of resources is indicative of the region's desire to support a holistic approach to management. This chapter presents and discusses some of the services derived from cultural products and practices in the WIO region and their significance in the management of the coastal environment.

CULTURAL PRODUCTS

Cultural products within the WIO region refers to objects that have been constructed or appropriated through human labour and thought. They are described hereby under two categories: cultural products constructed through human cultural interactions, and those obtained directly from the marine environment for human consumption.

PRODUCTS OF CULTURAL INTERACTIONS

Maritime history (including the slave trade involving WIO countries) extends from the late first millennium AD to the early 20th century and led to the development of a number of sites, many of which have been absorded into local people's identity (Seland 2014). These sites include natural or cultural landscapes or seascapes, and can be traced back to the evolution of human settlement, and the resulting unique cultures of the people of the region. A major indicator of this cultural heritage is provided by the ascribed

World Heritage Sites. Twenty nine of 1 007 World Heritage Site "properties" are found among the ten states of WIO region, with twelve of these (see Table 18.1) located within the coastal zone (UNESCO 2014). The aesthetic and historical value of some of these sites are sources of tourist attraction (Bakker and Odendaal 2008a, Obura and others, 2012). With regard to their value in terms of cultural ecosystem services, an added tribute is where the "cultural component has evolved to sustain the biodiversity and ecosystem integrity on which it is dependent" (Abdulla and others, 2013).

Natural landscapes of cultural significance include the sacred *Kaya* forests situated along the coastal plains and hills of Kenya. The *Kaya* forests are known to have been the settlement of nine coastal Mijikenda ethnic groups in the former Coastal Province of Kenya (Abungu and Githitho 2012). They have rich botanical properties and certain sacred sites in the area are still maintained through a pattern of ritual practices in honour of the ancestors of the original inhabitants, overseen by community groups and elders. The *Kaya* are currently residual patches (from ten to two hundred hectares) of once extensive and diverse and lowland forest of Eastern Africa occurring within the Zanzibar-Inhambane Regional Mosaic (UNESCO classification, cited in Githitho 2003). They are botanically diverse and have a high conservation value, home to more than half of the rare plants along the Kenyan coast (Githitho 2003) thereby giving them a high biodiversity significance. *Tenets* elders still uphold preservation of the remaining *kaya* through testimonies of a past coastal people's civilization and their right to maintain sacred places within the area for fear of displacement. Such commitment has contributed to the current ecological value of the area, allowed protection of the forest, controlling although not totally preventing, the rate of destruction caused by encroachment for human activities such as farming and mining.

Other landscapes of historical significance, include the island of Mozambique (Mozambique), Le Morne cultural landscape (Mauritius), Kilwa Kisiwani and Songo Mnara (Tanzania); Fort Jesus and Lamu (Kenya) and Stone Town (Zanzibar). Each of these represent particular archaeological and architectural evidence of a past history of interaction of local communities with other cultures through maritime trade and communication, pre-dating colonial settlement in the region with slave trade as an important component since the end of the first millenium. **Mozambique Island** is a natural landscape integrated into the Indian Ocean trade networks since pre-colonial times up to the 20th century. It was also used as a Portuguese trading-post on the route to India in the 16th century (Duarte 2012, Silva 2014). The interaction of trading cultures, primarily Portuguese, Indian, Arabian with local traditions is reflected by the remarkable architectural diversity visible in the current settlement (Silva 2014), adding a strong structural significance to the site. **Le Morne Cultural landscape in Mauritius,** located in one of the least developed coastal areas on the island, encompasses a natural fortress that was used as a retreat for escaping slaves in the 18th and early 19th centuries who took shelter in caves and on the mountain slopes of Le Morne Brabant. Le Morne's slave escapees were later to interact with labourers of the indenture system of Mauritius with whom they are strongly linked and together comprise the present day Mauritian Creole society and culture (Bakker and Odendaal 2008b).

Table 18.1. World Heritage Site properties within the WIO region and year of designation.

	Country	Natural sites with cultural value	Cultural structures of value
1	Kenya		Lamu Old Town (2001) Sacred Mijikenda Kaya Forests (2008) Fort Jesus Mombasa (2011)
2	Madagascar	Tsingy de Bemaraha Strict Nature Reserve (1990)	
3	Mauritius		Aapravasi Ghat (2006) Le Morne Cultural Landscape (2008)
4	Mozambique		Mozambique Island (1991)
5	Seychelles	Aldabra Atoll (1982) Valee de Mai Nature Reserve (1983)	
6	South Africa	iSimangaliso wetland (1999)	
7	Tanzania		Ruins of Kilwa Kisiwani/Songo Mnara (1981) Stone Town of Zanzibar (2000)

Ruins of Kilwa Kisiwani and Songo Mnara (Tanzania) are remnants of once prosperous settlements which later developed into important cities linked to the Indian Ocean and Red Sea trading networks along the Swahili East African coast from the 9th to the 19th centuries. These settlements declined in their trading prominence before the arrival of the Portuguese. **Fort Jesus** (Kenya), built towards the end of the 16th Century is another landmark illustrating Portuguese fortified architecture. **Lamu Old Town**, located on a small island off Kenya's north coast, served as an important commercial and cultural interface between the ocean and hinterland between the 5th and 19th centuries. It declined in prominence from 1896 onwards under British rule, but revived later through restoration efforts as an attraction for Swahili culture and tourism (Bremner 2013). The remarkable **Stone Town of Zanzibar**, said to have developed from a fishing village in the 12th century, is renown for its history, archaeological and aesthetic values and is currently a famous tourist destination (Awadh 2007). Its historical attraction, coupled with the Zanzibar spice tours and trades in uniquely crafted doors and brass-studded wooden caskets, contribute significantly to local livelihoods. The heritage of these sites is also related to development and expansion of Swahili coastal culture including the language. Archaeological studies on the Swahili coast also document a rich heritage of artefacts linked to trade and commerce, which have been of interest to research and tourism (Breen and Lane 2003), and in depicting aspects of cultural identity of the 'Swahili' people. Physical intrusion (and in places degradation) in all of these historical sites and low capacity in the management of intangible heritage has however threatened their aesthetic appeal and thus people's reference to them as significant in terms of cultural value. Yet they bear witness to a rich history of diverse interactions with the coastal environment, a necessary attribute of coastal identities.

Evidence of underwater cultural heritage that strengthens the WIO region's past connections to ancient navigation and maritime trade routes along the Indian Ocean is growing. Some examples include archaeological assets uncovered around the Island of Mozambique (Duarte 2012) and in Tanzania (Ichumbaki 2011, Jeffrey and Parthesius 2013). These resources are being subjected to severe threat by treasure hunting activities. Unfortunatly, underwater heritage of outstanding value, in Mozambique Island for instance, has not been considered as a component of World Heritage classification.

The only natural seascapes in this list, the **Aldabra Atoll** (Seychelles) and **iSimangaliso Wetland Park** (South Africa), represent areas of unique terrestrial and marine biodiversity. Aldabra Atoll is referred to as a rich biodiversity laboratory and very attractive for tourism. Its remoteness and inaccessibility have meant that it has minimal human interaction, which account for its good conservation quality (Obura and others, 2012). The iSimangaliso site in contrast, which includes lake, wetland, sand dune and marine systems, also includes centuries-old fishing traditions (see Box 18.1).

PRODUCTS FOR DIRECT CONSUMPTION: FOOD AND OTHER UTILITY VALUES

Many products from coastal and marine ecosystems have been appropriated for direct use by coastal people for household consumption, health care, ornaments and income. During the Indian Ocean trade, cowrie shells are said to have fulfilled a function similar to copper coins as token currency, although their monetary value was recognised. Together with Indian beads made of semi-precious stones, cowrie

BOX 18.1. ISIMANGALISO'S MULTIPLE CULTURAL ASSETS

iSimangaliso, which means *'miracle and wonder'* is documented to have exceptional natural beauty and aesthetic quality, which have been a tourist attraction. Traditional fishers and harvesting communities settled on the fringes of the park, are now organized under traditional authorities, but depend on the area for food and income. Their claims to resources are supported by archaeological evidence of a large repository of Stone Age and Iron Age sites, which indicate that people have inhabited the area for thousands of years (Abdullah and others, 2013). Its designation as a World Heritage Site led to the establishment of co-management systems, the development of ecotourism, fishing permits and an increasing influx of recreational fishers. The introduction of these modern management structures have been strongly criticized by local communities who feel that their livelihoods have been stymied at the expense of other ecosystem services.

BOX 18.2. TABOOS AND MANAGEMENT EFFECTIVENESS IN MADAGASCAR

In Madagascar, the institution of *Dina*, an important part of the traditional justice system at village level that employed taboos, rituals and observance of sacred places, regulated human interaction with resources, and was instrumental in marine resource use practices (Cinner 2007). The government in Madagascar has incorporated the cultural system of *Dina* into the official legal system and has been encouraging communities to create *Dina* regarding management of natural resources.

shells were the primary currency in the East African slave trade, and also as domestic currency (Chaudhuri 1985). The most common was the Cypraea annulus or the ring cowrie obtained from Zanzibar (and other areas) by Arab traders. Their value as exchange currency however eroded and evolved into objects for ornaments or as artefacts for tourist consumption (Chaudhuri 1985). Mangroves have also been harvested by coastal people for diverse uses (including as medicine, for building poles and fuel wood) and have been commercially exploited for centuries (Mainoya and others, 1986). The commercial exploitation of mangroves in East Africa was intensified during Arab rule, and its wood was a prized resource used for building in Zanzibar, and exported to the Middle East. In Tanzania, trade of mangrove timber was taken over by the Germans in 1893, and in 1901-2, the colonial government in Kenya reported significant export value from mangroves (Curtin 1981). The most preferred mangrove species for the mangrove poles and wood was the genus *Rhizophora* (*mkandaa*). Mangroves continue to be a very valuable resource to coastal communities and to be exported to the Middle East.

Other products include certain species of seagrasses such as *Enhalus accoroides* and *Halophila* spp which have traditionally been used as remedies for different human health problems (Mesaki and Salleh 2008). People of Chwaka Bay had many traditional and religious uses for seagrasses, including aesthetic, and understood its function in fish production (Mesaki and Salleh 2008). Traditional salt production and coral lime making have also historically been part of coastal community livelihoods. Producing brine from boiling sea water was common practice, usually in small amounts, with salt used for dietary, medicinal, preservation and other uses (Zeleza 1997). Local salt production and lime making have however been very destructive to mangrove forests because of clearing for salt pans, or cutting of wood for boil brine or burning corals to make lime. In addition, unregulated uses of mangroves for household consumption and commerce have ultimately affected the productive ability of mangrove ecosystems, hence the quality of other ecosystem services, including provisioning of food.

CULTURAL PRACTICES

Customary marine resource use systems, largely upheld through taboos, myths and traditional ecological knowledge, make an important part of coastal people's cultural heritage (see Box 18.2). These practices have been known to regulate resource use patterns, or to restrict certain forms of behaviour around ecosystems that are known to be detrimental to the system. Traditional patterns of closed seasons for the octopus fishery in response to resource cycles (or in response to perceived or proven resource abuse) have been known to be practiced in Nosy Fay in Madagascar (Cinner 2007), and in Kizimkazi in Menai Bay, Zanzibar (Masalu and others, 2010). In the northern coast of KwaZulu Natal Province in South Africa, among the Kosi Bay fishing community, a number of shared norms and rules relating to access, ownership and use of the *utshwayelo*, a decision-making, dispute resolution and monitoring system still exists. This is in addition to shared cultural rituals and rites that reinforce the distinctive culture and customary system of the area (Sunde 2013). Oral histories and anecdotal evidence also establish existence of traditional coastal forest and mangrove protection systems such as in Vikokotoni, Tumbatu and Chunguruma villages, in Zanzibar (Masalu and others, 2010). In some areas, preserving sacred forests and peninsulas, where use of mangroves was restricted by traditional beliefs about spirits and undesirable consequences, served to protect the mangrove forests, intertidal/shoreline areas and the associated marine organisms (Shalli 2011).

A somehow similar approach to the recognition of the *Dina* system in statutory policies and practices is found in the National Small-scale Fisheries Policy of South Africa, and the Menai Bay Marine Park regulations (Zanzibar). The Small-scale Fisheries policy of South Africa (2012) provides for the state to "recognise the existence of any rights conferred by common law, customary law or legislation to the extent that these are consistent with the Bill of Rights"

(RSA 2012). Such initiatives, that respect indigenous people of the area and their traditions, are illustrative of the region's appreciation of the iterative relationship between people, cultures and their environments (Tengberg and others, 2012).

However, except for a few areas, traditional or customary systems are largely in decline, and their current effectiveness in coastal and marine resource management is complicated to establish without a concerted in-depth study and careful ethnographic documentation. Modernization and intensification of the cash economy has led to fishing pressure both in terms of populations, and (destructive) technologies, and market pressures have served to weaken or erode such customary management systems (Cinner and Aswani 2007, Masalu and others, 2010, Shalli 2011). Furthermore, the role of cultural systems for resource management have declined with the erosion of the traditional authority of elders or local leaders, and failure by central governments to recognize traditional authority (Tobisson and others, 1998). These factors also led to the collapse of the traditional closed seasons for prawn fishing in Chwaka Bay (Zanzibar) that used to be maintained jointly by inhabitants of Chwaka and Charawe villages. The decline in these management systems has also partly resulted from the deterioration in quality of aesthetic and spiritual services offered by the coastal and marine environment.

Recently, changing belief practices, where communities refer to modern religions to guide their interaction with resources, has been applied as a management strategy. In Misali Island (Zanzibar) for example, participation and support of local Muslim elders was embraced in the management training for the Misali Island Conservation Area, a small MPA off the west coast of Pemba Island. This island comprises a closed sanctuary area and a larger area open to traditional forms of fishing by local communities (Khalid and Thani 2007). This strategy was taken after realizing that local people in the area placed much trust in messages from the Muslim religion and its elders, which could also influence how sensitive they should be in their interaction with marine ecosystems.

DRIVERS OF CHANGE

The WIO region is increasingly witnessing a decline in the quality of cultural heritage due to both natural and anthropogenic factors. The dynamics of society and the evolution of cultures have changed people's value systems and hence their uses of and interaction with the environment. The cultural value of many of the traditionally revered landscapes and seascapes, or customary practices, have deteriorated or eroded. Lack of skills to maintain intangible heritage is an important factor, as is the erosion of collective memory and oral histories to uphold the value of cultural assets through time (Bakker and Ondendaal 2008b). In addition, the competition between traditional and modern (commercial) resource extraction, overriding economic investments such as tourism and other forms of recreation, have negatively affected ecosystems and their productivity (refer to Chapters 5 and 6). At the same time, destructive resource extraction practices, combined with extreme weather events such as flooding and drought and their associated impacts on marine ecosystems, for example, through sedimentation and acidification, also reduce productivity of the natural habitats that coastal communities have been using/protecting/depending on for their livelihoods (Cinner 2007) thereby diminishing their immediate cultural relevance.



Figure 18.1. Kilwa Kisiwani historical site aerial view. (c) Matthew D. Richmond.

The current unrecognised or unappreciated relevance of traditional values in resource management interventions has often led to conflict (Duarte 2012). It is also evident in the degree of scientific interest dedicated to cultural ecosystem services. More interest is placed on the economic or ecological valuation of the ecosystems (Bacuez 2009), instead of examining them for sustaining the intangible, non-physical or non-material benefits on which cultural heritage lies (Bakker and Odendaal 2008a). Many archaeological studies focus on tangible features such as "buildings, architectural remains, and other features such as numismatic

evidence [of coins or medals] and documentary sources, which underlie the tangible heritage" of sites (according to Bacuez 2009), neglecting ethnographic description - the intangible historical accounts of people through which society make connections of time and space that are useful in understanding contexts for resource management (Breen and Lane 2003).

In summary, impacts have been multiple, with cultural, social and economic ramifications at different levels. Key among these is the loss of the sense of identity attached to places, and hence, even the sensitivity towards the nature of human interaction in those places. Destruction and loss of much of the *Kaya* forests and groves (Githitho 2003) are among such outcomes. This is evident in many places where there is a decline in value of traditional knowledge systems and practices, with inadequate replacement of management institutions (Masalu and others, 2010). The deterioration of assets that provided cultural ecosystem services often also weaken their aesthetic appeal thereby affecting their attractiveness.

Increasingly, however, dedicated scientific research and attention to cultural artefacts including heritage sites, by management and policies in the, region is having a positive impact (Jeffrey and Parthesius 2013). Through UNESCO and the World Monuments Fund for example, efforts to stem the deterioration of historical and archaeological sites led to the ruins of Kilwa Kisiwani and Songo Mnara (Tanzania) to be removed from the list of World Heritage in Danger in June 2014 (UNESCO 2014).

CONCLUSIONS: PROTECTION/MANAGEMENT OF CULTURAL HERITAGE

It is possible that subject-specific studies on ecosystem services may have limited the full appreciation of the importance of the aesthetic, cultural and religious ecosystem services in the region (Tengberg and others, 2012) and hence resulted in their neglect. Human pressures, leading to insensitive extraction of marine resources of value to the marine and coastal environment are also significant in this regard. Equally important is understanding how the protection of cultural artefacts should be pursued. The role of science in terms of providing a multi-disciplinary research approach (combining biological, sociological and cultural approaches) that will inform the policy making process on the value of cultural services in sustaining ecosystem health needs to be emphasised (Bakker and Odendaal 2008a, Githitho 2003, Tengberg and others, 2012).

In addition, because of the increasing realisation that sensitivity to local contexts is a necessary component in sustainable and inclusive resource management practice, it is important for the management of coastal land- and seascapes to include customary systems into the evolving policy and legal frameworks for management. At the same time, societal evolution also generates different perceptions of the value of cultural ecosystem services by different stakeholders. These differing perceptions sometimes also limit the monitoring or regulating of behavior that is detrimental to the ecosystem. It is therefore important to identify and harmonise perceptions on cultural ecosystem services from different stakeholders for management. Likewise, it is recommended that the significance of various levels of practices, belief systems or faiths that are used to uphold ethical relationships with nature, need to be identified, for possible integration in ecosystem management (Cinner and Aswani 2007). It is also important to up-scale local capacity building for management planning and monitoring of natural and cultural heritage, among both heritage managers and local committees assigned to monitor the conservation of archaeological sites.

References

Abdulla, A., Obura, D., Bertzky, B. and Shi, Y. (2013). *Marine Natural Heritage and the World Heritage List: Interpretation of World Heritage criteria in marine systems, analysis of biogeographic representation of sites, and a roadmap for addressing gaps*. IUCN, Gland, Switzerland.

Abungu, G.O. and A. Githitho, (2012). Homelands of the Mijikenda people: Sacred Mijikenda Kaya Forests, Kenya. In: *World Heritage*: Benefits Beyond Borders (ed. A. Galla) pp. 147-157. Cambridge: Cambridge University Press

Awadh, G.O. (2007). "*Tourism and Heritage Conservation: 21st Century Challenge*" *Case: Zanzibar Stone Town*. Department of Surveys and Urban Planning, Zanzibar

Bacuez, P.J. (2009). *Intangible Heritage, Tourism and Raising*

Awareness on Kilwa Kisiwani and Songo Mnara. Findings and Recommendations. UNESCO. Dar es Salaam

Bakker, K.A. and Odendaal, F. (2008a). Managing heritage in a contested space: the case of Le Morne Cultural Landscape in Mauritius. *South African Journal of Art History* 23(1), 225-244

Bakker, K.A. and Odendaal, F. (2008b). *Le Morne Cultural Landscape: Protecting intangible heritage.* In *16th ICOMOS General Assembly and International Symposium: 'Finding the spirit of place – between the tangible and the intangible'*, 29 sept – 4 oct 2008. Quebec, Canada. [Conference or Workshop Item] http://www.international.icomos.org/quebec2008/cd/toindex/77_pdf/77-nv6H-63.pdf

Breen, C. and Lane, P.J. (2003). Archaeological approaches to East Africa's changing seascapes *World Archaeol.* 35(3), 469–489

Bremner, L. (2013). Towards a minor global architecture at Lamu, Kenya. *Social Dynamics: A journal of African Studies* 39(3), 397-413

Chaudhuri, K.N. (1985). *Trade and Civilization in the Indian Ocean: An Economic History from the Rise of Islam to 1750*. Cambridge University Press

Cinner, J.E (2007). The role of taboos in conserving coastal resources in Madagascar. SPC *Traditional Marine Resource Management and Knowledge Information Bulletin* 22, 15-23

Cinner, J.E. and Aswani, S. (2007). Integrating customary management into marine conservation. *Biol. Conserv.* 140(3), 201-216

Curtin, P.D. (1981). African Enterprise in the Mangrove Trade: The Case of Lamu. *Afri. Econ.Hist.* 10, 23-33

Duarte, R.T (2012). Maritime History in Mozambique and East Africa: The Urgent Need for the Proper Study and Preservation of Endangered Underwater Cultural Heritage. *Journal of Maritime Archaeology* 7(1), 63–86

Githitho, A.N. (2003). The Sacred Mijikenda kaya forests of coastal Kenya and biodiversity conservation. Session I: presentations of case studies from Africa and Latin America. In *The Importance of Sacred Natural Sites for Biodiversity Conservation*, 27-35. Kunming and Xishuangbanna Biosphere Reserve. People's Republic of China

Ichumbaki, E.B. (2011). *Tanzania's Maritime and Underwater Cultural Heritage Assets: Strategies Towards Sustainable Conservation and Management*. The MUA Collection, http://www.themua.org/collections/files/original/d915fc33e1b0a9d4be705a59945d8280.pdf accessed 27 March 2015

Jeffrey, B, and Parthesius, R. (2013). Maritime and Underwater Cultural Heritage Initiatives in Tanzania and Mozambique. *Journal of Maritime Archaeology 8*(1), 153-178

Khalid, F. and Thani, A.Kh. (2007). Promoting Conservation for Misali Island, Pemba. In *Teachers' Guidebook for Islamic Environmental Education*. Misali Island Conservation Association. Tanzania

Mainoya, J.R., Mesaki, S. and Banyikwa, F.F. (1986). The distribution and socio-economic aspects of mangrove forests in Tanzania. In *Man in the Mangroves. The Socio-economic Situation of Human Settlements in Mangrove Forests*. (eds. Kunstadter, P., Bird, E.C.F. and Sabhasri, S.) ONU. Nong Nuch Village, Pattaya, Thailand

Masalu, D.C.P., Shalli, M. and Kitula, R. (2010). *Customs and taboos: The role of indigenous knowledge in the management of fish stocks and coral reefs in Tanzania*. Coral reef, targeted research and capacity building for Management Program, 2010. Currie Communications, Melbourne, Australia

Mesaki, S. and Salleh, M. (2008). *Study on indigenous knowledge in Zanzibar (Unguja and Pemba) for MACEMP*. Ministry of Agriculture, Livestock and Environment (MALE). Zanzibar

Obura, D.O., Church, J.E. and Gabrié, C. (2012). *Assessing Marine World Heritage from an Ecosystem Perspective: The Western Indian Ocean*. World Heritage Centre, United Nations Education, Science and Cultural Organization (UNESCO)

RSA (2012). Policy for the Small-scale Fisheries Sector of South Africa. *Government Gazette* No 35455 Republic of South Africa

Seland, E.H. (2014). Archaeology of Trade in the Western Indian Ocean, 300 BC–AD 700. *J. Archaeol. Res.* 22, 367–402

Shalli, M. (2011). *Taditional Knowledge in the Management of Coastal and Marine Resources in Tanzania*. PhD Thesis. Aquatic Sciences. University of Dar es Salaam

Silva, A.T., Derks, R., Roders, A.P. and Hougaard, J. (2014). Cultural Heritage Management Ownership Regime in the Island Of Mozambique. In *Vernacular Heritage and Earthern Architecture: Contributions for Sustainable Development* (eds. Correia, Carlos and Rocha) pp. 171-176. Taylor and Francis, London

Sunde, J. (2013). *Living customary law along the South African coast: securing the rights of small-scale fishing communities*. Environmental Evaluation Unit, University of Cape

Town

Tengberg, A., Fredholm, S., Eliasson, I., Knez, I., Saltzman, K. and Wetterberg, O. (2012). Cultural Ecosystem Services provided by Landscapes: Assessment of heritage values and identity. *Ecosystem Services* 2, 14-26

Tobisson, E., Andersson, J., Ngazi, Z., Rydberg, L. and Cederlöf, U. (1998). Tides, monsoons and seabed: local knowledge and practice in Chwaka Bay, Zanzibar. *Ambio* 27(8), 677-685

UNESCO (2014). *World Heritage in Africa Region: UNESCO WORLD HERITAGE CENTRE*. June 2011. http://Whc.unesco.org/en/sessions/35COM

UNESCO (2003). *International Workshop on the Importance of Sacred Natural Sites for Biodiversity Conservation*. 17–20 February 2003. Kunming and Xishuangbanna Biosphere Reserve. People's Republic of China,

Zeleza, T. (1997). *A modern economic history of East Africa: The nineteenth century*. East African Publishers



19
Summary on Major Ecosystem Services

Jared Bosire

Opposite page: Waterfront of Lamu old town, Kenya. © Kiunga Kareko.

Part IV dealt with ecosystem services from the coastal and marine environment, as opposed to goods. Whereas ecosystem goods have been widely discussed in literature due to their direct benefits to humans, services (e.g., critical buffering, regulating and life-supporting services or processes) are commonly forgotten or taken for granted. Ecosystems also provide less tangible benefits such as recreational, aesthetic, cultural and spiritual values that are important in fulfilling people's emotional and psychological needs.

The ocean's role in the hydrological cycle is critical in sustaining life on earth, because it influences the process of water circulation and exchange. This inert ability of global oceans stem from their coverage of 70% of earth's surface, and the higher heat exchange capacity of water, than land and atmosphere. Almost half of the absorbed solar energy at the sea surface is released back into the atmosphere as vapour – this eventually forms clouds that bring rain, thus completing the hydrological cycle on which life on earth depends. Global warming disturbs the balance, by melting polar ice caps and glaciers, and releasing water into the oceans, causing a rise in sea level. Hence, future inundation of low-lying coastal areas is expected, with implications for infrastructure (e.g., coastal developments or cities), agriculture, trade and tourism. It is forecast that the greatest impact will be on the economies and livelihoods of the developing world (Dasgupta et al. 2009), such as the SW Indian Ocean.

Gaseous exchange at the **sea/air interface** is irregular, and depends on sea surface layer dynamics and mixing, driven by solar radiation, wind and waves. This exchange affects biogeochemical processes, weather and climate, through causing fluctuation of physical and chemical properties. If the sea/air interaction processes remained unchanged, a dynamic balance between the concentrations of CO_2 in the atmosphere and in the ocean would be maintained. However, rising atmospheric concentrations of CO_2 also increases its level in sea water, thus leading to ocean acidification, with major negative implications for calcifying organisms, marine ecosystem functioning and ultimately food security.

Phytoplankton primary production forms the basis of oceanic food webs, on which marine ecosystems rely. Phytoplankton productivity is governed by photosynthesis and largely depends on levels of light, temperature, nutrients and CO_2. Principal drivers of primary productivity in the Indian Ocean are monsoon seasons, ocean circulation, upwelling and eddies, irradiance and water temperature. Reduced primary production in the region would cascade through the trophic levels, producing less fish for capture. Conversely, elevated primary production may cause harmful algal blooms (HABs), with implications on food safety, human health, and income-generating activities.

Production of ocean-based carbonates drives the calcification process that builds coral reefs and supplies carbonate sands to coastal lagoons and beaches. Worldwide, calcium carbonate ($CaCO_3$) from corals and calcifying algae is the greatest source of biogenic sediments in

the oceans. Major anthropogenically induced threats to carbonate producers are acidification and coral bleaching (exacerbated by climate change), eutrophication (influences habitat structure) and poor land-uses (enhances sedimentation) which enhance bioerosion and disease prevalence.

Important **aesthetic, cultural, and spiritual services** are also derived from Western Indian Ocean coastal and marine environments. Some sites attract significant tourism because of these values, for instance iSimangaliso Wetland Park (South Africa) and Lamu Old Town (Kenya). In some cases, historical sites and landscapes have suffered from poor management, or physical intrusion. Equally important are traditional knowledge systems and institutions, such as *Kayas* in Kenya and *Dina* in Madagascar. Such systems illustrate the existence of customary resource management methods, or a traditional understanding and appreciation of ecosystem functioning.

RECOMMENDATIONS

Key recommendations under this Part IV include:

Holistic ecosystem services valuation: Ecosystem services are often ignored in management planning, hence only goods having direct human benefits get considered. It is recommended that services e.g. supporting, regulating and cultural (including aesthetic and spiritual) should be integral in planning considerations. It is also important to invest in wholesome economic valuation of ecosystem services to inform policy/development decisions. This is critical, pending the future of coastal areas as major economic development corridors.

Blue economy approach: It is important that governments comprehensively integrate blue economy principles, to minimize environmental impacts of new developments. Planning tools e.g. SEA, marine spatial planning and Integrated Ocean Management (IOM) should be applied to safeguard ecosystem services.

Knowledge integration: Local communities have sustainably managed their natural resources for millennia. Degradation thereof often follows on from external interference, including population growth. It is therefore important that traditional management systems are integrated with modern management systems. This might include recognition in law.

Investment in research to address gaps: There is an established positive correlation between the level of investment in research by countries and corresponding level of development. Research gaps include valuation of ecosystem services; productivity trends; status of traditional management systems; and climate change vulnerability and mitigation.

Environmental awareness: People will appreciate, manage and conserve what they know, identify with and value. Awareness and promotion of the nature and value of ecosystem services need to be enhanced among the general public and especially in school curricula. Promotion of ecosystem services with intrinsic values will be critical when large-scale developments are considered.

Climate change impacts: Studies need to be undertaken of the potential environmental, economic and social impacts of climate change on ecosystems and aquatic organisms. Comprehensive risk assessments should also be designed and implemented to prioritize adaptive responses.

References

Dasgupta, S., Laplante, B., Meisner, C., Wheeler, D. & Yan, J. 2009. The impact of sea level rise on developing countries: a comparative analysis. Climate Change 93: 379-388.

Part V
Assessment of Food Security from Marine Resources

Johan Groeneveld

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20

The Western Indian Ocean as a Source of Food

Johan Groeneveld

Opposite page: Fish drying at the Ruvuma Estuary, Tanzania. © José Paula.

INTRODUCTION

The Western Indian Ocean (or FAO major fishing area 51) extends from eastern South Africa in the south to India and the Arabian Gulf in the north. The present chapter deals only with the sub-area south of the equator, namely the Southwest (SW) Indian Ocean. The SW Indian Ocean region has a sub-tropical / tropical climate, with warm water characterised by high biodiversity, hotspots with high endemism, fishes with unique behaviour, and taxa of special design and physiology (Figure 20.1) (Smith and Heemstra 1986, van der Elst and others, 2005). It claims the world's oldest fish, the coelacanth (*Latimeria chalumnae*), and the world's largest fish, the whale shark (*Rhincodon typus*). In contrast to high biodiversity, the biomass of individual species is generally low, with marine productivity depending more on nutrient input from rivers along the coasts of eastern Africa and Madagascar, than on upwelling systems (Caddy and Bakun 1994).

Coastal inhabitants of most SW Indian Ocean countries rely heavily on fishing as a source of food and economic activity, and over many centuries fishing has become part of local culture and customs (Christie 2013). Rock paintings show that fishing took place as long as 40 000 years ago (Erlandson and Rick 2010, Gartside and Kirkegaard 2007), and more recently, the development of artisanal fishing in Ungwana Bay (Kenya) in the 9th century coincided with the rise of the East African Indian Ocean trade with Arabia, Persia and India (Fulanda 2003). Early human inhabitants were few and had comparatively small needs; thus they may only have impacted lightly on coastal environments and exploited fish stocks. Rapid population growth and global economic expansion over the past 50 years have, however, exponentially increased the pressure on coastal resources (Jackson and others, 2001, Vitousek and others, 1997). Overfishing and coastal developments hasten long-term changes to productivity, with outcomes such as reduced abundance and biological diversity.

After humans, top predators in the SW Indian Ocean are large sharks, marine mammals (mostly whales and dolphins) and seabirds. Large migratory tuna schools and billfish predate on small mesopelagic fishes, crustaceans (swimming crabs) and cephalopods (Potier and others, 2007), which in turn depend on secondary and primary productivity at lower trophic levels (José and others, 2014, Potier and others, 2014). The oligotrophic (nutrient-poor) nature of coastal waters coupled with high biodiversity underscores an interesting question: whether overfishing of higher-level predators such as sharks and tunas will alter marine food webs, with cascading consequences (Baum and Worm 2009, Pauly and others, 1998). Such a pattern might be observed from changes in the species composition of catches.

Compared to fishing, mariculture is a newcomer to food production in the SW Indian Ocean. Most documented mariculture initiatives date from the 1990s to present, but apart from successful seaweed farms, mainly in Zanzibar, farming of other organisms, such as prawns, fish





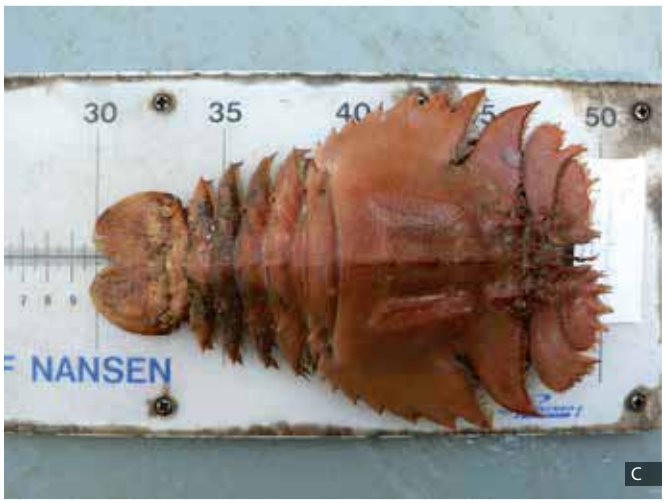


Figure 20.1. (a-c) The SW Indian Ocean is characterized by high biodiversity, hotspots with high endemism and colourful species of special design and physiology. **(a)** Emperor angelfish *Pomacanthus imperator*; **(b)** bluebarred parrotfish *Scarus ghobban* and coral rockcod *Cephalopholis miniata;* and **(c)** smooth fan lobster *Ibacus novemdentatus*. © Johan Groeneveld

and seacucumbers, have had mixed results (see Chapter 22). Nevertheless, there appears to be a general feeling of optimism around future prospects, particularly in Madagascar, Mozambique, Tanzania and Kenya (Troell and others, 2011).

Part V describes the longer term trends in the abundance of key species groups important for food security, and the social and economic aspects of fisheries and mariculture practices in the SW Indian Ocean. Observed trends are based on fisheries data from many different sources, which are often sparse, or not well resolved at species or spatial levels (van der Elst and others, 2005). Nevertheless, in combination this information provides important insights into the present status of fish resources, relative to systemic drivers such as climate change, population growth, and associated pressures such as increasing fishing and coastal development. Although all the riparian countries of the SW Indian Ocean subscribe to the Code of Conduct for Responsible Fisheries (FAO 1995), their ability to comply with it and to introduce effective measures to ensure long-term sustainability is compromised by economic and socio-political realities. Therefore, Part V also addresses emerging issues in capture fisheries and mariculture in the region, relative to progress made towards specific Millennium Development Goals (MDG).

GEOGRAPHICAL EXTENT

The SW Indian Ocean covers the maritime zones (Exclusive Economic Zones up to 200 nm offshore) of eastern South Africa, Mozambique, Tanzania (including Zanzibar), Kenya, Somalia, Madagascar, Mauritius, Seychelles, Comoros and France (by virtue of its islands including Mayotte and Reunion) (Figure 20.2; van der Elst and others, 2009). This vast area is influenced by major ocean current systems and submerged landforms, such as continental shelves, slopes and basins, mid-ocean ridges, seamounts and ocean trenches. Monsoon winds affect coastal flow in the north, where the East Africa Coastal Current (EACC) strengthens during the southeast monsoon, and weakens during the northeast monsoon, giving rise to a seasonally reversing Somali Current (Schott and McCreary Jr 2001, Schott and others, 1990). Upwelling and deep-water mixing makes the Somali Current region nutrient rich and productive, compared to oligotrophic waters further to the south. The westward flowing South Equatorial Current (SEC) flows across the Mascarene Plateau, and encounters

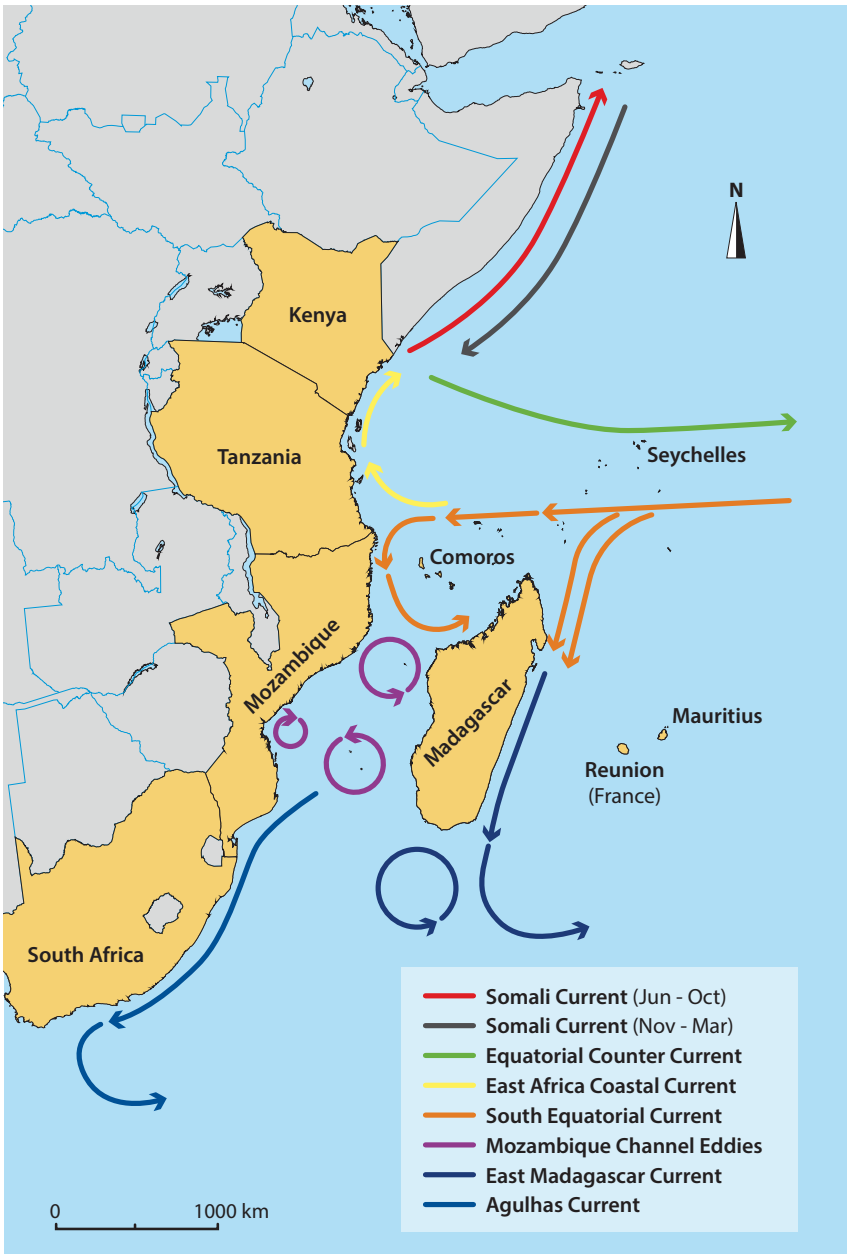


Figure 20.2. The developing countries of the SW Indian Ocean are some of the poorest in the world, but they flank onto a tropical ocean with high biodiversity and potentially rich fishing grounds. The ecosystems of the SW Indian Ocean are governed by complex ocean current systems, and monsoon seasons in the north. Adapted from Lutjeharms 2006.

eastern Madagascar, where it forks to form the East Madagascar Current (southern branch) and a northern branch that feeds into the EACC. The general circulation of the Mozambique Channel is characterised by mesoscale cyclonic and anticyclonic eddies or cells (Lutjeharms 2006, Ternon and others, 2014). The Agulhas Current originates near the southern extreme of the Mozambique Channel, and flows southwest along the shelf edge, within a few kilometres of the coast in eastern South Africa. The current moves further offshore where the Agulhas Bank widens, and it eventually retroflects northwards to form the Agulhas Return Current.

Shelf topography is narrow and steep along much of eastern Africa, widening in bights or near river deltas, such as the Natal Bight (South Africa), Maputo Bay and the Boa Paz Banks (Mozambique), the Rufiji Delta (Tanzania) and Malindi-Ungwana Bay (Kenya). A fringing coral reef extends between 0.5 and 2 km offshore along much of the Kenya and Tanzania coasts, creating shallow coastal lagoons that are easily accessible to fishers. Madagascar has an EEZ of 1.14 million km^2; its western coast consists of many estuaries and bays, colonized by dense mangrove forests, while

the eastern coast is straight and featureless, with few estuaries, capes and bays.

UTILIZATION OF SEAFOOD BY HUMANS FROM HISTORICAL TIMES TO THE PRESENT

Archaeological sites with marine shells, fish bones, fishing tools, and rock paintings as evidence of exploitation of inshore marine resources for food date from about 200 000 years BP (Breen and Lane 2004, Hu and others, 2009). Later Stone Age (4 120 years BP) hunter-gatherers used simple dug-out canoes, and by 2 300 years BP the entire littoral zone in some areas of the coast was fished using stone tool technology (Breen and Lane 2004). New forms of settlement such as stone-built architecture arose along the coast after the 8th century AD, and at this time hook-and-line and trap fishing originated. True commercialization of the SW Indian Ocean started after the 9th century, when fishing practices expanded greatly and trans-oceanic trade in commodities was introduced (Breen and Lane 2004). From about the 11th century, neritic species such as sharks and barracuda were captured using lures, and other species were fished to such an extent that several taxa showed patterns of decline over time (Christie 2013). The advent of colonialism with the arrival of the Portuguese and more modern fishing techniques in the late 15th century altered many traditional practices and economies. This was exacerbated by a shift in the balance of political power towards Oman and Zanzibar in the 17th century. Twentieth and 21st century changes in the use of marine resources have been shaped by gradual technological advances in fishing gear allowing easier access to deeper water (Kennelly and Broadhurst 2002), independence from colonialism, rapid growth of human populations and economic globalization. Today the fishermen along the coasts of the SW Indian Ocean rely heavily on marine resources across large areas of the continental shelf for food security, local trade and export to foreign markets.

SOCIAL AND ECONOMIC IMPORTANCE OF SEAFOOD

An estimated 60 million people live within 100 km of the coast in the wider WIO region (van der Elst and others, 2005), and many of them rely on the sea for their economic, social and cultural security (Standing 2009, FAO 2010, Cox 2012,). Some states in the region are amongst the poorest in the world, based on *per capita* Gross National Product (GNP) (Cunningham and Bodiguel 2005, World Bank 2011a) and a low Human Development Index (HDI) (UNDP 2013). About 80 per cent of Mozambicans live in rural areas, and 50 per cent of them rely on fish for their main protein source (van der Elst and others, 2005). The export of fish products, mainly prawns, is also a major contributor to gross domestic product (GDP) of Mozambique (FAO 2010, UNEP 2014). In Mauritius, almost all of the fish landed by the domestic sector is locally consumed, except for some high-value species that are exported (Cox 2012). A large tuna-canning factory and international fishing port in Seychelles process fish products, responsible for about 95 per cent of domestic exports (Heileman and others, 2009). Marine capture fisheries in the SW Indian Ocean are typically structured into artisanal fisheries (also called traditional, subsistence or small scale commercial fisheries) and industrial fisheries (or semi-industrial) that operate further from the coast using ocean-going fishing vessels (see Chapter 21). Compared to capture fisheries, mariculture (Chapter 22) is still in its infancy, but it is encouraged by governments as an alternative to generate fish protein and wealth, especially when capture fisheries are in decline (Rönnbäck and others, 2002).

Trading, processing (including salting and drying) and distribution of fish catches at local markets along the coast are important economic activities. Local women do most of the trading at fish markets, where they form an important role in the processing and distribution chain. Catches on these markets come mainly from artisanal fishers using small boats in nearshore waters. Women also participate in artisanal fishing, mostly by wading in the intertidal during low tides to collect invertebrates and small fish. Artisans that make and repair boats and fishing gear, and middlemen that own and rent out their own gear (seine or gill nets) or boats are also important (Jiddawi and Ohman 2002). Migrant fishers follow fish movements along the coast, thus illustrating a social adaptation to a complex environment (Fulanda and others, 2009). These migrations are associated with social and economic challenges at home and at host destinations. Fishing and its trade is therefore intricately interwoven into the socio-ecological systems of coastal communities (see Chapter 23).

Seaweed is cultured in shallow subtidal areas in Zanzibar and Pemba Islands (Tanzania), mostly by women (Bryceson and Beymer-Farris 2011). Dried seaweed is sold to middlemen, exported and used for medicine, toothpaste and agar. Fish culture is presently a small industry, with

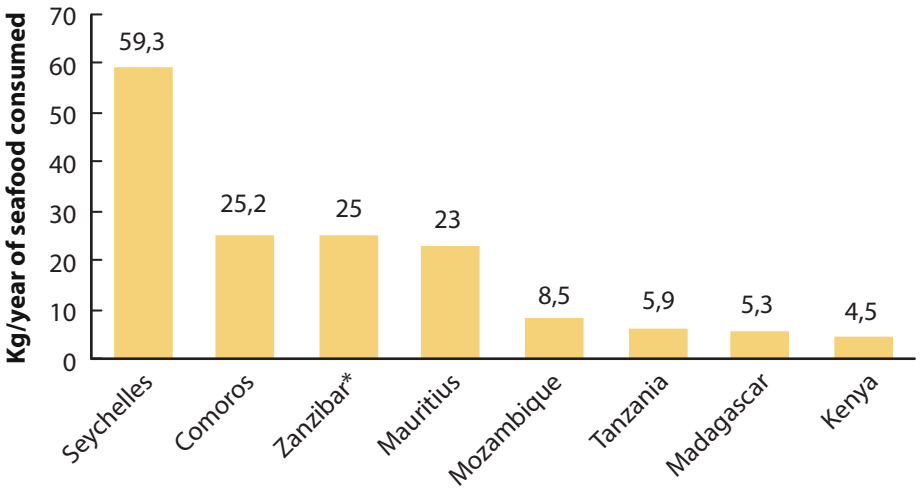


Figure 20.3. Per capita seafood consumption is much higher in island states than on the mainland, reflecting the maritime influence on communities living against the sea. *Zanzibar = part of the United Republic of Tanzania.

some farming of milkfish, sea cucumber, *Scylla* crabs and oysters (for pearls). Traditional fishers in southwest Madagascar grow sea cucumbers for export (Robinson and Pascal 2009, Iltis and Ranaivason 2011) and participate in community-based culture of red seaweed. Commercial prawn farming in Madagascar and Mozambique began in the mid-1990s, with development aid and technical assistance of the UNDP and FAO. Rising production costs, lower global prices for farmed prawns and white spot syndrome plagued prawn farms after 2007, but a rising demand for high quality products in China revived farming after 2012. A detailed description of mariculture in the SW Indian Ocean is provided in Chapter 22, and the social and economic importance of capture fisheries and mariculture is described in Chapter 23.

REGIONAL VARIATION IN HUMAN DEPENDENCE ON SEAFOOD

Per capita seafood consumption on small islands of the SW Indian Ocean (Comoros, Mauritius and Seychelles) is much higher than in Madagascar or the East African mainland states (Figure 20.3). Seychelles ranks 12th in the world for *per capita* seafood consumption (59.3 kg), and in Zanzibar seafood consumption is also high (17-30 kg; Jiddawi and Ohman 2002, Jiddawi 2012). The reliance on seafood on small islands reflects the relatively limited space for agriculture, and the proximity of communities to the sea, thus fostering a maritime culture. On the East African mainland, annual *per capita* seafood consumption is much lower, for example 3.4 kg in Kenya and 5.5 kg in mainland Tanzania (Kariuki 2005). Here, agriculture provides most animal protein, except along the coast and in burgeoning coastal cities, where seafood is more important.

Total reported landings of marine species in the region are highest in Madagascar and Mozambique. These two countries have the longest coastlines and large well-organized industrial fisheries, eg trawling for crustaceans. They also provide concessions to foreign vessels to fish for large pelagic fishes in their waters. Despite its small size and population but vast EEZ, Seychelles also reports a large marine catch, mainly because foreign longliners and purse-seiners land catches of large pelagic fishes there. A relatively long coastline, and several small islands with a maritime culture (Zanzibar, Pemba, Mafia) can explain higher landings in Tanzania than in Kenya, where the coastline is shorter and marine fisheries produce far less than those from freshwater bodies. It is almost certain that landing statistics vastly under-represent actual landings (Jacquet and others, 2010), especially in countries with large artisanal fisheries in remote areas, where catches are infrequently reported.

EMERGING ISSUES IN CAPTURE FISHERIES AND MARICULTURE

Open access fisheries: These fisheries, in which the numbers of fishers, methods used, and harvest quantities are not controlled, inevitably lead to overexploitation and habitat degradation, particularly when the numbers of fishers and their needs continue to grow. This is the main issue facing capture fisheries in the SW Indian Ocean (van der Elst and others,

2005). Given the heavy reliance of coastal communities on fisheries for food security, placing limits on harvests cannot be done without major social, economic and political upheaval, and the provision of alternative livelihood options. Consequently, there is limited political will to effect change, even in the face of strong evidence of overfishing.

Illegal, Unreported and Unregulated (IUU) fishing: This includes fishing without permission from national or international authorities, not reporting catches, or ignoring closed seasons or areas, catch limits, species limits, or gear specifications (Laipson and Pandya 2009). In the SW Indian Ocean, IUU fishing refers not only to the artisanal sector, in which many fishers are unlicensed, but also to industrial fisheries (long-lining, purse-seining, gill-netting) that operate further offshore in territorial or EEZ waters. They fall under the jurisdiction of coastal states (through licensing) or regional organizations (such as the Indian Ocean Tuna Commission, or IOTC), but most states do not have the capacity to enforce national or international laws. Consequently, IUU fishing is common in the SW Indian Ocean, where it is responsible for considerable economic, social and ecological losses in developing countries (MRAG 2005)

Development of deep-sea fisheries: To offset declining catches in nearshore fisheries, states are increasingly looking further offshore to increase catches. However, sustainable exploitation appears to be feasible for only very few deep-sea species under prevailing economic conditions and governance arrangements (Norse and others, 2012), mainly because these species are often slow-growing and have low productivity. This was recently demonstrated for a deep-water trap fishery in eastern South Africa, where spiny lobster biomass was rapidly depleted, despite low fishing effort (Groeneveld and others, 2012). The discovery of orange roughy (*Hoplostethus* sp.) concentrations on SW Indian Ocean seamounts in 1999 led to an 'explosion' of fishing effort, when 53 vessels flagged to 17 states suddenly arrived in the area (www.siodfa.org). Such was the influx of fishing vessels that *Fishing News International* (May 2000 issue), referred to "Roughy Bonanza in Indian Ocean". The fishery collapsed within a year. Other deep-sea fisheries are for alfonsino (*Beryx splendens*) and red snapper (*Etelis coruscans*) (Bensch and others, 2008).

Moving from management of single species to ecosystems approaches: Single-species approaches to fisheries management do not consider broader social, economic or ecological consequences (Jennings 2006). A paradigm shift towards managing whole ecosystems developed after the 1992 Rio Declaration on Environment and Development (United Nations Code of Conduct for Responsible Fisheries; FAO 1995). The ecosystem approach to fisheries management (EAF) is a relatively new concept in the region and supported by most states, although implementation is slow. Using ecological indicators for evaluating and comparing the status of exploited marine ecosystems in the SW Indian Ocean is a promising initiative (Shin and Shannon 2010) - a good example for the prawn fishery in coastal Kenya is provided by Swaleh and others, (2015).

From national to regional fisheries management strategies: Cooperative management of shared fish stocks among neighbouring countries may confer many ecological and economic advantages, but it is also a complex political process (see Payne and others, 2004, and the papers therein). Highly migratory tunas and billfishes are shared stocks (usually straddling stocks in high seas and EEZ waters) and managed by the IOTC. Other stocks (eg deep-water prawns) that occur across geopolitical boundaries are potentially shared, because the harvesting activities of one country may impinge on the opportunities of another (Everett and others, 2015). This has led to several recent initiatives to determine which stocks are shared and to regionalize and align fisheries policy and management objectives (van der Elst and others, 2009).

Co-management through Beach Management Units (BMUs): New legislation in some countries (e.g. Kenya, Tanzania) allow for the establishment of BMUs to co-manage fisheries jointly with officials of fisheries departments. BMU objectives are to strengthen the management of fish landing stations, involve all stakeholders in decisions, and prevent or reduce user conflicts. The expectations and requirements of setting up and running a BMU are quite demanding, thus requiring considerable financial and logistic assistance (Oluoch and Obura 2008). Nevertheless, it currently remains the most promising management approach.

Research capacity and the linkage between fisheries management and applied research: The scarcity of competent fisheries researchers in the SW Indian Ocean region is presently being addressed through capacity-building initiatives by several international programmes (for example SWIOFP, SWIOFish, InteGRADE). The linkage between fisheries management requirements and applied research undertaken by a limited number of active scientists is presently inadequate. Consequently, crucial studies, such as those to estimate stock status, or to provide solutions to recent or long-standing management issues, are not prioritized.

There are very few active fisheries management plans of any kind in the region (WIOFish 2011).

Mariculture: Mariculture is encouraged by governments as an alternative activity to generate fish protein and wealth. It is an important emerging issue with high complexity, from area planning (over land and maritime areas), to finding the right species and culture technology, and to encouraging responsible mariculture practises (see Chapter 22).

THREATS TO CAPACITY OF THE WIO TO PRODUCE SEAFOOD

Climate change, as a driver of the state of the ocean, and human use patterns, as direct impacts on the health and functioning of ecosystems, are the primary threats to food security. Climate change will potentially cause changes to sea level, the pH of oceans, water temperature and primary productivity over the next decades. The effect of these changes on the capacity of the ocean to produce food is not yet fully understood. At the same time, degradation of key habitats or nursery areas along the coast through dynamite fishing, use of drag- or mosquito nets, unplanned development, changes in land-use and fresh-water impoundments erode the biological systems on which ecological sustainability relies (Gammelsrød 1992, Wells 2009, Bush 2013, Mkare and others, 2014). Human populations in SW Indian Ocean states continue to grow at a rate of 2.5-3.0 per cent per year (2010-2014 data; World Bank 2011b), with a concurrent increase in their dependence on food extracted from the ocean. It is difficult to see how the spectre of 'too many fishers, too few fish' can be avoided without successful interventions to reduce fishing pressure and mitigate impacts of coastal development on marine resources.

CONCLUSIONS

The lack of infrastructure and management capacity of SW Indian Ocean states to moderate the multiple threats to the marine environment as a source of food, coupled with the perilous socio-economic conditions of many coastal human populations, is of great concern. The relentless increase in need for food and raw materials by growing urban centres along the coast suggests that the pressure on marine resources will continue to escalate.

References

Baum, J. K. and Worm, B. (2009). Cascading top-down effects of changing oceanic predator abundances. *J. Anim. Ecol.* 78(4), 699-714

Bensch, A., Gianni, M., Gréboval, D., Sanders, J. S. and Hjort, A. (2008). *Worldwide review of bottom fisheries in the high seas*. FAO Fisheries and Aquaculture Technical Paper, 522. FAO, Rome

Breen, C. and Lane, P. (2004). Archaeological approaches to East Africa's changing seascapes. *World Archaeol.* 35(3), 469-489

Bryceson, I. and Beymar-Farris, B. (2011). Main challenges for coastal aquaculture development in the WIO region – who are the winners and losers? In *Mariculture in the WIO Region "Challenges and Prospects" Proceedings from the Workshop on Mariculture, December, 2009* (eds. M. Troell, T. Hecht, M. Beveridge, S. Stead, I. Bryceson, N. Kautsky, F. Ollevier and A. Mmochi) WIOMSA Book Series No 11, pp. 6-8. Jamana Printers Limited, Tanzania

Bush, E. R. (2013). *What's the catch? Mosquito Net Fishing in Coastal East Africa*. MSc ConSci, Imperial College Conservation Science

Caddy, J.F. and Bakun, A. (1994). A tentative classification of coastal marine ecosystems based on dominant processes of nutrient supply. *Ocean Coast. Manage.* 23(3), 201-211

Christie, A. C. (2013). Exploring the social context of maritime exploitation in Tanzania between the 14th – 18th c AD: Recent research from the Mafia archipelago. In *Prehistoric Marine Resource Use in the Indo-Pacific Regions (Terra Australis 39)* (eds. D. Addison, R. Ono and A. Morrison) pp. 97-122. Anu E press. Canberra, Australia

Cox, J. (2012). *Assessment Report on Small-Scale Fisheries in Africa*. Masifundise Development Trust for AU-IBAR

Cunningham, S. and Bodiguel, C. (2005). Subregional review: Southwest Indian Ocean. In *Review of the state of the world marine capture fisheries management: Indian Ocean* (ed. C. de Young) pp. 67-84. FAO, Rome

Erlandson, J.M. and Rick, T.C. (2010). Archaeology meets marine ecology: the antiquity of maritime cultures and

human impacts on marine fisheries and ecosystems. *Ann. Rev. Mar. Sci.* 2, 231-251

Everett, B.I., Groeneveld, J.C., Fennessy, S.T., Dias, N., Filipe, O., Zacarias, L., Igulu, M., Kuguru, B., Kimani, E., Munga, C.N., Rabarison, G.A., Razafindrakoto, H. and Yemane, D. (2015). Composition and abundance of deep-water crustaceans in the Southwest Indian Ocean: Enough to support trawl fisheries? *Ocean Coast. Manage.* 111, 50-61

FAO (1995). *Code of Conduct for Responsible Fisheries*. Food and Agriculture Organization. http://www.fao.org/docrep/005/v9878e/v9878e00.htm

FAO (2010). *The state of world fisheries and aquaculture*. Food and Agriculture Organization of the United Nations, Rome

Fulanda, B. (2003). Shrimp trawling in Ungwana Bay: a threat to fishery resources. African Studies Centre research report 70. In *Recent advances in coastal ecology: Studies from Kenya* (eds. J. Hoorweg and N. Muthiga) pp. 233-242. Print Partners Ipskamp BV, Leiden, Enschede

Fulanda, B., Munga, C., Ohtomi, J., Osore, M., Mugo, R. and Hossain, M. Y. (2009). The structure and evolution of the coastal migrant fishery of Kenya. *Ocean Coast. Manage.* 52(9), 459-466

Gammelsrød, T. (1992). Variation in shrimp abundance on the Sofala Bank, Mozambique, and its relation to the Zambezi River runoff. *Estuar. Coast. Shelf Sci.* 35(1), 91-103

Gartside, D. and Kirkegaard, I. (2007). A History of Fishing. In *The Role of Food, Agriculture, Forestry, and Fisheries in Human Nutrition* (ed. V.R. Squires) vol. 2, pp. 105-139. Encyclopedia of Life Support Systems, Australia

Groeneveld, J. C., Kirkman, S.P., Boucher, M. and Yemane, D. (2012). From biomass mining to sustainable fishing — using abundance and size to define a spatial management framework for deep-water lobster. *Afr. J. Mar. Sci.* 34(4), 547-557

Heileman, S., Lutjeharms, J. R. E. and Scott, L. E. P. (2009). *A comprehensive overview of the Agulhas and Somali Coastal Current LMEs*. The Agulhas and Somali Current Large Marine Ecosystems Project

Hu, Y., Shang, H., Tong, H., Nehlich, O., Liu, W., Zhao, C., Yu, J., Wang, C., Trinkaus, E. and Richards, M.P. (2009). Stable isotope dietary analysis of the Tianyuan 1 early modern human. *Proc. Natl. Acad. Sci.* 106(27), 10971-10974

Iltis, J. and Ranaivoson, E. (2011). A Synopsis of Marine Aquaculture in Madagascar. In *Mariculture in the WIO Region "Challenges and Prospects" Proceedings from the Workshop on Mariculture, December, 2009* (eds. M. Troell, T. Hecht, M. Beveridge, S. Stead, I. Bryceson, N. Kautsky, F. Ollevier and A. Mmochi) WIOMSA Book Series No 11, pp. 17-18. Jamana Printers Limited, Tanzania

Jackson, J. B., Kirby, M. X., Berger, W. H., Bjorndal, K. A., Botsford, L. W., Bourque, B. J., Bradbury, R. H., Cooke, R., Erlandson, J. and Estes, J. A. (2001). Historical overfishing and the recent collapse of coastal ecosystems. *Science* 293(5530), 629-637

Jacquet, J., Fox, H., Motta, H., Ngusaru, A. and Zeller, D. (2010). Few data but many fish: marine small-scale fisheries catches for Mozambique and Tanzania. *Afr. J. Mar. Sci.* 32(2), 197-206

Jennings, S. (2006). From single species to ecosystem-based management: prospects for effective biodiversity conservation. *MarBEF Newsletter*. 24-25

Jiddawi, N.S. and Öhman, M.C. (2002) Marine fisheries in Tanzania. *Ambio* 31, pp. 518-527

Jiddawi, N.S. (2012). The artisanal fisheries and other marine resources in Chwaka Bay. In *People, Nature and Research in Chwaka Bay, Zanzibar, Tanzania* (eds. de La Torre-Castro, M. and Lyimo, T.J.) pp. 213-212. Zanzibar Town

José, Y.S., Aumont, O., Machu, E., Penven, P., Moloney, C.L. and Maury, O. (2014). Influence of mesoscale eddies on biological production in the Mozambique Channel: Several contrasted examples from a coupled ocean-biogeochemistry model. *Deep Sea Res. Part II Top. Stud. Oceanogr.* 100, 79-93

Kariuki, J. (2005). Country review: Kenya. In *Review of the state of the world marine capture fisheries management: Indian Ocean*. (ed. de Young, C.) pp. 349-364. FAO, Rome

Kennelly, S.J. and Broadhurst, M.K. (2002). By-catch begone: changes in the philosophy of fishing technology. *Fish. and Fish.* 3(4), 340-355

Laipson, E. and Pandya, A. (2009). *The Indian Ocean-Resource and Governance Challenges*. Stimson, Washington

Lutjeharms, J.R.E. (2006). Three decades of research on the greater Agulhas Current. *Ocean Science Discussions* 3, 939-995

Mkare, T.K., von der Heyden, S., Groeneveld, J.C. and Matthee, C.A. (2014). Genetic population structure and recruitment patterns of three sympatric shallow-

water penaeid prawns in Ungwana Bay, Kenya, with implication for fisheries management. *Mar. Freshwater Res.* 65, 255-266

MRAG (2005). *Review of Impacts of Illegal, Unreported and Unregulated Fishing on Developing Countries*. Final Report, Department for International Development (DFID, UK), and Norwegian Agency for Development Cooperation (NORAD)

Norse, E.A., Brooke, S., Cheung, W.W., Clark, M.R., Ekeland, I., Froese, R., Gjerde, K.M., Haedrich, R.L., Heppell, S.S. and Morato, T. (2012). Sustainability of deep-sea fisheries. *Marine Policy* 36(2), 307-320

Oluoch, S.J. and Obura, D. (2008). Assessment of fisherfolk organizations and beach management units (BMU) in the management of fishery resources in Diani-Chale, Southern Kenya. In *Ten years after bleaching—facing the consequences of climate change in the Indian Ocean*. (eds. D.O. Obura, J. Tamelander, and O. Linden) CORDIO Status Report, Coastal Oceans Research and Development in the Indian Ocean/Sida-SAREC, Mombasa, Kenya, 335-344

Pauly, D., Christensen, V., Dalsgaard, J., Froese, R. and Torres, F. (1998). Fishing down marine food webs. *Science* 279(5352), 860-863

Payne A.I.L., O'Brien C.M. and Rogers, S.I. (2004). *Management of shared fish stocks*. Blackwell Publishing, UK

Potier, M., Marsac, F., Cherel, Y., Lucas, V., Sabatié, R., Maury, O. and Ménard, F. (2007). Forage fauna in the diet of three large pelagic fishes (lancetfish, swordfish and yellowfin tuna) in the western equatorial Indian Ocean. *Fish. Res.* 83(1), 60-72

Potier, M., Bach, P., Ménard, F. and Marsac, F. (2014). Influence of mesoscale features on micronekton and large pelagic fish communities in the Mozambique Channel. *Deep Sea Res. Part II Top. Stud. Oceanogr.* 100, 184-199

Robinson, G. and Pascal, B. (2009). From hatchery to commumity – Madagascar's first village-based holothurian mariculture programme. *SPC Beche-de-mer Information Bulletin* 29, 38-43

Rönnbäck, P., Bryceson, I. and Kautsky, N. (2002). Coastal aquaculture development in Eastern Africa and the Western Indian Ocean: Prospects and problems for food security and local economies. *AMBIO*. 31(7), 537-542

Schott, F., Swallow, J.C. and Fieux, M. (1990). The Somali Current at the equator: annual cycle of currents and transports in the upper 1000 m and connection to neighbouring latitudes. *Deep-Sea Res. Oceanogr., A.* 37(12), 1825-1848

Schott, F.A. and McCreary Jr, J.P. (2001). The monsoon circulation of the Indian Ocean. *Prog. Oceanogr.* 51(1), 1-123

Shin, Y-J. and Shannon, L.J. (2010). Using indicators for evaluating, comparing and communicating the ecological status of exploited marine ecosystems. 1. The IndiSeas project. *ICES J. Mar. Sci.* 67, 686–691

Smith, M.M. and Heemstra, P.C.H. (1986). *Smiths' sea fishes*. McMillan, Johannesburg

Standing, A. (2009). *The Growth of Marine Fisheries Ecolabelling in Southern and Eastern Africa*. vol.18. Institure for Security Studies, Pretoria, South Africa

Swaleh, K., Kaunda-Arara, B., Ruwa, R. and Raburu, P. (2015). Ecosystem-based assessment of a prawn fishery in coastal Kenya using ecological indicators. *Ecol. Indic.* 50, 233-241

Ternon, J.F., Bach, P., Barlow, R., Huggett, J., Jaquemet, S., Marsac, F. and Roberts, M.J. (2014). The Mozambique Channel: from physics to upper trophic levels. *Deep Sea Res. Part II Top. Stud. Oceanogr.* 100, 1-9

Troell, M., Hecht, T., Beveridge, M., Stead, S., Bryceson, I., Kautsky, N., Ollevier, F. and Mmochi, A., (2011). Mariculture in the WIO region – Introduction and some perspectives. In *Mariculture in the WIO region "Challenges and Prospects" Proceedings from the Workshop on Mariculture, December, 2009* (eds. M. Troell, T. Hecht, M. Beveridge, S. Stead, I. Bryceson, N. Kautsky, F. Ollevier and A. Mmochi) WIOMSA Book Series No 11, Pp. 1-5. Jamana Printers Limited, Tanzania

UNDP (2013). *Human Development Index and its components*. Human Development Report 2013 Media Toolkit. https://data.undp.org/dataset/Table-1-Human-Development-Index-and-its-components/wxub-qc5k

UNEP (2014). *The environment of Eastern Africa*. United Nations Environmental Program. http://www.unep.ch/regionalseas/main/eaf/eafenv.html

van der Elst, R., Everett, B., Jiddawi, N., Mwatha, G., Afonso, P. S. and Boulle, D. (2005). Fish, fishers and fisheries of the Western Indian Ocean: their diversity and status. A preliminary assessment. *Phil. Trans. R. Soc. A.* 363(1826), 263-284

van der Elst, R. P., Groeneveld, J. C., Baloi, A. P., Marsac, F., Katonda, K. I., Ruwa, R. K. and Lane, W. L. (2009). Nine nations, one ocean: A benchmark appraisal of the

South Western Indian Ocean Fisheries Project (2008–2012). *Ocean. Coast. Manage.* 52(5), 258-267

Vitousek, P.M., Mooney, H.A., Lubchenco, J. and Melillo, J.M. (1997). Human domination of Earth's ecosystems. *Science.* 277(5325), 494-499

Wells, S. (2009). Dynamite fishing in northern Tanzania–pervasive, problematic and yet preventable. *Mar. Pollut. Bull.* 58(1), 20-23

WIOFISH 2011. *Western Indian Ocean Fisheries Database: A catalogue of small-scale fisheries.* http://www.wiofish.org/

World Bank (2011a). *World Development Indicators*. http://data.worldbank.org/indicator/NY.GNP. PCAP.CD

World Bank (2011b). *Population growth (annual %).* http://data.worldbank.org/indicator/SP.POP. GROW



21
Capture Fisheries

Johan Groeneveld

Opposite page: Prawn trawler operating in Maputo Bay, Mozambique. © José Paula.

ARTISANAL AND INDUSTRIAL FISHING SECTORS

The Southwest (SW) Indian Ocean supports a myriad of capture fisheries, along the coasts of eastern Africa and Madagascar, around small island states such as Mauritius, Seychelles and Comoros, and on shallow offshore banks such as the Mascarene Plateau. Capture fisheries in this region are typically categorized into artisanal (also called subsistence, traditional or small-scale commercial) and industrial (or semi-industrial) sectors. Artisanal fisheries comprise fishing households with small amounts of capital and access to simple gear that can be used from the shore or small boats. A mixed basket of invertebrate and fish species is captured, and the distinction between target and bycatch is vague. Fishing gear includes sticks, spears or harpoons, nets (cast, drag, mosquito, seine and gillnets), hand- and longlines with hooks, and several trap types (Jiddawi and Öhman 2002, Fulanda and others, 2011). Boats are traditional dugouts and small crafts constructed of planks and propelled by sail, with more modern boats with outboard engines and larger dhows with lateens and inboard engines for fishing further offshore (Fulanda and others, 2011, Munga and others, 2014). Artisanal fisheries dominate the SW Indian Ocean by numbers of fishers and gears, (van der Elst and others, 2005, www.wiofish.org), but because fishers are widely dispersed and some groups migrate to follow fish concentrations (Fulanda and others, 2009), records of fishing effort and catches are incomplete.

Industrial fisheries of the SW Indian Ocean comprise fleets of pelagic longliners and purse-seiners that target tuna and tuna-like species (Cochrane and Japp 2015), bottom trawlers for penaeid prawns on shallow mudbanks (Fennessy and Everett 2015a) and deep-water trawling for mixed crustaceans (Everett and others, 2015, Groeneveld and Everett 2015). Long-line trapping for spiny lobsters and crabs has been trialled, with some success (Groeneveld 2015). Semi-industrial hook-and-line (or drop line) fisheries catch demersal fishes on the banks of the Mascarene Plateau and Chagos Archipelago (Heileman and others, 2015). The artisanal and industrial fishing sectors differ in their social and economic perspectives, and to a large extent serve separate markets or economies – thus, artisanal fishers supply local or informal markets important for food security, and industrial fleets supply more affluent domestic or export markets, important to Gross Domestic Product (GDP).

The present chapter focusses on the long-term trends and status of key species groups exploited by the artisanal and industrial fishing sectors, based on information submitted by governments to the FAO and the Indian Ocean Tuna Commission (IOTC). The known environmental impacts of fishing practices in the region are outlined. Policy and management plans at local and regional (transboundary or ocean-wide) levels are synthesized, including the role of the IOTC. Recent initiatives, such as the implementation of ecosystem approaches to fisheries management in the SW Indian Ocean (eg Swaleh and others, 2015) and impact of donor-funded regional fisheries research pro-

jects on capacity development (eg SWIOFP; van der Elst and others, 2009, van der Elst and Everett 2015) are highlighted.

PRIMARY DATA AND ASSESSMENTS

For artisanal fisheries, primary data on species composition of catches, quantities landed, fishing effort and basic biology are incomplete. Landings data are unevenly collected in remote areas, where the numbers of fishers or landing points are not known with any precision (van der Elst and others, 2009, Groeneveld and others, 2014). Data are rarely reported to species level, and are mostly categorized by species groups (for instance pelagic or demersal fishes), thus precluding quantitative analyses. Frame surveys to enumerate fishing vessels, gears and fishers are conducted every few years in some countries (Kenya, Tanzania), but data on the actual numbers of fishing trips or gear-sets undertaken are virtually absent. Catch rate information (catch/fishing effort) as a measure of relative abundance trends over time is therefore unavailable for most artisanal fisheries in the SW Indian Ocean (van der Elst and others, 2005). Consequently, few well-informed decisions on fisheries development in the artisanal sector can be made by governing bodies.

Landings, fishing effort and species composition data are, however, more regularly collected in the economically important industrial prawn trawl fisheries in Mozambique and eastern South Africa (Fennessy and Everett 2015a, Groeneveld and Everett 2015). Catch and fishing effort information per trawl is reported in logbooks, and fisheries observers collect biological and species composition information at sea or at landing points. Prawn fisheries in Mozambique are assessed regularly, and recommendations are made for management purposes. Tunas and billfish (swordfish, marlins, sailfish) are considered to be highly migratory stocks, which are shared by the different countries of the region. These stocks are primarily exploited by industrial surface purse seine and long-line fisheries, and data on catches and fishing effort are reported to the IOTC (www.iotc.org). The scientific committee of the IOTC analyses catch and effort statistics and other scientific information to assess trends in stock status of tuna and tuna-like species, and in bycatch.

All governments of the SW Indian Ocean region voluntarily submit landings data from their fisheries to the FAO. These data are then summarized in standardized statistical groups (i.e. FAOStat or ICSAAP groups), and are made available on the FAO website, from where it can be accessed as summaries by country, region, time period, or species groups. It should be noted that the data submitted to the FAO are 'official' figures, which may exclude substantial unreported landings or reflect coarse estimates of actual landings. For example, catch reconstructions have added more than 200 per cent to official landing statistics from Madagascar (Le Manach and others, 2011) and 42 per cent to landings from Mauritius and its outer islands (Boistol and others, 2011) for the 1950-2008 period. Reconstructed catch for Tanzania was 77 per cent higher than reported to the FAO in 1950-2010 (Bultel and others, 2015). Therefore, trends obtained from the FAO summaries are indicative only, and should be interpreted with caution.

TRENDS IN LANDINGS AND STOCK STATUS

Official landings data were extracted from the FAO online database, by country (eastern South Africa, Mozambique, Tanzania [incl. Zanzibar], Kenya, Somalia, Madagascar, Mauritius, Seychelles, Comoros and France [Reunion and Mayotte Islands]) and by species groups (ASFIS species; all marine landings combined, cephalopods, crustaceans, pelagic fish and marine fish) for the period 1985 to 2012.

Landings from the SW Indian Ocean in 2011 was reported as 462 000 tonnes, and exports as 389 000 tonnes (FAO 2014). The difference between the two quantities (73 000 tonnes), which was presumably consumed locally, is a gross under-estimate, because much of the artisanal landings are not reported (see above). Mozambique, Madagascar and Tanzania (incl. Zanzibar) contributed the most to marine landings (all FAOStat groups combined; Figure 21.1a). Mozambique and Madagascar have the longest coastlines and substantial industrial fisheries for crustaceans (FAO 2007a, 2008). A long coastline, several densely populated islands (Zanzibar, Mafia) and many shallow and easily accessible fishing areas can also explain the high landings reported for Tanzania. In addition to its national tuna fleet, foreign tuna fleets land their catches in Seychelles, thus explaining the large contribution of this small island state to regional landings (FAO 2005, Marsac and others, 2014). Comoros, Mauritius and Kenya contributed only a small proportion to the regional marine landings (FAO 2006, 2007b). These countries have relatively short coastlines, but the former two island states have comparatively large EEZs. In Comoros, the littoral zone drops off

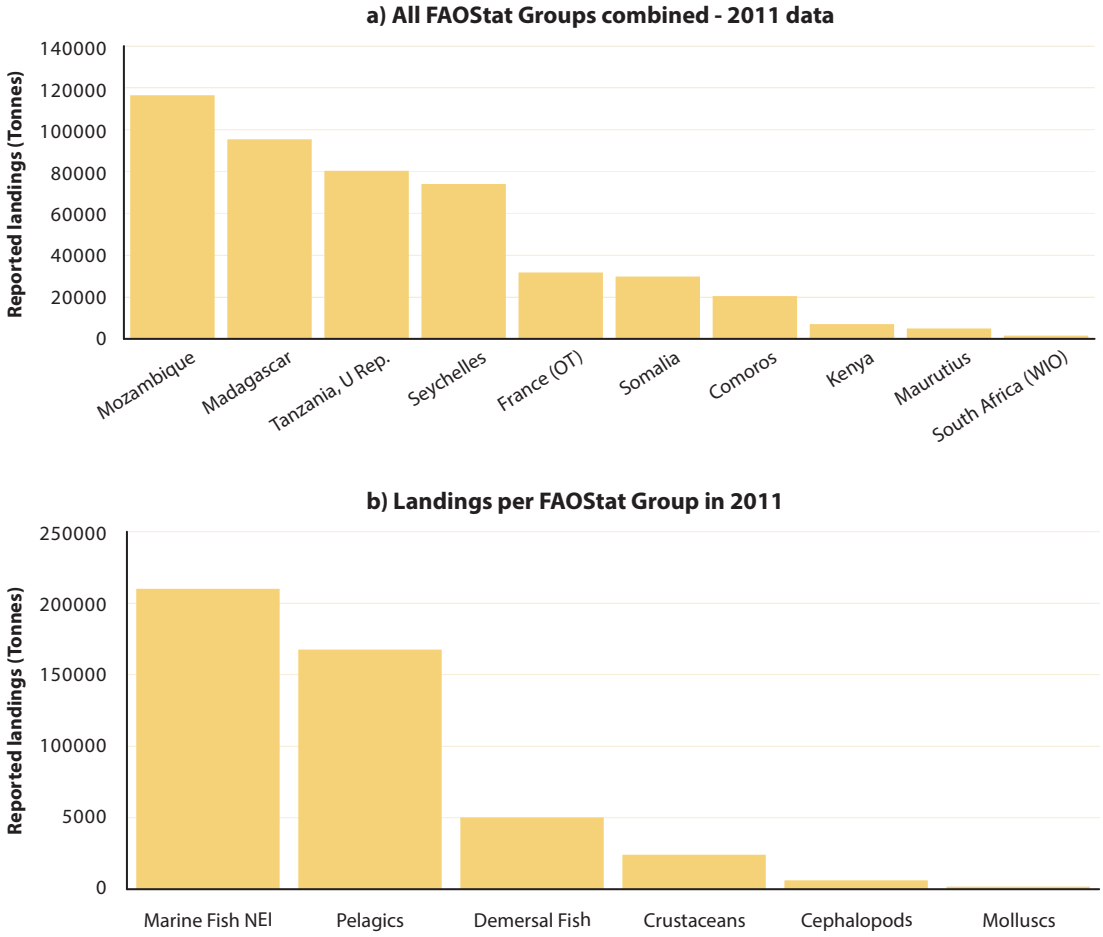


Figure 21.1. **a)** Contribution of regional countries to marine landings (FAOStat Groups combined). **b)** Landings per FAOStat Group (FAO 2014).

steeply to abyssal depths, with little or no shelf area available for artisanal fishing; large pelagic fish caught in its extensive EEZ by foreign vessels are probably reported for Seychelles (port of off-loading) or in flag countries. In Kenya, freshwater fish from lakes make up the bulk of landings reported to the FAO (not included here).

Excluding the category for marine fish NEI (meaning any species Not Elsewhere Included), pelagic fish made up 67 per cent of the reported landings in 2011 (Figure 21.1b). Presumably most pelagic fish landings are correctly categorized by industrial fisheries that report to the IOTC, thus explaining the dominance of this group. Most of the marine fish NEI category presumably comprises demersal fish landed by artisanal fishers therefore the actual contribution of demersal fish to regional landings is most likely much greater than the 20 per cent suggested in Figure 21.1b. Despite the contributions of artisanal and industrial prawn trawl fisheries to crustacean landings, this group made up only 10 per cent of total reported landings, by weight. Other invertebrates (cephalopods, molluscs) are collected in the intertidal, often by women, and their landings are grossly under-reported (except for octopus, which is a high-value export product).

A sudden increase in landings of all FAOStat groups combined in Mozambique in 2002 / 2003 (Figure 21.2a) reflects improved reporting of artisanal landings, rather than an actual quantum leap in catches over a short period. Nevertheless, it is clear that Mozambican landings have continued to increase over the past decade, illustrating growth of the fishing sector.

Octopus is extensively exploited by artisanal fishers in Tanzania, Madagascar, Mozambique and Kenya (Figure 21.2b), often for export to foreign markets (Guard and Mgaya 2002, Humber and others, 2006, Guard 2009). It is one of the main exported fishery products of Tanzania, and >95 per cent of the catch comprises *Octopus cyanea* (crepuscular or common reef octopus), a fast-growing and short-lived species that matures in 6 months and can weigh up to 11 kg. Octopus is traditionally caught in intertidal and shallow subtidal waters, by women and children using spears

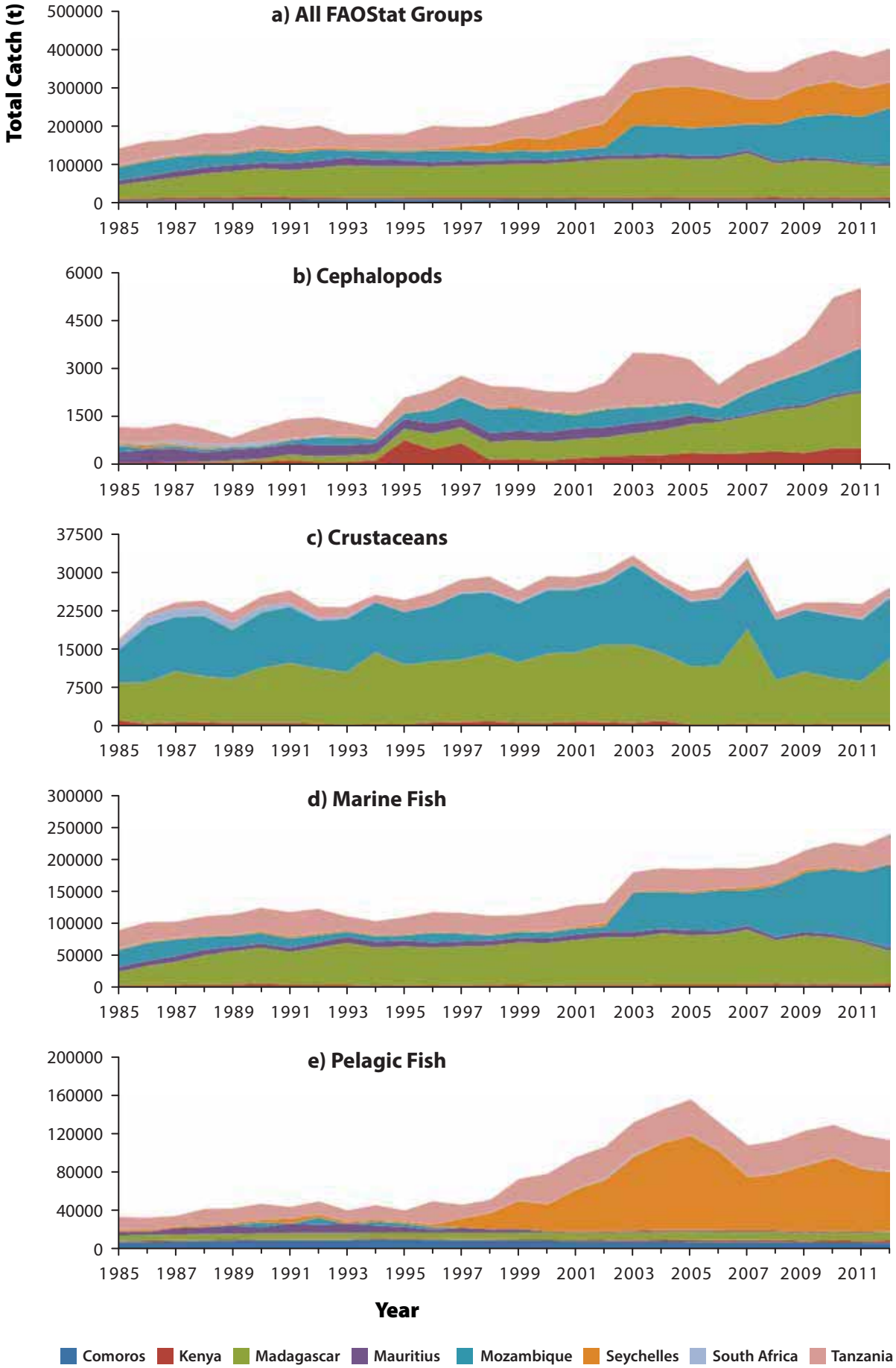


Figure 21.2. Reported landings by species group for the SW Indian Ocean region for the period 1985-2012

and sticks. Men are increasingly active in the fishery because of high demand and price. Landings in Madagascar have increased in recent years, where seasonal closures are used to recover heavily fished populations (Humber and others, 2006, Benbow and Harris 2011). In southern Kenya, octopus landings increase during the northeast monsoon, but decrease during the southeast monsoon, when sea conditions deteriorate.

Several co-occurring penaeid prawns (mainly *Penaeus indicus*, *P. monodon* and *Metapenaeus monoceros*) are targeted by industrial bottom trawl fisheries in shallow water (< 50 m deep) in Mozambique and Madagascar (Figure 21.2c), and to a lesser extent in eastern South Africa, Tanzania and Kenya (Fennessy and Everett 2015a). The trawl fisheries operate on mud and sandbanks near river outlets (Forbes and Demetriades 2005, Munga and others, 2013). Prawn abundance is susceptible to degradation of estuarine nursery habitats (see Mkare and others, 2014), and declines in landings have been observed throughout the SW Indian Ocean. A collapse of the prawn trawl fishery in South Africa was attributed to the construction of dams, which decreased river runoff, thus reducing the recruitment of juvenile prawns to offshore mudbanks. Industrial prawn trawling in Kenya and Tanzania have been discontinued, at least temporarily (Munga and others, 2012), and in Mozambique many trawlers have diverted to a deep-water trawl fishery in 2013 and 2014, because of low penaeid prawn catch rates. Deep-water trawl fisheries for mixed crustaceans (prawns, langoustines, spiny lobsters and deep-sea crabs) operate in Mozambique and eastern South Africa, and have been trialled in western Madagascar (Everett and others, 2015, Groeneveld and Everett 2015). Importantly, trends shown in Figure 21.2c exclude potentially large unreported landings of shallow water crustaceans by artisanal fishers, which are consumed or sold informally on local markets.

The marine fish category (Figure 21.2d) comprises mostly demersal and reef fish landings made by artisanal fishers, fish bycatch of industrial prawn trawlers, and shark landings (demersal and pelagic). Madagascar, Tanzania and Mozambique have consistently reported the highest landings in this category, commensurate with their long coastlines and dependence on nearshore fish resources. The 'marine fish' category apparently also includes pelagic fish landings from Mozambique after 2001, which might explain the virtual absence of pelagic fish landings reported there (see Figure 21.2e).

Small pelagic fishes (mackerels, sardines, anchovies) are caught with gill and ring nets wherever there are artisanal fisher communities along the coast and around the islands. Larger species such as skipjack, other small tunas, Spanish mackerel, dolphin fish, and some carangids are caught by artisanal fishers using gill nets further from the coast. Cochrane and Japp (2015) indicated that the catches of many pelagic species were well above 4 000 tonnes from 2004 to 2010, but these data have not been recorded in the FAO database. The increase in large pelagic fish landings in Seychelles after 1997 (Figure 21.2e) reflects the development of its fishing port as a hub for the international tuna industry. During the mid-1990s, some of the port operations were privatized, reducing trans-shipment fees and increasing efficiency. The secretariat of the IOTC was established in Seychelles in 1996. The former canning factory, Conserveries de l'Ocean Indien Ltd, created in 1987 between the Government of Seychelles and private investors, was restructured and renamed Seychelles Tuna Canning Factory. It was privatized in 1995, when 60 per cent of it was purchased by the American food company Heinz. Presently the cannery is named Indian Ocean Tuna and is owned by the Seychelles government and leased and operated by Heinz Europe. Tuna fishing is now a significant economic activity of Seychelles (28 per cent of GDP, 92 per cent of exports, Marsac and others, 2014), with earnings growing annually from licensing fees paid by foreign vessels fishing in its territorial waters (Robinson and others, 2010). Most tuna landings in Seychelles comprise yellowfin (*Thunnus albacares*), skipjack (*Katsuwonis pelamis*) and bigeye (*Thunnus obesus*).

ILLEGAL, UNREPORTED AND UNREGULATED (IUU) FISHING

In its International Plan of Action (IPOA-IUU), the FAO defines IUU fishing as any fishing activity that is illegal (in violation of the laws of a fishery), unreported (not reported to relevant national or regional authorities) and unregulated (operates without nationality, or under flag of a non-participant country in a managed area) (www.fao.org). The drivers behind IUU fishing could be as simple as food security in impoverished fishing communities, or in the case of industrial scale or systematic overharvesting, have strong economic incentives such as harvesting high value species for export markets. IUU fishing can flourish when governments fail to enforce national or international laws through weak enforcement (eg because of lack of capacity,

BOX 21.1. SWIOFP - LEGACY AND LESSONS

The South West Indian Ocean Fisheries Project (SWIOFP) formed part of the Global Environment Facility (GEF) Large Marine Ecosystems Programme in the Western Indian Ocean between 2008 and 2013. The project extended across the Exclusive Economic Zones of Comoros, Kenya, Madagascar, Mauritius, Mozambique, Seychelles, eastern South Africa, Tanzania and the French islands of Reunion and Mayotte. SWIOFP aimed to assess offshore fisheries potential and provide scientific information and capacity for fisheries management. Many important lessons were learnt over the duration of the project (Groeneveld et al. 2013). A truly participatory process in project design and implementation ensured stakeholder buy-in and relevance of project objectives. A strong collaborative network developed, and challenges could be addressed by pooling of scarce resources across the region. An extensive Master's degree programme proved efficient in achieving two objectives simultaneously: capacity development to a masters degree level, and providing scientific manpower to analyse survey data. Linking fisheries research projects with RFMO's (such as the SWIO Fisheries Commission) enhanced post-SWIOFP continuity. On the down side, project design was over-optimistic (for instance, implementing 40 surveys at sea using research and fishing vessels, and establishing a regional observer programme) and some of it could not be fully implemented, or placed a heavy burden on project resources. SWIOFP relied largely on existing government employees and structures for its implementation – progress was therefore slower, compared to relying on consultants, but benefits included enhanced skills and networking within government agencies. The legacy of SWIOFP lies not only in its many scientific and applied outputs, but also in growing a strong, interacting network of fisheries scientists and managers in the region.

or poor levels of governance) or inadequate coverage of international agreements. Most SW Indian Ocean countries have inadequate financial, technical and manpower resources to effectively combat IUU fishing by artisanal and industrial fishing sectors (Samoilys and others, 2007, SADC 2008), and therefore the quantities of illegally caught fish are expected to be high. Social impacts of IUU fishing are numerous, but importantly, it may affect food security over short and longer terms, and cause resource-user conflicts. Apart from depleting valuable fish stocks, economic impacts of IUU fishing are a direct loss of revenue to governments (namely foregoing license fees, port and chandling income, transhipment of catches) and an indirect loss to licensed fishers confronted by diminishing catch rates of affected fish stocks, and thus higher operational costs (SADC 2008).

Individual countries in the SW Indian Ocean have taken important steps to combat illegal fishing: these include use of EU access agreement funds to improve monitoring, control and surveillance (MCS); developing fisheries monitoring centres and fitting licensed vessels with satellite monitoring devices; and chartering of additional fisheries patrol boats. International development agencies provide technical or financial support – for example the IOTC, IUCN, SADC, WWF and the World Bank. An IOTC resolution in 2010 supported the adoption of FAO port state measures to combat, prevent, deter and eliminate IUU fishing (IOTC Resolution 10/11). It also implements a regional observer programme to monitor transhipments at sea, to prevent laundering of fish through at-sea transhipments, and publishes records of authorised, active and suspected IUU fishing vessels (www.iotc.org). Although the above steps by national and regional bodies are encouraging, effective prevention of IUU fishing might

require far greater political will and investment in infrastructure and expertise, probably at an integrated regional level.

ENVIRONMENTAL IMPACTS OF CAPTURE FISHERIES

Capture fisheries affect the environment in which they operate at several levels. Apart from removals of the harvested resource, bycatches of non-targeted species can be substantial when non-selective gears, such as trawl nets, are used. These bycatches may include endangered, threatened or protected (ETP) species, including marine mammals, sea turtles, seabirds and vulnerable elasmobranch or teleost species. At another level, fishing methods may be destructive to the physical environment, or to habitats required to sustain fish populations. Destructive fishing gear or methods include dragging bottom trawls or dredges that crush, smother or uproot benthic structures, or the use of poison and dynamite fishing that cause excessive incidental mortalities and reef damage (FAO 2009). At an ecosystem level, trophic balance is affected through the depletion of key species – for example, a cascading effect was observed after overfishing of triggerfish in Kenya allowed their prey (sea urchins) to multiply and overgraze seagrass beds, eventually leading to the erosion of coral reefs (Laipson and Pandya 2009).

A recent retrospective analysis of fisheries impacts in the SW Indian Ocean (van der Elst and Everett 2015) dealt with bycatch, marine mammals, sea turtles, seabirds, elasmobranchs, vulnerable teleost species and biodiversity hotspots. Defining what bycatch is can be complex, because it depends on value judgements of individual fishers, and is affected by market demand and season (Fennessy and Everett 2015b). Undesirable bycatch with low value, or which is too small to eat, non-palatable or toxic is mostly dumped at sea. It is generally assumed that small-scale fisheries have little to no bycatch, whereas industrial-type fisheries have larger amounts. Fennessy and Everett (2015b) found few bycatch issues in recreational, subsistence, artisanal and small-scale fisheries in the SW Indian Ocean, whereas more sophisticated industrial fisheries, particularly those with nets, returned high bycatches. Discard rates for industrial longline fisheries were high (~22 per cent), but varied regionally and by fleet, for example, in Seychelles the rate was around 10 per cent (Kelleher 2005). Blue sharks *Prionace glauca* and mako sharks *Isurus oxyrhinchus* comprise most of the bycatch in the industrial longline fisheries.

The bycatch of bottom trawl fisheries in the SW Indian Ocean is diverse, greatly exceeding (>70 per cent by weight) the target catch of crustaceans, and is mostly killed by trawling. Some bycatch species are retained, but most are discarded (reviewed in Fennessy and others, 2004). Notwithstanding legal requirements for the use of bycatch reduction devices in most countries in the region (mainly intended to reduce catches of turtles), high bycatch levels persist, and have led to the closure of trawl fisheries in some countries (Fennessy and others, 2008). Bottom trawling is banned in Seychelles, Comoros and Mauritius.

Kiszka (2015) reviewed existing information on the status and conservation of 37 known marine mammal species in the SW Indian Ocean. Among large cetaceans, humpback whales *Megaptera novaeangliae* are the most common and widely distributed during winter, when they breed in the region. Oceanic islands and archipelago's provide quality habitats for several toothed cetaceans. Dugongs are endangered in the region, and their numbers have progressively declined. A viable population occurs at Bazaruto Archipelago, Mozambique. While capture fisheries pose the greatest threat to marine mammal numbers, other threats include disturbance and noise pollution.

Strong legislation prohibits the direct take of sea turtles throughout the entire SW Indian Ocean, but despite this, turtle populations face significant threats from fishing (reviewed by Bourjea 2015). Gill-netting, prawn trawling and long-lining incidentally catch many sea turtles, with high mortality rates. Breeding females, eggs and hatchlings face land-based threats during nesting on sandy beaches.

Fisheries can impact seabirds through direct mortality and by reducing food availability through competition for resources. The scale and impact of fishing on seabirds in the SW Indian Ocean remains unknown, but could be significant in areas where high gill net fishing effort overlaps with the foraging ranges of diving seabird species, such as shearwaters and cormorants (Wanless 2015).

Elasmobranchs are targeted or taken as bycatch in several SW Indian Ocean fisheries, including longline, purse seine, pelagic drift net and especially shrimp trawling (Kiszka and van der Elst 2015). Some 188 shark and ray species have been recorded by 39 Indian Ocean nations, totalling a catch of >100 000 tonnes in 2012; this is considerably less than peak landings of 180 000 tonnes reported in 1996 (www.fao.org). Few mitigation measures for sharks and rays have been implemented, but the MADE project (Mitigating ADverse impacts of open ocean fisheries, www.

BOX 21.2. INDIAN OCEAN TUNA COMMISSION (IOTC)

The largest offshore fisheries in the Western Indian Ocean are those for highly migratory tunas, caught by international fleets of purse seiners and pelagic longlines. Total catches of tunas, billfishes and other species made up about 1.7 million tonnes in 2013, mostly skipjack (390 000 t) and yellowfin (380 000 t) tunas (IOTC, 2014). The fishing fleets follow the migrating tuna stocks, and fishing grounds extend over the high seas and the Exclusive Economic Zones of coastal countries in the region. The management of the fisheries for tuna and tuna-like resources, their associated environment and bycatch is coordinated by the IOTC, located in Victoria, Seychelles. The IOTC is an inter-governmental organization established under Article XIV of the FAO constitution in 1993, and as such its member countries can make binding decisions regarding tuna management in the Indian Ocean areas 51 (west) and 57 (east). The IOTC has 32 members, mostly nation states from around the world. Species under IOTC management include tuna (yellow- and bluefin, skipjack, albacore, bigeye, longtail, eastern little, frigate and bullet tuna), marlins (blue, black and striped), swordfish, Indo-pacific sailfish, and king and Spanish mackerels. In addition, the IOTC collates data on non-target species affected by tuna fishing operations, i.e. marine turtles, mammals, seabirds, sharks and fish species caught incidentally (bycatch). The key functions of the IOTC are: to review stock trends, analyse and disseminate scientific information required for fishery management; coordinate research and development, including technology transfer and training; adopt – on the basis of scientific evidence – Conservation and Management Measures; and to keep the economic and social aspects of the fisheries under review, particularly in developing coastal States.

made-project.eu) is investigating the effectiveness of "ecological FADs", better practices on board vessels, use of artificial baits, and a better vertical distribution of hooks (Dagorn 2011). Data on elasmobranch catches remain sparse, but the IOTC has greatly improved data collection protocols (www.iotc.org).

Vulnerable (or red-flagged) teleosts are captured in several fisheries as incidental or target catch (van der Elst 2015). Line fishing near reefs targets Serranidae and Labridae, including red-flagged species such as *Epinephelus tukula*, *E. lanceolatus*, *E. albomarginatus*, *E. areolatus*, *Plectropomus laevis* and *Bolbometopon muricatum*. Capture of coelecanth (*Latimeria chalumnae*) by deeper water line fisheries has been reported. In most cases, the capture of red-flagged species is not seen as a matter of concern by management agencies, except perhaps for the coelacanth. Van der Elst (2015) proposed that a list of species be drawn up which reflects a collated red-flagged species list for the SW Indian Ocean, and that countries are encouraged to managed these species accordingly.

Some 59 specific geographic sites within the SW Indian Ocean have recently been listed as biodiversity hotspots (Everett and van der Elst 2015); these sites may be vulnerable to fishing pressure, of importance to regional biodiversity, or provide control areas against which to monitor the impact of fishing at other sites. While this list is by no means complete, it begins to identify and describe critical areas in the SW Indian Ocean.

Marine Protected Areas (MPA) can conserve critical habitats and provide refuges for breeding populations of exploited species; if placed correctly, they can form a source of recruits to fishing grounds through spill-over or larval export (Planes and others, 2009, Robinson and Samoilys 2013). A WIOMSA survey listed 83 MPAs in the SW Indian

Ocean, with Seychelles having as many as 16 officially gazetted marine conservation areas (www.dlist-asclme.org). The largest MPA is the Quirimbas National Park in Mozambique, which spans over 7 500 km^2. Mozambique also has the oldest MPA, with the "Ilhas da Inhaca e dos Portugueses" Faunal Reserve gazetted as early as 1965. Three large MPAs in the Malindi-Watamu area in Kenya date from 1968. Some of the 83 MPAs are strict "no-take" areas while others are "multiple use areas" where fishing is still allowed, but restricted in terms of fishing gear, methods, and seasonal closures. Some MPAs have management plans in place, but most are only partially managed.

FISHERIES MANAGEMENT AND POLICY FRAMEWORKS

Policy and legislation

All countries bordering the SW Indian Ocean are signatories to the Law of the Sea (UNCLOS), which covers limits of maritime zones, rights of navigation, protection and preservation of the marine environment, scientific research and activities on the seabed beyond the limits of national jurisdiction (van der Elst and others, 2009). All countries also subscribe to the 1995 FAO Code of Conduct for Responsible Fisheries and the more recent Ecosystem Approach to Fisheries (EAF) (Garcia 2003), although they often do not have the capacity to implement specific management strategies.

Management of artisanal fisheries

Beach Management Units (BMUs) are the backbone of artisanal fisheries co-management in Tanzania (>170 BMUs active) and Kenya (73 BMUs) (Kanyange and others, 2014). In both countries, BMUs are supported by a legal framework (since 2006 in Kenya and 2009 in Tanzania), and are intended to bring resource user groups and governmental bodies together to share resource management and conservation responsibilities. Individual BMUs have jurisdiction over distinct geographical areas, where they manage fish-landing stations and stakeholders on behalf of fisheries departments, and are empowered to levy fees. A recent performance assessment of BMUs in Kenya and Tanzania (Kanyange and others, 2014) showed numerous factors affecting BMU performance: critical among them were leadership, representation, conflict resolution, inclusion, cost vs benefit, MCS, mutual trust and jurisdiction. Inadequate resources and infrastructure deficiencies were in the midst of this mix. Achievement of objectives was below expectations, and stakeholder livelihood had not improved. BMUs remain a promising mechanism for the decentralization of fisheries management, but as a co-management system, it needs to mature and will require considerable financial and logistic assistance (Oluoch and Obura 2008).

Van der Elst and others, (2005) evaluated artisanal fisheries in the SW Indian Ocean in terms of specific management strategies that would assist in its sustainable development. Forty-six per cent of artisanal fisheries were subject to a specific management policy, which set out, among others, management strategies, jurisdiction, access controls and licensing. Only 16 per cent of fisheries were subject to specific management plans with set objectives, whereas 84 per cent had no, or ineffective management plans in existence (van der Elst and others, 2005). A recent study in Tanzania (Groeneveld and others, 2014) showed that fishery management plans had been developed for octopus, tuna, prawn and small pelagic fisheries along the mainland coast, but that none of these had been fully implemented, because of logistical and financial constraints.

Management of industrial fisheries

Industrial fisheries for tuna and tuna-like species in the Indian Ocean are multi-national and managed by the intergovernmental Indian Ocean Tuna Commission (IOTC) located in Seychelles. The IOTC estimates stock status of key species from catch return and research data, and allocates quotas to member countries (IOTC 2014). Specific policies and conservation and management measures of the IOTC (see www.iotc.org) address target tuna species, as well as bycatches of elasmobranches and other ETP species. Longline fisheries for swordfish in the SW Indian Ocean are operated under national jurisdiction in South Africa, Seychelles and La Reunion (Kolody and others, 2010). Deep-water trawl fisheries are managed nationally, or access to resources in EEZ waters are allowed through licensing.

Regional research and management bodies

Regional Fisheries Management Organizations (RFMO) in the SW Indian Ocean region include the IOTC (described above) and the SW Indian Ocean Commission (SWIOFC), established in 2004 by the FAO council. The Indian Ocean Commission (IOC) is an intergovernmental organization created in 1982 to serve the interests of small

island developing states (Comoros, Reunion, Madagascar, Mauritius and Seychelles) – these states share geographic proximity, historical and demographic relationships, natural resources and common development issues. Recent IOC cooperation has focused on marine conservation and fisheries management at regional and national levels. An example is the SmartFish project (www.smartfish-coi.org), with a focus on fisheries governance, management, monitoring control and surveillance, trade, and food security.

The SW Indian Ocean Fisheries Project (SWIOFP) from 2008 to 2013 provided a regional framework for data collection and capacity building in the offshore environment for nine countries (van der Elst and others, 2009). SWIOFP produced a detailed retrospective data analysis to show long-term fisheries and stock status trends, and environmental impacts of fishing (van der Elst and Everett 2015). The project undertook a series of resource-based knowledge gap-analyses (see Groeneveld and Oellermann 2013), facilitated regional training courses and workshops, and supported 21 Master's degree projects to analyse data collected during dedicated surveys at sea. SWIOFP left a legacy of strengthened ties among fisheries scientists and students across the region, and provided key information on abundance, biology, distribution patterns and genetic population structure of key species for fisheries management purposes (Macfadyen 2012).

The Western Indian Ocean Marine Science Association (WIOMSA) promotes educational, scientific and technological development of marine science (WIOMSA 2010). The Nairobi Convention provides resources and expertise to solve interlinked problems of coastal marine environments through regional cooperation (UNEP 2014).

Progress with World Summit on Sustainable Development (WSSD) commitments

Between 2011 and 2015, SW Indian Ocean countries made only modest progress towards WSSD commitments to implement EAF strategy (FAO 2015). The implementation of EAF is supported by the EAF-Nansen Project in African countries, and its focus areas are: understanding ecosystem impacts of fisheries; social well-being of those depending on fishing; economic well-being of the fishing industry; transparent and participatory management structures; management plans incorporating EAF; compliance with regulations; sufficient capacity, skills, equipment; good data procedures; and addressing external impacts of fisheries. The overall implementation level was computed as 49.4 per cent in 2015, compared to 46.2 per cent in 2011. Key areas of progress, challenges and possible barriers need to be evaluated.

GAPS IN CAPACITY TO ENGAGE IN CAPTURE FISHERIES AND TO ASSESS STATUS, TRENDS AND ENVIRONMENTAL IMPACTS

Several countries (Mozambique, Tanzania, Kenya, Madagascar and Comoros) have inadequate infrastructure, trained manpower and scientific skills to fully assess their marine resources (van der Elst and others, 2009). Nearly all countries bordering the SW Indian Ocean lack sufficient data and expertise to fully describe their fisheries and the anthropogenic pressures on stocks – although much pro-





Figure 21.3. Two aspects of Dar es Salaam fishmarket. © Johan Groeneveld

gress was made by the SWIOFP project after 2008. Basic information on fished species is incomplete, and more information is required to describe biological characteristics and reference points, distribution patterns, fishing pressure and stock status of key fished species. A minority of species / fisheries have effective management plans, whilst most species are at risk of overexploitation by a growing human population in the coastal areas.

The influence of environmental fluctuations on fish stocks and ecosystem functioning are weakly understood – a factor exacerbated by global climate change and predicted temperature, pH and sea level changes. A shift towards EAF management has been initiated in several countries (South Africa, Mozambique, Kenya) through donor-funded projects such as the EAF-Nansen programme. The positive spin-offs of EAF management will need to be demonstrated to stakeholders, especially in the artisanal fishing sector, to encourage its acceptance and support at community level.

Although permits are legally required by all fishers, this may not always be adhered to in remote areas, so that some artisanal fisheries are, in effect, open access in nature. The status of exploited resources is consequently often unknown. Coastal towns and communities continue to grow, thus increasing the exploitative pressure on marine resources. How to redress the scenario of dwindling fish resources versus increasing demand towards favourable socio-economic (improved food security; alternative economic and social opportunities) and environmental (sustainable fisheries and healthy ecosystems) outcomes will be a major challenge to governments in decades to come.

References

Benbow, S. and Harris, A. (2011). *Managing Madagascar's octopus fisheries. Proceedings of the workshop on Octopus cyanea fisheries.* BlueVentures. Aberdeen Centre, London

Boistol, L., Harper, S., Booth, S. and Zeller, D. (2011). Reconstruction of marine fisheries catches for Mauritius and its outer islands, 1950-2008. In *Fisheries catch reconstructions; Islands, Part II* (eds. S. Harper and D. Zeller) Fisheries Centre Research Reports 19(4), pp. 39-61. Fisheries Centre, University of British Columbia

Bourjea, J. (2015). Sea turtles: A review of status, distribution and interaction with fisheries in the Southwest Indian Ocean. In *Offshore fisheries of the Southwest Indian Ocean: their status and the impact on vulnerable species* (eds. R.P. van der Elst and B.I. Everett) Special Publication No 10. Durban: South African Association for Marine Biological Research

Bultel, E., Doherty, B., Herman, A., Le Manach, F. and Zeller, D. (2015). An update of the reconstructed marine fiheries catches of Tanzania with taxonomic breakdown. In *Fisheries catch reconstructions in the Western Indian Ocean, 1950–2010* (eds. F. Le Manach and D. Pauly) Fisheries Centre Research Reports 23(2), pp. 151–161. Fisheries Centre, University of British Columbia

Cochrane, K.L. and Japp, D. (2015). Pelagic fisheries: A retrospective analysis of their status in the Southwest Indian Ocean. In *Offshore fisheries of the Southwest Indian Ocean: their status and the impact on vulnerable species* (eds. R.P. van der Elst and B.I. Everett) Special Publication No 10. Durban: South African Association for Marine Biological Research

Dagorn, L. (2011). An update of the EU MADE project. IOTC–2011–WPEB07–52. Victoria, Seychelles

Everett, B.I., Groeneveld, J.C., Fennessy, S.T., Dias, N., Filipe, O., Zacarias, L., Igulu, M., Kuguru, B., Kimani, E., Munga, C.N., Rabarison, G.A., Razafindrakoto, H. and Yemane, D. (2015). Composition and abundance of deep-water crustaceans in the Southwest Indian Ocean: Enough to support trawl fisheries? *Ocean Coast. Manage.* 111, 50-61

Everett, B.I. and van der Elst, R.P. (2015). Biodiversity hotspots of the Southwest Indian Ocean: Their location and primary features. In *Offshore fisheries of the Southwest Indian Ocean: their status and the impact on vulnerable species* (eds. R.P. van der Elst and B.I. Everett) Special Publication No 10. Durban: South African Association for Marine Biological Research

FAO (2005). *National Fishery Sector Overview: The Republic of Seychelles*. FAO, Rome

FAO (2006). *National Fishery Sector Overview: The Republic*

of Mauritius. FAO, Rome

FAO (2007a). *National Fishery Sector Overview: The Republic of Mozambique*. FAO, Rome

FAO (2007b). *National Fishery Sector Overview: The Republic of Kenya*. FAO, Rome

FAO (2008). *National Fishery Sector Overview: The Republic of Madagascar*. FAO, Rome

FAO (2009). *FAO/UNEP Expert meeting on impacts of destructive fishing practices, unsustainable fishing, and illegal, unreported and unregulated (IUU) fishing on marine biodiversity and habitats*. FAO, Rome

FAO (2014). *Southwest Indian Ocean Fisheries Commission (SWIOFC)*. Available at http://www.fao.org/fishery/rfb/swiofc/en [accessed 09/05/2014 2014]

FAO (2015). *Final report of the sixth session of the Scientific Committee of the South West Indian Ocean Fisheries Commission*. Dar-es-Salaam, Tanzania. FAO, Rome.

Fennessy, S.T., Mwatha, G.K. and Thiele, W. (2004). *Report of the Regional Workshop on Approaches to Reducing Shrimp Trawl Bycatch in the Western Indian Ocean: Mombasa, Kenya, 13-15 April 2003*. No. 734. FAO, Rome

Fennessy, S.T., Vincent, X., Budeba, Y., Mueni, E.M. and Gove, D. Z. (2008). Short Communication: An Update on Initiatives to Reduce Prawn Trawl Bycatch in the Western Indian Ocean. *Western Indian Ocean J. Mar. Sci.* 7(2)

Fennessy, S.T. and Everett, B.I. (2015a). Crustacean shallow-water trawl fisheries: A retrospective analysis of their status in the Southwest Indian Ocean. In *Offshore fisheries of the Southwest Indian Ocean: their status and the impact on vulnerable species* (eds. R.P. van der Elst and B.I. Everett) Special Publication No 10. Durban: South African Association for Marine Biological Research

Fennessy, S.T. and Everett, B.I. (2015b). Fisheries bycatch: An updated assessment of the status in the Southwest Indian Ocean. In *Offshore fisheries of the Southwest Indian Ocean: their status and the impact on vulnerable species* (eds. R.P. van der Elst and B.I. Everett) Special Publication No 10. Durban: South African Association for Marine Biological Research

Forbes, A.T. and Demetriades, N.T. (2005). *A review of the commercial, shallow water penaeid prawn resource of South Africa: Status, fisheries, aquaculture and management*. Specialist report. Ezemvelo KZN Wildlife: Marine and Estuarine Research

Fulanda, B., Munga, C., Ohtomi, J., Osore, M., Mugo, R. and Hossain, M.Y. (2009). The structure and evolution of the coastal migrant fishery of Kenya. *Ocean Coast. Manage.* 52(9), 459-466

Fulanda, B., Ohtomi, J., Mueni, E. and Kimani, E. (2011). Fishery trends, resource-use and management system in the Ungwana Bay fishery Kenya. *Ocean Coast. Manage.* 54(5), 401-414

Garcia, S. M. (2003). *The ecosystem approach to fisheries: issues, terminology, principles, institutional foundations, implementation and outlook*. Report No. 443. FAO, Rome

Groeneveld, J.C., Oellermann, L.K., van der Elst, R.P., Fennessy, S.T., Everett, B.I. and Athayde, T. (2013). Harmonization of knowledge gap analyses and associated research programmes for SWIOFP components 2, 3, 4 & 5. Specialist Report. March 2013. SWIOFP RMU, KMFRI, Mombasa, Kenya (50 pp).

Groeneveld, J.C., Fennesy, S.T., Everett, B.I. and Robey, J. (2014). *Rapid Assessment of the State of Commercial Fisheries and Main Species Exploited in Tanzania*. Specialist Report. Oceanographic Research Institute. Durban

Groeneveld, J.C. (2015). Crustacean deep-water trap fisheries: A retrospective analysis of their status in the Southwest Indian Ocean. In *Offshore fisheries of the Southwest Indian Ocean: their status and the impact on vulnerable species* (eds. R.P. van der Elst and B.I. Everett) Special Publication No 10. Durban: South African Association for Marine Biological Research

Groeneveld, J.C. and Everett, B.I. (2015). Crustacean deep-water trawl fisheries: A retrospective analysis of their status in the Southwest Indian Ocean. In *Offshore fisheries of the Southwest Indian Ocean: their status and the impact on vulnerable species* (eds. R.P. van der Elst and B.I. Everett) Special Publication No 10. Durban: South African Association for Marine Biological Research

Guard, M. (2009). *Biology and fisheries status of octopus in the Western Indian Ocean and the suitability for marine stewardship council certification*. United Nations Environmental Programme

Guard, M. and Mgaya, Y.D. (2002). The artisanal fishery for *Octopus cyanea* Gray in Tanzania. *AMBIO* 31, 528-536

Heileman, S., Fennessy, S.T. and van der Elst, R.P. (2015). Demersal fisheries: A retrospective analysis of their status in the Southwest Indian Ocean. In *Offshore fisheries of the Southwest Indian Ocean: their status and the impact on vulnerable species* (eds. R.P. van der Elst and B.I. Everett) Special Publication No 10. Durban: South African Association for Marine Biological Research

Humber, F., Harris, A., Raberinary, D. and Nadon, M.

(2006). *Seasonal closures of no-take zones to promote a sustainable fishery for Octopus cyanea (Gray) in Southwest Madagascar*. BlueVentures Conservation Report. , London.

IOTC. (2014). *The Commission*. Available at http://www.iotc.org/about-iotc, accessed 09 May 2014

Jiddawi, N.S. and Öhman, M.C. (2002). Marine fisheries in Tanzania. *AMBIO* 31, 518-527

Kanyange, N., Kimani, P., Onyango, P., Sweenarain, S. and Yvergniaux, Y. (2014). *Performance Assessment of Beach Management Units Along the Coastlines of Kenya and Tanzania*. IOC, Smartfish, SF/2014/47

Kelleher, K. (2005). *Discards in the world's marine fisheries: an update*. Report No. 470. FAO, Rome

Kiszka, J. (2015). Marine mammals: A review of status, distribution and interaction with fisheries in the Southwest Indian Ocean In *Offshore fisheries of the Southwest Indian Ocean: their status and the impact on vulnerable species* (eds. R.P. van der Elst and B.I. Everett) Special Publication No 10. Durban: South African Association for Marine Biological Research

Kiszka, J. and van der Elst, R.P. (2015). Elasmobranchs (sharks and rays): A review of status, distribution and interaction with fisheries in the Southwest Indian Ocean. In *Offshore fisheries of the Southwest Indian Ocean: their status and the impact on vulnerable species* (eds. R.P. van der Elst and B.I. Everett) Special Publication No 10. Durban: South African Association for Marine Biological Research

Kolody, D., Robinson, J. and Lucas, V. (2010). *Swordfish Catch Rate Standardization for the Seychelles Semi-Industrial and Industrial Longline Fleets*. Indian Ocean Tuna Commission Working Party on Billfish Working Paper: IOTC-2010-WPB-04

Laipson, E. and Pandya, A. (2009). *The Indian Ocean-Resource and Governance Challenges*. Stimson, Washington,

Le Manach, F., Gough, C., Humber, F., Harper, S. and Zeller, D. (2011). Reconstruction of total marine fisheries catches for Madagascar (1950-2008). In *Fisheries catch reconstructions; Islands, Part II* (eds. S. Harper and D. Zeller) Fisheries Centre Research Reports 19(4), pp. 21-37. Fisheries Centre, University of British Columbia

Macfadyen, G. (2012). *Implementation completion report prepared by the participating countries (Comoros, Kenya, Madagascar, Mauritius, Mozambique, Reunion, Tanzania, Seychelles, South Africa) for the South West Indian Ocean Fisheries Project*. Unpublished Report. http://www.swiofp.net.

Marsac, F., Fonteneau, A. and Michaud, P. (2014*). L'or bleu des Seychelles: histoire de la pêche industrielle au thon dans l'océan Indien*. Marseille

Mkare, T.K., von der Heyden, S., Groeneveld, J.C. and Matthee, C.A. (2014). Genetic population structure and recruitment patterns of three sympatric shallow-water penaeid prawns in Ungwana Bay, Kenya, with implication for fisheries management. *Mar. Freshwater Res.* 65, 255-266

Munga, C., Ndegwa, S., Fulanda, B., Manyala, J., Kimani, E., Ohtomi, J. and Vanreusel, A. (2012). Bottom shrimp trawling impacts on species distribution and fishery dynamics; Ungwana Bay fishery Kenya before and after the 2006 trawl ban. *Fisheries Sci.* 78(2), 209-219

Munga, C.N., Mwangi, S., Ong'anda, H., Ruwa, R., Manyala, J., Groeneveld, J.C., Kimani, E. and Vanreusel, A. (2013). Species composition, distribution patterns and population structure of penaeid shrimps in Malindi-Ungwana Bay, Kenya, based on experimental bottom trawl surveys. *Fish. Res.* 147, 93-102

Munga, C.N., Omukoto, J.O., Kimani, E.N. and Vanreusel, A. (2014). Propulsion-gear-based characterisation of artisanal fisheries in the Malindi-Ungwana Bay, Kenya and its use for fisheries management. *Ocean Coast. Manage.* 98,130-139

Oluoch, S.J. and Obura, D. (2008). Assessment of fisherfolk organizations and beach management units (BMU) in the management of fishery resources in Diani-Chale, Southern Kenya. In *Ten years after bleaching-facing the consequences of climate change in the Indian Ocean*. (eds. D.O. Obura, J. Tamelander, and O. Linden) CORDIO Status Report, Coastal Oceans Research and Development in the Indian Ocean/Sida-SAREC. Mombasa, Kenya

Planes, S., Jones, G.P. and Thorrold, S.R. (2009). Larval dispersal connects fish populations in a network of marine protected areas. *Proc. Natl. Acad. Sci. U.S.A.* 106(14), 5693-5697

Robinson, J., Guillotreau, P., Jimenez-Toribio, R., Lantz, F., Nadzon, L., Dorizo, J., Gerry, C. and Marsac, F. (2010). Impacts of climate variability on the tuna economy of Seychelles. *Clim. Res.* 43, 149-162

Robinson, J. and Samoilys, M.A. (2013). *Reef fish spawning aggregations in the Western Indian Ocean: Research for Management*. WIOMSA/SIDA/SFA/CORDIO. WIOMSA Book Series 13

SADC (2008). *Study and analysis of the IUU fishing situation in the SADC region and an estimate of the economic, social and biological impacts*. Southern African Development Community. Cape Town: Fishing SI

Samoilys, M., Domingue, G., Kariuki, J., Payet, R., Hersi, A. and Mohammed, A. (2007). *Application of the Global List of irresponsible fishing vessels as a tool to combat Illegal Unregulated and Unreported Fishing in Eastern Africa*. IUCN. Kenya

Swaleh, K., Kaunda-Arara, B., Ruwa, R. and Raburu, P. (2015). Ecosystem-based assessment of a prawn fishery in coastal Kenya using ecological indicators. *Ecol. Indic.* 50, 233-241

UNEP (2014). *Welcome to the Nairobi Convention*. http://www.unep.org/nairobiconvention/, accessed 13 May 2014

van der Elst, R., Everett, B., Jiddawi, N., Mwatha, G., Afonso, P.S. and Boulle, D. (2005). Fish, fishers and fisheries of the Western Indian Ocean: their diversity and status. A preliminary assessment. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*. 363, 263-284

van der Elst, R.P., Groeneveld, J.C., Baloi, A.P., Marsac, F., Katonda, K.I., Ruwa, R.K. and Lane, W.L. (2009). Nine nations, one ocean: A benchmark appraisal of the South Western Indian Ocean Fisheries Project (2008–2012). *Ocean Coast. Manage.* 52, 258-267

van der Elst, R.P. and Everett, B.I. (2015). *Offshore fisheries of the Southwest Indian Ocean: their status and the impact on vulnerable species* . Special Publication No 10. Durban: South African Association for Marine Biological Research

van der Elst, R.P. (2015). Vulnerable teleost fishes: A review of fisheries impacts on threatened species in the Southwest Indian Ocean. In *Offshore fisheries of the Southwest Indian Ocean: their status and the impact on vulnerable species* (eds. R.P. van der Elst and B.I. Everett) Special Publication No 10. Durban: South African Association for Marine Biological Research

Wanless, R. (2015). Seabirds: A review of status, distribution and interaction with fisheries in the Southwest Indian Ocean. In *Offshore fisheries of the Southwest Indian Ocean: their status and the impact on vulnerable species* (eds. R.P. van der Elst and B.I. Everett) Special Publication No 10. Durban: South African Association for Marine Biological Research

WIOMSA (2010). *About Us*. http://www.wiomsa.org/index.php?option=com_content&view=article&id=48&Itemid=63, accessed 09 May 2014



22
Mariculture

Aviti Mmochi

Opposite page: Sea cucumber pens, village-based aquaculture of sea cucumbers in Tampolove, southwest Madagascar. © Garth Cripps.

INTRODUCTION

Aquaculture is the cultivation of aquatic animals and plants in natural or controlled marine or freshwater environments, whereas mariculture is restricted to marine and estuarine (brackish) waters. On a worldwide scale, aquaculture is a fast-growing industry, showing a 12-fold increase between 1980 and 2010, or average annual growth of 8.8 per cent (FAO 2012). Recent statistics show that growth has slowed, with food fish annual production rates decreasing from 9.5 per cent (1990-2000) to 6.2 per cent (2000-2012) (FAO 2014). World production through aquaculture increased to 90.4 million tonnes in 2012 (66.6 million tonnes food fish and 23.8 million tonnes aquatic plants; FAO 2014) with about 50 per cent of production originating from mariculture (Figure 22.1). This is in stark contrast with the global levelling off in harvests from capture fisheries, at about 80 million tonnes per year since the mid 1990's (FAO 2014).

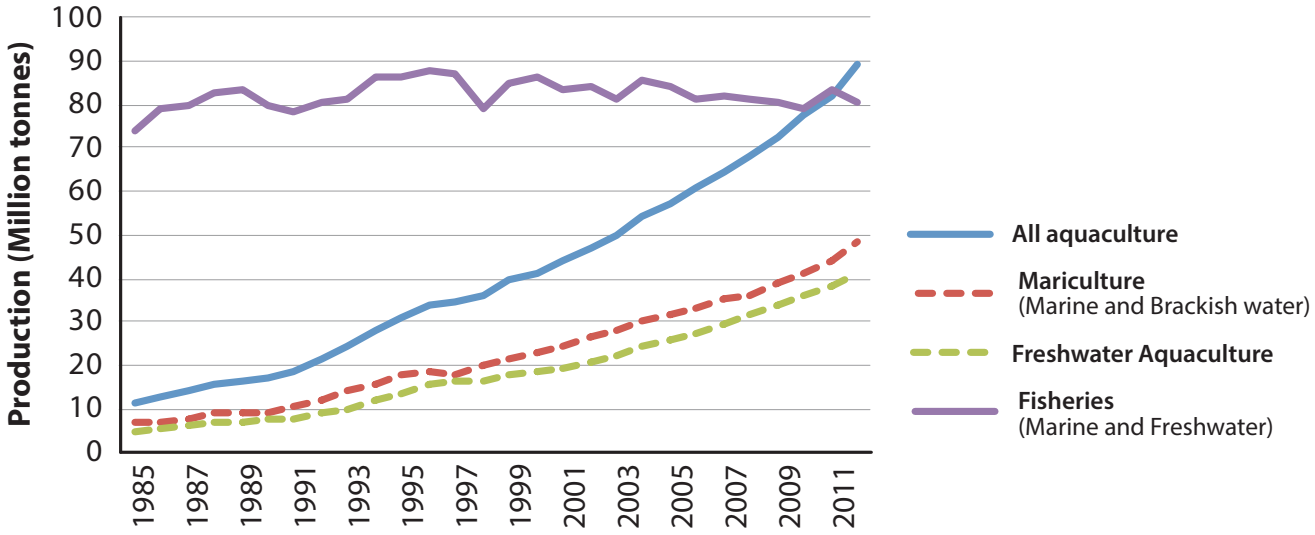


Figure 22.1. Growth in world production by capture fisheries compared to aquaculture between 1985 and 2012 (FAO 2013).

The FAO categorizes aquaculture production by 'inland waters' (such as lakes with their floodplains, reservoirs, rivers, wetlands and coastal lagoons) and 'marine areas'. In this study, the FAO categories are followed, whereby all aquatic plants and animals cultured in marine areas (marine and brackish waters, but excluding inland waters) are considered mariculture products. Production statistics are submitted annually to the FAO by the governments of member countries; these statistics are summarized on an online database (see www.fao.org), from where it can be accessed as summaries of production figures by species, areas or time units. As for fisheries data (see Chapter 21) the FAO aquaculture summaries are based on 'official' statistics, which may exclude the production of smaller mariculture initiatives, or those in remote areas. Data from these initiatives may either not be available (for example, not incorporated in country reports submitted to the FAO) or may have been misreported under categories for capture fisheries, particularly if based on export data or originating from local fish landing sites or markets. Thus production tonnages are indicative only, and underestimate actual tonnages.

World mariculture production in 2012 was 53 million tonnes, of which aquatic plants (mainly seaweeds; wet weight) made up 44 per cent, followed by mollusks (28 per cent), various groups of finfish (23 per cent) and crustaceans (7 per cent) (Figure 22.2). Asian countries dominated mariculture production (90 per cent), whereas African countries contributed only 0.4 per cent or 0.18 million tonnes (Figure 22.3a). Egypt is by far the largest producer of farmed fish in Africa (0.88 million tonnes in 2012), but most farming occurs in inland waters around the Nile, for tilapia and mullet. Excluding data from Egypt, Tanzania (including Zanzibar) produced 89 per cent of mariculture products in Africa in 2012, mainly seaweeds (Figure 22.3b). Red seaweed *Eucheuma denticulatum* makes up the bulk of cultured seaweed in Tanzania, whereas *Kappaphycus alvarezii* and *K. striatum* are also farmed (Msuya and others, 2014); the market price of dried seaweed remains low at 0.17 US$/kg (Bryceson and Beymer-Farris 2011). Other SW Indian Ocean countries among the eight highest mariculture producers in Africa were Madagascar (4 per cent; mainly tiger prawn *Penaeus monodon*) with a value of approximately US$ 65 million in 2006 (Iltis and Ranaivoson 2011), and Mauritius (0.3 per cent; mainly red drum *Scyanops ocellatus*).

Growth of mariculture provides many social and eco-

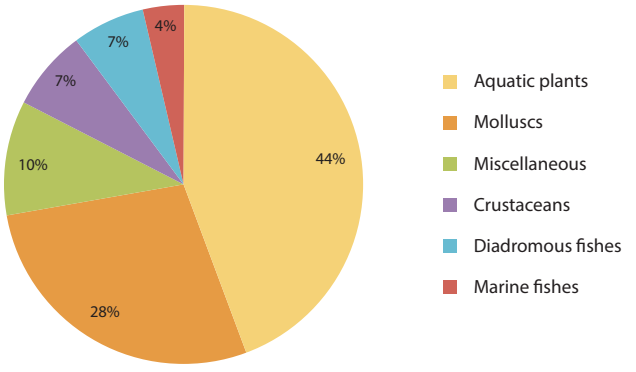


Figure 22.2. World mariculture production by culture group in 2012 (FAO 2013).

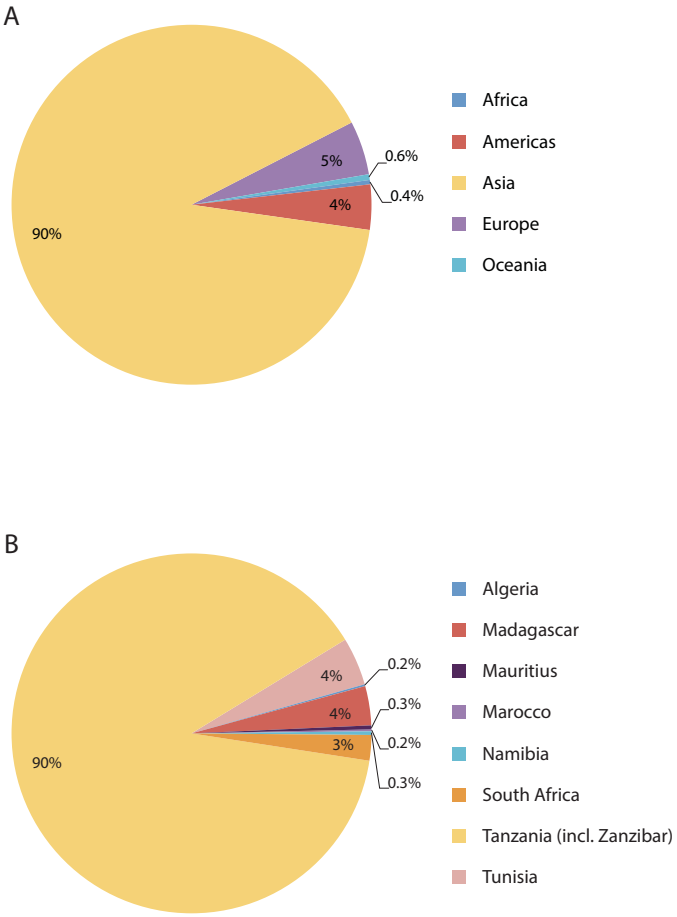


Figure 22.3. Mariculture production in 2012 **(A)** by continent, and **(B)** by the eight leading African countries.

nomic opportunities as well as challenges (HLPE 2014). Benefits to local communities may include better food security, increased income and employment opportunities (Troell and others, 2011). Apart from producing affordable food fish for local consumption, it may generate revenues from sales on national and international markets. Mariculture production in the region doubled between 2000 and 2003, but with the exception of seaweed in Tanzania, it has since remained relatively stable at 24 000 tonnes, with production of marine fish and prawns declining in some countries (Troell and others, 2011). Despite the inconsistent performance, there appears to be a general feeling of optimism around future prospects (Troell and others, 2011).

This chapter describes mariculture in Tanzania, Kenya, Mozambique, Madagascar, Mauritius, Seychelles and the French Indian Ocean territories of Reunion and Mayotte. There are no reports of mariculture in Comoros and Somalia and most mariculture activities in South Africa are restricted to the south and west coasts, outside the FAO statistical area 51 (Western Indian Ocean) addressed in this chapter. The emphasis is on the history and development of the mariculture sector, species groups cultured and production trends. The environmental, social and economic impacts of mariculture are highlighted together with successes, gaps and challenges.

MARICULTURE PRODUCTION BY COUNTRY

Tanzania

Mariculture production in Tanzania is dominated by the seaweed sector (Msuya 2013), which has shown continued growth since the early 1990s (Figure 22.4). *Eucheuma* and *Kappaphycus* are red seaweeds produced for the high-value extract known as carrageenan, which is used as a stabilizer, emulsifier or thickening agent in food additives, cosmetics and pharmaceutical products (Bryceson and Beymer-Farris 2011). In 2013, a wet weight of 157 386 tonnes of seaweed was reported to the FAO, ranking Tanzania as the 9th largest exporter of aquatic plants in the world at 0.66 per cent (FAO 2014). Seaweed contributes 7.6 per cent of Zanzibar GDP, 2nd after cloves (47 per cent) among cash crops in 2009 (National Bureau of Statistics 2011). However, the seaweed is sold raw to processors in Europe and America with very little value-adding taking place in Tanzania.

Seaweed farming trials using the local strain of *Eucheuma* started in Zanzibar in the 1970s. Since then, there have been many mariculture initiatives, including governmental, private sector and by NGOs or donors, to grow and improve the sector (Table 22.1). Commercial farming using seed and technology transfer from the Philippines expanded during the 1990s in Zanzibar, followed

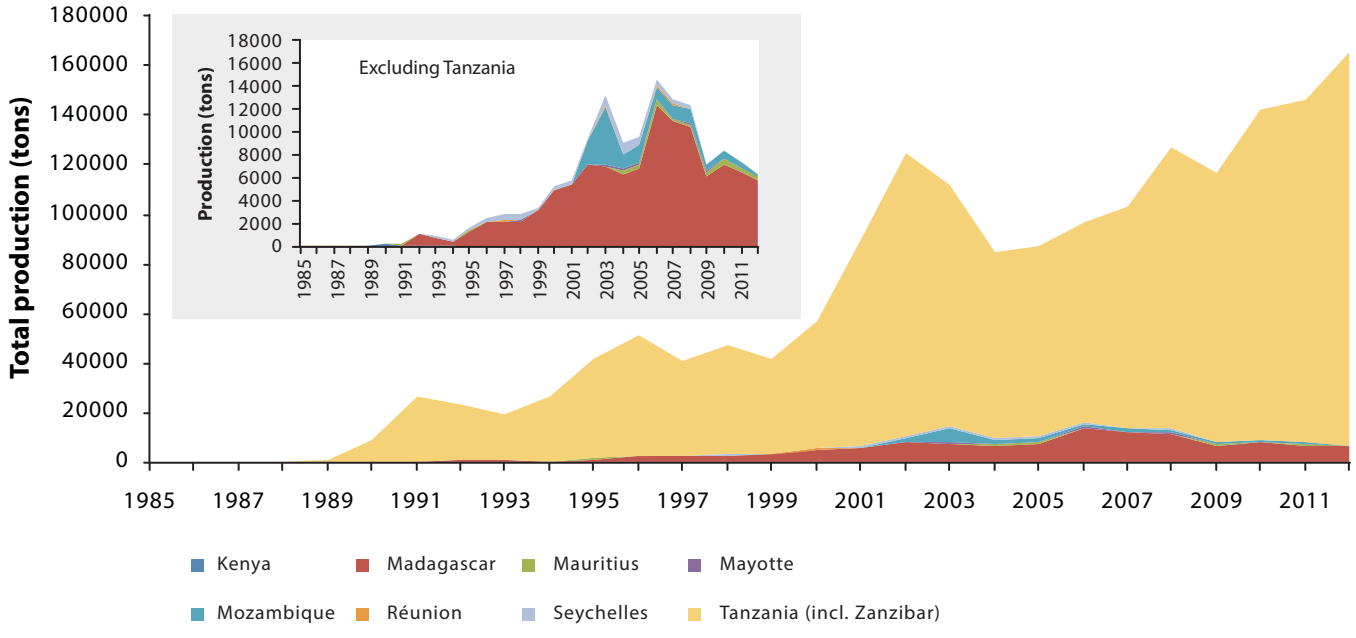


Figure 22.4. Total reported mariculture production in the SW Indian Ocean between 1985 and 2012.

Table 22.1. A chronology of major advances in mariculture in Tanzania.

1980s	• Seaweed culture experiments • Research on cage culture of rabbit fish (*Siganus*)
1990s	• Commercial seaweed farming by private sector starts in Zanzibar • Seaweed farming introduced to Tanga and Bagamoyo (1992-1994) and to Mtwara, Lindi, Mafia and Kilwa (1995 - 1996) • Integrated mariculture and biofiltration experiments at Makoba
2000-2005	• Mariculture project on milkfish farming • Workshop on "Advances in mariculture" Zanzibar in 2004 • Crab fattening experiments • Shellfish farming piloted • Pilot studies of small-scale / commercial finfish culture in ponds
2006-2014	• Shellfish, pearl farming and entrepreneurship develops • Initiatives to add value to seaweed industry • Sea-cucumber farming experiments in Pemba • Production of prawn postlarvae in 2009 • Sponge farming experiments in Zanzibar • Experiments with marine tilapia farming in Zanzibar • Tilapia acclimatization for mariculture

by introduction of the technique at mainland sites (Figure 22.5). Some 88 per cent of the people involved in seaweed farming in Zanzibar are women. The sector provides local women with an opportunity to contribute to their households and local economies.

Seaweeds are cultured in shallow subtidal areas over sandy bottoms along the coast. An off-bottom culture method has also been introduced, in which cuttings are tied to lines strung above the sea bottom. This method reduces seaweed die-offs caused by tidal and seasonal fluctuations in water quality, and works well at Pemba Island (Msuya 2011). Seaweed is fast-growing and crops are harvested every 6 weeks. It is dried, and the unprocessed product is sold to middlemen who export it. Dried seaweed can be stockpiled to take advantage of market fluctuations, but villagers depend strongly on the income generated and therefore tend to sell immediately after drying. Seaweed production is irregular because weather changes sometimes lead to die-offs, or international markets become saturated, affecting the prices that can be obtained. The die-offs often occur during the long rain season, when farmers can lose up to 3 out of 8 harvests that make up an annual cycle (Msuya and others, 2007).

There remains a large disparity between the low prices paid to farmers for dried seaweed in Tanzania (approx. 0.17 US$/kg) and the high market price for refined carrageenan (30-50 US$/kg) for *E. denticulatum* (Bryceson and Beymer-Farris 2011). To increase bargaining power and achieve higher prices for dried seaweed, women farmers are collectively organizing themselves through cooperatives (a good example being the Chole Society for Women's Development, on Mafia Island). Some value-adding in Tanzania is achieved at a small scale, for instance through the development of cosmetics and foodstuffs. Processing facilities for carrageenan have also been suggested by Zero Emissions Research and Initiatives and Zanzibar Seaweed Cluster Initiative (Msuya 2011) to increase value, through direct sale and export of carrageenan to international markets.

Threats from seaweed farming are often aesthetic, especially where farms are sited along the lower fringe of the intertidal and shallow subtidal, particularly in Zanzibar, in areas where tourism generates most income. The eco-

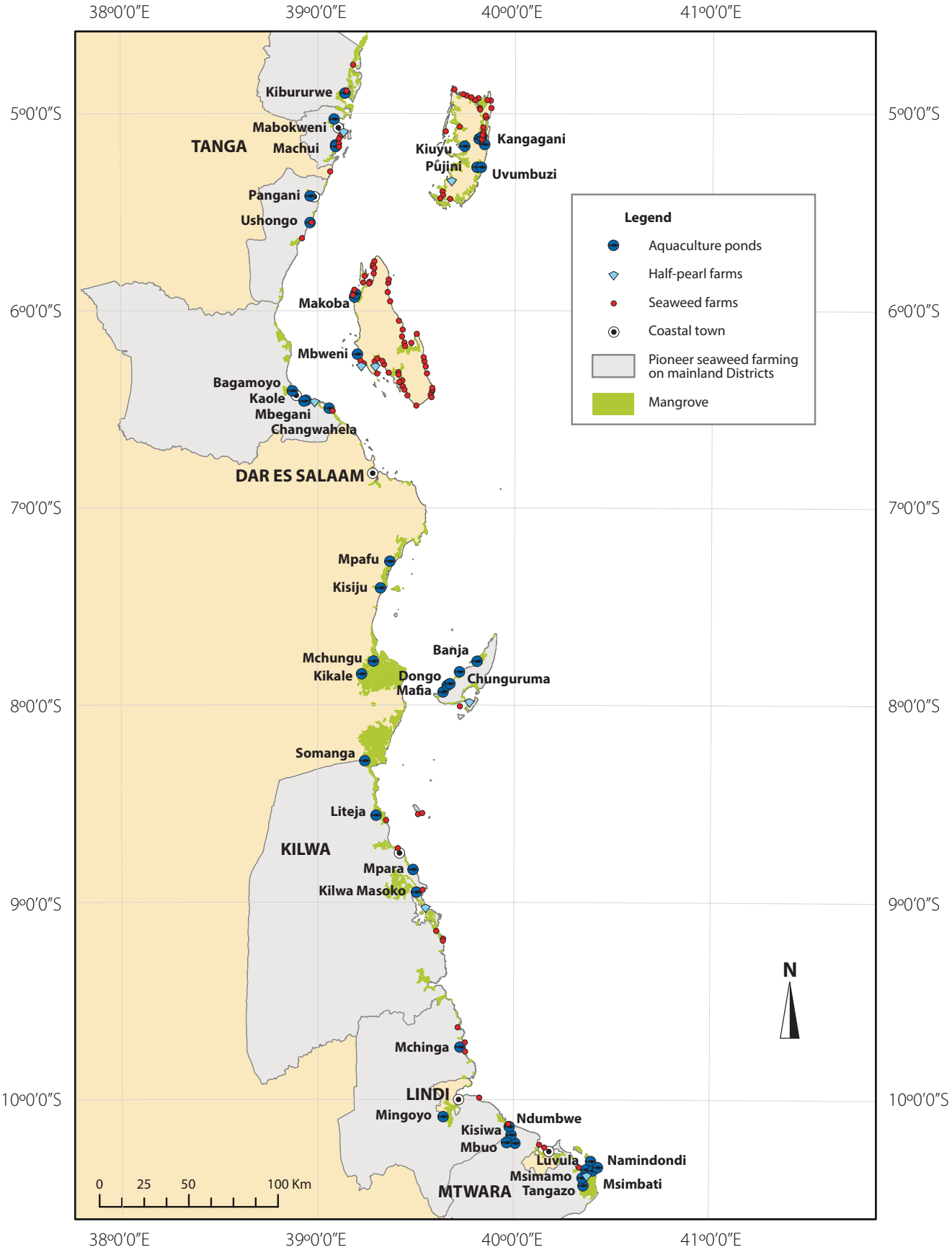


Figure 22.5. Map of the Tanzanian coast showing villages practicing mariculture of finfish, shellfish/half pearls and seaweeds.

BOX 22.1 COMMUNITY-BASED SEA CUCUMBER AND SEAWEED CULTURE IN SOUTHERN MADAGASCAR



Seaweed farming, Lambaora, southwest Madagascar. © Garth Cripps.

Sea cucumbers (*Holothuria scabra*) and red "cottonii" seaweed (*Kappaphycus alvarezii*) are well-suited to Madagascar's extensive shallow coastal lagoons, where simple production methods can be used at low running costs. Farmers require minimal initial training, and importantly, farming methods cause negligible adverse environmental impacts. Sea cucumbers (known as trepang after processing) are in high demand as a delicacy and health food on Asian markets, while red seaweed is widely used in food and cosmetics industries as a texturing agent. Nevertheless, the lack of technical and marketing skills were major obstacles to the development of aquaculture in the isolated villages of southern Madagascar. Blue Ventures, a science-led social NGO, worked with the the University of Toliara's Marine Science Institute (IHSM), local seafood exporter Copefrito and aquaculture company Indian Ocean Trepang (IOT) to establish a model community-based aquaculture hub in southern Madagascar. The group collaborated to provide assured access to markets, develop hatchery technology and supply, and assist with start-up costs. Training programmes helped to build the technical, financial and managerial skills needed by fishermen and women to manage their own aquaculture businesses – to date over 700 farmers have been trained. Community-based aquaculture with strong NGO and private investor support proved to be a success, providing new sources of income, and allowing improved access to food and education, while alleviating pressure on fisheries and marine biodiversity. (http://www.blueventures.org).

logical impact appears to be relatively mild, because seaweed culture does not require chemicals or feeds. Nevertheless, possible impacts are changes in the benthic meiofauna and microfauna, invasion of the farmed species to the wild, deforestation (resulting from the demand for wooden pegs on which to attach the ropes), introduction of plastics (tie ties and ropes) and user conflicts.

Rabbitfish (*Siganus sutor*) cage culture started in the 1980s (Table 22.1). Milkfish (*Chanos chanos*) farming started in 1998, when stray specimens that invaded ponds showed high tolerance to salinity variation. By 2007 there were an estimated 100 milkfish ponds in Tanzania (Sullivan and

others, 2010). A project conducted at Pemba Island, Mtwara and Tanga regions improved milkfish farming to producing an average of about one tonne per hectare (Mmochi 2010). Milkfish farming is now practiced in all coastal districts in Tanzania (Figure 22.5), using methods described in a milkfish culture manual (Requintina and others, 2008). Several tilapia species have shown tolerance to brackish and marine environments under experimental conditions, with fastest growth at salinities between 20 and 25 ppt (Hassan 2011, Nehemia and others, 2013). The total amount of finfish cultured in Tanzania remains unclear.

Shellfish farming started in 2004, supported by international aid organizations, and includes pearl farming and shell jewelry making activities (Table 22.1). Experimental pens for black-lipped pearl oyster (*Pinctada margaritifera*), winged pearl oyster (*Pteria penguin*), *Isognomon* species and *Anadara antiquata* were established in the intertidal in Bweleo, Fumba and Nyamanzi, in Zanzibar. Half pearls were first produced on a floating raft or line system in Zanzibar, and farms have spread to Pemba, Mafia Island and mainland sites (Figure 22.5). Around 1 000 half pearls valued at US$ 10 to 20 each were produced in 2012 (Mmochi, pers. obs.). Mud crab (*Scylla serrata*), sponge and sea cucumber farming are in an experimental phase (Vaterlaus and Bumbak 2011). Crab fattening at subsistence level occurs in several districts. The mainland Ministry of Livestock and Fisheries Development has expanded to include an aquaculture department, to enhance further development of the sector. On Mafia Island, a local company Alpha Krust Ltd constructed a 300-hectare prawn farm operation in 2003, producing prawns for the export market.

Kenya

Mariculture in Kenya has made some progress over the past decades, through development of simple innovative technologies, such as construction of inexpensive ponds, pens and cages. Culture species that need limited water management and feed low in the food chain (milkfish, mullets, mud crabs, penaeid prawns) have been studied (Mwaluma 2002, Wakibia and others, 2006, Mirera and Ngugi 2009, Mirera 2009, 2011, 2014). Prawn pond culture started in the late 1980s at Ngomeni Prawn Farm with funding from the FAO (Mirera 2011). The farm produced substantial quantities of prawns (Figure 22.6a), and provided technical assistance for the development of two satellite farms (Wampare's prawn farm and Kwetu Training Centre prawn farm) before it collapsed after donor funds were withdrawn. Milkfish and mullet were also harvested from the ponds.

Mud crab farming in Kenya can be traced back to the late 1990s, when it was introduced at Kwetu Training Centre (close to Mombasa) as a livelihood and mangrove conservation tool. Some level of success was achieved by introducing mud crabs to local communities, although farming was hindered by a lack of knowledge of their biology and unreliable funding (Mirera 2011). Juvenile and sub-adult crabs for grow-out are collected in intertidal areas, and sold to farmers at lower rates than market size crabs. Culture systems comprise mainly floating and dive-in cages, or pens made from mangrove poles (Mirera 2014).

Oyster culture at Gazi Bay and Mtwapa creek in the 1990s resulted in the production of 10 million oysters (*Crassostrea cucullata*), but the project was discontinued because of a lack of markets for the product. Seaweed culture initiatives at Gazi Bay and Shimoni, based on floating raft technology brought across from Tanzania, suffered a similar fate.

Despite some growth in the sector, mariculture in Kenya has not realized its economic or ecological potential, because of several reasons: conflicting government policies; impact of donor driven conservation projects; lack of capital investment; lack of access to international markets; and limited technological expertise. Most mariculture produce over the last decades were not reflected in national production statistics. Harvests were mainly for subsistence and sale to tourist hotels and restaurants (Mirera 2011). The Government has promoted mariculture of prawns, finfish and crabs (KMFRI 2010), and in 2012 the World Bank approved US$ 35 million for the Kenya Coastal Development Programme (KCDP) including aquaculture development (www.un-foodsecurity.org).

Mozambique

Mariculture in Mozambique has a chequered history, despite the potential competitive advantages of a long coastline and climate ranging from sub-tropical in the south to tropical in the north (Omar and Hecht 2011). Industrial scale prawn farming was first tried in the late 1980s, when the "Pilot Project for Coastal Shrimp Aquaculture" was set up by the UNDP and government and executed with FAO technical assistance. The farm near Maputo produced yields of 2.5 tonnes per hectare per year of *Penaeus indicus* during the project lifetime, and laid the foundation for the development of culture technologies

BOX 22.2. SEED PRODUCTION AND FISH STOCK PROPAGATION



Sea cucumber pens, village-based aquaculture of sea cucumbers in Tampolove, southwest Madagascar. © Garth Cripps.

Seed production is a major hurdle for the development of mariculture in the SW Indian Ocean. Madagascar is a pioneer country in holothurian aquaculture with a research programme that started in 1999, leading to the creation of a commercial hatchery, Holothurie SA (MHSA) (Rougier et al. 2013). The availability of *H. scabra* locally solves the need for the communities to invest in a hatchery that requires a considerable technical knowhow. Once the source of juveniles is secured, holothurian farming (the grow-out of juveniles in sea pens in natural lagoon habitat) requires an acceptable initial investment, no feeding or nutrient input, and little supervision from farmers other than in safeguarding stocks from environmental disturbances, predation and poaching. Community groups purchase juveniles from MHSA at a price subsidised by project donors, and are responsible for growing the juveniles to market size (minimum of 350 g). Market-ready adults are then sold back to MHSA for processing and export.

Acclimatization and growth performance studies of Rufiji tilapia (*Oreochromis urolepis*), Pangani tilapia (*O. pangani*) and *Tilapia zillii* in a marine environment have shown faster growth in brackish and seawater compared to freshwater in Tanzania. *O. urolepis* were made to spawn at different salinities, and fry were grown to fingerlings. Best reproduction performance was achieved at a salinity of 15, while growth performance peaked at 25. Hatchery development to produce acclimatized tilapia for farming in brackish and seawater is being considered. Other hatcheries for fish (red drum cobia) are located in Reunion and Mayotte.

Several private prawn farms in Madagascar have their own hatcheries, for instance, Aquamas farm at Soalala produces its own *P. monodon* post-larvae for on-growing (maximum of 20-30 million post-larvae per month). Prawn hatcheries also operated at Aquapesca in Mozambique and Alphakrust Shrimp Farm on Mafia island in Tanzania, but their present status is unclear. Two prawn hatcheries in Seychelles operated for nearly 20 years, but production ceased in 2008.

(Rafael and Ribeiro 2002). It was privatized in the mid-1990s, and more private investment in industrial scale prawn farming at Quelimane followed during the same period (Hecht and others, 2005). Two industrial scale farms were operational in 2008 namely Aquapesca at Quelimane and Sol & Mar at Beira, while a third, Indian Ocean Aquaculture at Pemba, was dormant. Total prawn production in 2010 was estimated to be around 1 200 tonnes (Omar and Hecht 2011), about double the quantity reflected in the national statistics reported to the FAO in that year (Figure 22.6b).

The Mozambique action plan for the Reduction of Absolute Poverty (2001-2005) promoted small-scale mariculture (or coastal aquaculture) as a means to contribute to food and nutritional security and socio-economic development. In spite of this, small-scale mariculture has not really been successful (Ribeiro 2007), and is presently limited to scattered prawn, fish and seaweed farming operations. Small-scale prawn farms of 4-6 ha produce between 250 kg to 10 t of tiger prawn *P. monodon* per year under extensive conditions in Beira and Angoche areas. Fish farming in Nampula produce mullet and milkfish in polyculture with tilapia, where ponds are supplied by tidal exchange and fish rely on natural productivity for food. Seaweed farming (*Eucheuma* and *Kappaphycus*) in Cabo Delgado and Nampula is promoted by NGOs as part of a wider programme of assisting coastal communities. Marketing the dried product (approximately 160 tonnes per year) remains problematic because of the distance to the buyers in Zanzibar, but surveys have shown extensive suitable areas for bottom culture by peg and line method in Nampula.

Marine fish farming in cages for dusky kob (*Argyrosomus japonicas*) and cobia *(Rachycentron canadum*) were initiated in 2009 in Pemba Bay by Aqua Pemba Lda. Currently the project is fully vertically integrated with laboratory, hatchery, rearing pens and processing facilities (http://www.hik.co.za/).

Madagascar

Commercial prawn farming for *P. monodon* commenced in the early 1990s and has received regular financial, technical and infrastructure support from NGOs especially Blue Ventures and foreign investors (Robinson 2011). Productivity exceeded 8 000 tonnes per year between 2006 and 2008, but collapsed to 3 000 tonnes in 2009 (Figure 22.6c), when the combination of increased international competition, declining shrimp prices and rising cost of energy and fishmeal resulted in a severe crisis (Iltis and Ranaivoson 2011). Production has since recovered. Pond farming takes place behind mangrove areas along the northwest Madagascar coast where mangroves have come under threat through erosion, siltation and related effects from ponds constructed on salt flats. An aquaculture plan guides the development of the sector, and promotes small-scale commercial and family-based prawn culture. It includes protocols for identifying appropriate culture sites and biosecurity (Shipton and Hecht 2007).

Seaweed (*Eucheuma* and *Kappaphyccus*) farming was introduced after 1998 and is the second largest contributor to mariculture production in terms of income after prawns (Figure 22.6c). It is popular in northeastern Madagascar, where most farmers are women. Dried seaweed is exported. Some environmental effects are deforestation for timber to make drying platforms and for the hard wood stakes onto which seaweeds are attached, introduction of the farmed species, and shading of the substrate. Culture of the blue-green alga *Spirulina* is a new activity being trialed in southwest Madagascar.

Culture of sea cucumber (*Holothuria scabra*) started in 1999 through funding and scientific cooperation between the government and Belgian Universities (Eeckhaut and others, 2008, Erikson and others, 2012). Between 1999 and 2007 the project developed technology and facilities (hatchery, nursery site and sea pens) at Toliara to produce juveniles and grow them to commercial size. Farms are mostly on the southwest coast, where local communities rear sea cucumbers while NGOs and a start-up company condition and export the boiled and dried product (Iltis and Ranaivoson 2011). Farms have expanded since 2010, with production in weight and income rising steadily, except for the effect of cyclone Haruna in 2013 (Rougier and Razafinama 2013).

Overall, mariculture in Madagascar is recently-established, with most production systems post-dating the 1990s. Other than prawn farming, many activities have not moved beyond the pilot phase, despite suitable natural conditions and technically successful results (for instance oysters, milkfish, *Artemia*). Plausible explanations include economic isolation, insufficient training, and degraded road infrastructure (Iltis and Ranaivason 2011).

Seychelles

Prawn farming in Seychelles was first established on Coetivy Island in 1989 by the Islands Development Company

Ltd and managed by the Seychelles Marketing Board. The farm comprised two hatcheries and around 200 ponds with a total area of 80 hectares, and at its peak in 2004 it produced about 1 200 tonnes of *P. monodon* (Figure 22.6d). Production had declined to just 400 tonnes by 2007, and ceased altogether in late 2008, citing high operational costs and insufficient post-larvae numbers for stocking grow-out ponds as the primary reasons (Lesperance 2011).

Pearl oyster farming started in 1995 and continues at Praslin in the Curieuse Marine National Park. Oysters are suspended on ropes attached to long lines or are inserted into the pouches of "kangaroo nets" (Hecht 2013). The quality of the pearls harvested has improved over the years, and some of them are used as jewelry on local markets whereas the remainder is exported to Japan and Australia (Central Bank of Seychelles 2006). Annual production statistics are not reported to the FAO.

Mariculture development in Seychelles is constrained by a poor understanding of the sector, reliance on capture fisheries for protein supply, lack of investment and scientific or technical capacity, and the absence of a properly defined legislative and regulatory framework (Lesperance 2011).

Mauritius

Mariculture in Mauritius dates back to French colonial times when juvenile marine finfish were collected from the wild and fattened in cages or pens (Lesperance 2011). A mariculture programme at the Albion Fisheries Research Centre developed innovative technologies during the 1990s, but private sector and government support were modest. A cage-culture farm in the Mahebourg lagoon has been in operation since 2001, and produces red drum in circular floating cages. The farm employs about 65 workers, and produced about 500 tonnes of fish in 2010 (Figure 22.6e). Farmed fish are consumed locally or exported. The culture of other species, such as seabream (*Rhabdosargus sarba*), has also been tried in cages. A mariculture sector development plan (2007) identified 21 sites for cage aquaculture; though few of these have been exploited because of a lack of investment.

Reunion and Mayotte

Reunion and Mayotte islands have aggressively pursued mariculture development over the past two decades, to offset undersupply from local fisheries (Lesperance 2011). These developments were spearheaded by the "l'Association Réunionanaise de Développement de l'Aquaculture" (ARDA) and AQUAMAY (the Mayotte Aquaculture Development Association) with support from IFREMER. Three species are farmed, namely red drum, goldline seabream, and cobia, and by 2008 several farms produced cultured fish on a commercial basis. Production trends for the two territories (Figure 22.6f) highlight a recent decline in finfish culture in Reunion. ARDA and AQUAMAY have some of the most advanced technologies in the region in seed and feed production and cage culture.

ENVIRONMENTAL IMPACTS OF MARICULTURE

Potential environmental impacts from mariculture expansion are in general determined by the characteristics of the culture systems (species, intensity, technology etc.) and site characteristics including nature of the seascape and landscape, waste assimilating capacity, waste loadings, other users, etc. (Troell and others, 2011). Collection of seed from the wild may put pressure on wild populations, or alter community structure by removals of new recruits (Ishengoma and others, 2011). Many high-end farmed species such as prawns and salmon are carnivorous, requiring more protein than herbivores and omnivores. Using fishmeal to feed farmed species may stimulate fishers to harvest more - usually species lower down the food chain. Instead of reducing fishing pressure on wild stocks, mariculture can therefore potentially increase it, through a high demand for fishmeal. Between 2007 and 2012, fish used as animal food remained fairly constant, ranging between 19.9 and 24.5 million tonnes (FAO 2014). Nevertheless, finding food for farmed species (whether for fish or land animals) is a global challenge, where interconnections between mariculture, fisheries, crops and livestock farming can act as impediments or opportunities for increased resilience (Klinger and Naylor 2012, Troell and others, 2014).

Clearing mangrove areas to build ponds for finfish mariculture is still practiced, and if left uncontrolled, may lead to loss of mangrove common property, and a reduction in ecosystem services (for instance nursery and filtration functions). Mangrove cuttings are used as pegs to hold lines, poles to construct drying racks for seaweed farming, or to construct cages for crab farming. The extent of clearance of mangrove areas in the region is presently unknown, but removal of mangroves to accommodate prawn farms

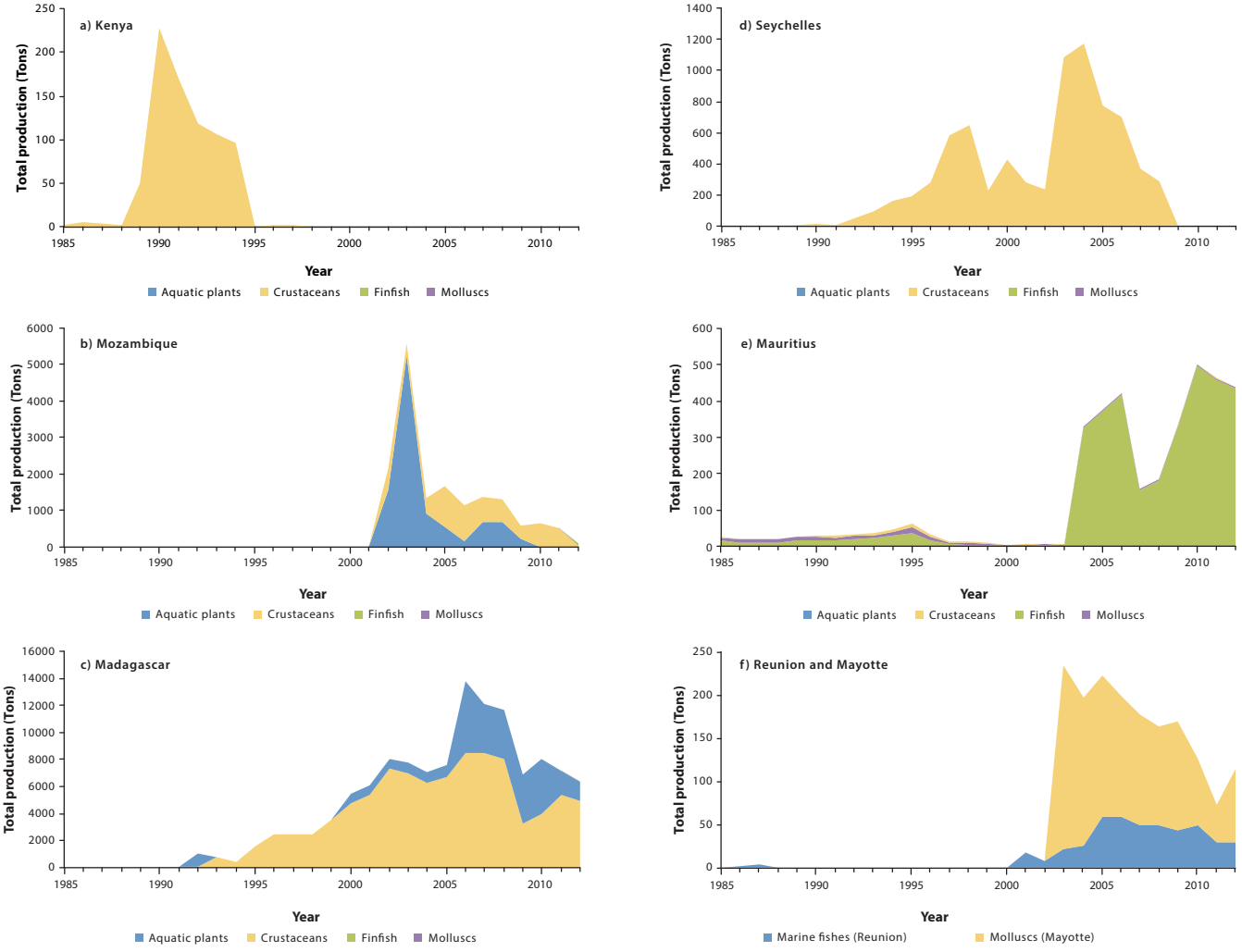


Figure 22.6. Mariculture production by species groups for the period between 1985 and 2012 for Kenya, Mozambique, Madagascar, Seychelles and the French territories of Reunion and Mayotte.

has stimulated controversy in Rufiji (Tanzania) and Quelimane (Mozambique).

Pond mariculture development in the intertidal can cause eutrophication and pollution through effluents of wastes, chemicals and pharmaceuticals, especially where farming takes place on a large scale, and controls over effluents are inadequate. Farming systems can give rise to spreading of diseases or antibiotic-resistant bacteria to other farms and wild stocks during water exchange (Gräslund 2004). Moving genetic materials between water bodies may introduce alien species and threaten indigenous populations. There have been reports of invasive species such as *Hypnea* and tilapia (*Oreochromis* species) in the region, mostly through aquaculture and marine transportation.

Seaweed mariculture competes with tourism for beachfront space and access routes, because neither farmers nor tourist operators recognize boundaries of public properties. Seaweed farms may affect aesthetics and therefore the marketing potential of popular tourist areas, whereas hotels may impede access to areas used by farmers by blocking off beachfront areas. Such conflicts can be moderated through marine spatial planning that includes broad stakeholder participation. One option is to integrate mariculture with tourism activities by making it a part of tourist attractions, for example, oyster farm tours and an annual oyster festival offered in Knysna, South Africa.

CHALLENGES TO MARICULTURE DEVELOPMENT

The UNDP classifies Mozambique (178th), Tanzania (160th), Comoros (159th) and Madagascar (155th) as having a low HDI (Indicators by Country, 2014; www.hdr.undp.org/en). This implies high poverty levels, inadequate nutrition

and health services, high adult illiteracy and a lack of trained people, technical expertise, research and education. The development of a mariculture industry within this setting is a challenge, particularly when extension systems fail to disseminate technical know-how required for farming and marketing (Troell and others, 2011). Targeted human resource or capacity development is therefore essential for the establishment of the mariculture sector.

Mariculture development may take place along different pathways, depending on the available infrastructure, capital means and technical ability of potential farmers. Extensive mariculture is based on food supply by natural resources; it is often suitable for small farms in the SW Indian Ocean region, where farmers do not have access to capital and technical skills. Intensive mariculture is based on provision of external food, and the cost of input per kilogramme of fish produced is higher; hence this system is suitable for larger, technologically-advanced investors culturing high value products for export (notably prawn or abalone farms). Whether farming uses extensive or intensive systems, or is targeted at local, tourist or export markets, it is important that robust impact assessments are undertaken, before construction is approved, to assess potential effects of farms on the environment and socio-economic systems, including food security and poverty alleviation.

Weak business skills among farmers and lack of market access place economic constraints on mariculture development. Funding agencies and NGOs can play important bridging roles. There is a clear role for the private sector in facilitating small-scale farming as a part of its strategy, through identifying new products, seeking opportunities for value adding, introducing new processing technologies and securing market access and shares (Troell and others, 2011). A good example of NGO involvement comes from southwest Madagascar, where local communities rear sea cucumbers, supported by NGOs that handle conditioning, marketing and export (Iltis and Ranaivoson 2011).

Governance systems are often opaque, with many different policies that lack coordination among ministries, or are even contradictory. A prospective farmer might need permission from ministries responsible for land, environment, water, forestry (mangroves), and fisheries. Such a protracted process discourages the development of community-based aquaculture. Improved governance systems to encourage and support prospective farmers would stimulate mariculture.

Finding a balanced trade-off between mariculture and conservation is another challenge. An Ecosystem Approach to Aquaculture (EAA, FAO 2010) is defined as "a strategy for the integration of the activity within the wider ecosystem such that it promotes sustainable development, equity, and resilience of interlinked social-ecological systems". It implies a transition from traditional piecemeal planning and decision-making to a more holistic approach of integrated and adaptive management. For example, pond mariculture can easily affect mangrove conservation and salt-water intrusions. Therefore, site selection and farming methods (including disposal of wastes from the farm) are important in determining the health of mangrove stands, and their ability to buffer the coast against rising sea levels.

Bryceson and Beymer-Farris (2011) proposed an integrated 'rights-based' and 'ecosystem' approach to address the interests of the local communities and small-scale farmers, because it combines citizens knowledge with conventional science, and will moderate underlying political-economic and social issues related to the industry. Within such a system, all stakeholders need to be consulted when coastal zone development is undertaken. The development of new technologies jointly with stakeholders is important, but projects should avoid subsidies, as these create unsustainable industries (Troell and others, 2011).

Retaining biological (or genetic) diversity can be challenging in areas where seeds are imported from elsewhere. Most cultured finfish and seaweeds are widely distributed in the SW Indian Ocean, but when they are transported between areas, they can contribute to the spread of diseases, facilitate biological invasions, or reduce genetic variability (Responsible Aquaculture Foundation 2013, Keightley and others, 2015).

CONCLUSIONS

Mariculture in the SW Indian Ocean is still in an early developmental phase, with the exception of seaweed culture in Tanzania (especially Zanzibar), where production and farming methods have grown substantially over the past two decades. The growth in seaweed farming faces some constraints related to a buyers monopoly (namely the low prices paid to farmers for dried seaweed), and therefore low economic returns. It is important that the influence of markets on seaweed mariculture development be addressed, either through establishing a strong collective bargaining position, or by adding value to products through

further processing before export.

There have been numerous attempts by NGOs, developmental organizations and governmental research organizations in the SW Indian Ocean region to stimulate mariculture growth through demonstration projects, or establishing small farms or centers for technology transfer. Very few initiatives extended much beyond the lifetime of the projects, whereafter momentum was lost. Whereas the impediments to sustainable projects may differ (particularly the lack of skills, technology, infrastructure etc.), a common problem appears to be the remoteness of most of the SW Indian Ocean region from large urban centers and foreign markets. Without access to foreign markets, local food security is the main driver for mariculture. Where this is the case, mariculture still competes with established food production activities such as capture fishing and agriculture, instead of complementing them – after all, it is much easier to catch a fish than to culture it. A paradigm shift is therefore required at community level.

Prawn farming takes place on an industrial scale in Madagascar, Mozambique and Tanzania. Large-scale prawn farms are capital intensive, and require companies or owners with financial and technological means to succeed; their products are mostly exported. Several large farms have been operational in Madagascar and Mozambique since the 1990s (see above), but their success have been tempered by the recent (since 2008) global economic slowdown and the spread of white spot disease. Nevertheless, the model of industrial scale farms that form a node for economic activity (possibly smaller farms or related industries in their vicinity) and employment could be investigated.

Mariculture undoubtedly has high growth potential in the SW Indian Ocean over the next decade, as it starts from a relatively low base, and is generally supported by local communities, investors, NGOs and governments. The many constraints to growth mentioned throughout this chapter need to be overcome. An example of progress is provided by sea cucumber farming in southwest Madagascar, where collaboration between farmers (rearing), NGOs (technology) and business (marketing) has proved successful (see above, and in Rougier and Razafinama 2013).

Mariculture in the SW Indian Ocean region is presently at an important junction: it can either develop along a planned path supported by good governance, private sector investment, and NGO support; or it can spread unchecked, to gradually fill the gap left by decreasing returns from capture fisheries.

References

Bryceson, I. and Beymar-Farris, B. (2011). Main challenges for coastal aquaculture development in the WIO region – who are the winners and losers? In *Mariculture in the WIO Region "Challenges and Prospects"* (eds. Troell, M., Hecht, T., Beveridge, M., Stead, S., Bryceson, I., Kautsky, N., Ollevier, F. and Mmochi, A.) No 11, pp. 6-8. WIOMSA Book Series

Central Bank of Seychelles (2006). Fisheries Industry of the Seychelles: At a Crossroad. Extracted from First Quarterly Review 2006. XXIV no.1

Eeckhaut, N., Lavitra, T., Rasoforinina, R., Rabenevanana, M.W., Gildas, P. and Jangoux, M. (2008). Madagascar holothurie SA: The first trade company based on sea cucumber aquaculture in Madagascar. *SPC Beche-de-Mer information bulletin* 28, 22-23

Eriksson, H., Robinson, G., Slater, M.J. and Troell, M. (2012). Sea cucumber aquaculture in the Western Indian Ocean: challenges for sustainable livelihood and stock improvement. *Ambio* 41(2), 109–121

FAO (2010). World review of fisheries and aquaculture: Fisheries resource trends in production, utilization and trade. State of fisheries and aquaculture part 1. FAO, Rome

FAO (2012). World Review of Fisheries and Aquaculture part 1. FAO, Rome

FAO (2014). *The State of World Fisheries and Aquaculture 2014*. FAO, Rome

Gräslund, S. (2004). *Chemical use in shrimp farming and environmental implications of antibiotic pollution*. Department of Systems Ecology. Stockholm University, Stockholm

Global Food Security (2011). *World Bank Approves US$-35million for Kenya's Coastal Development*. http://www.un-foodsecurity.org/node/666

Hassan, A. (2011). *Acclimatization survival and growth rates of Pangani tilapia (Oreochromis pangani) in different salinities in Tanzania*. MSc thesis. University of Dar es Salaam

Hecht, T., Shipton, T. and Andrew, T.G. (2005). *State of Play*

Report: Capture Fisheries and Aquaculture in Mozambique. Enviro-Fish Africa (Pty) Ltd. Report. Rhodes University, Grahamstown

Hecht, T. and Shipton, T. (2007). *Coastal Mariculture Assessment Mission*. Report submitted to the Regional Programme for the Sustainable Management of the Coastal Zones of the Indian Ocean Countries (ReCoMaP)

Hecht, T. (2013). *Aquaculture in Seychelles: History, current state of play and lessons learnt. Advance Africa Management Services*. African Union Inter African Bureau for Animal Resources. www.au-ibar.org

HLPE (2014). *Sustainable fisheries and aquaculture for food security and nutrition*. A report by High Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, Rome

Iltis, J. and Ranaivoson, E. (2011). A Synopsis of Marine Aquaculture in Madagascar. In *Mariculture in the WIO Region "Challenges and Prospects"* (eds. Troell, M., Hecht, T., Beveridge, M., Stead, S., Bryceson, I., Kautsky, N., Ollevier, F. and Mmochi, A.) No 11, pp. 17-18. WIOMSA Book Series

Ishengoma, E.B., Jiddawi N.S., Tamatama, R.A. and Mmochi, A. J. (2011). Wild black-lip pearl oyster (*Pinctada margaritifera*) spat collection in Tanzania. *Western Indian Ocean J. Mar. Sci.*10 (1), 49-57

Keightley, J., von der Heyden, S. and Jackson, S. (2015). Introduced Pacific oysters *Crassostrea gigas* in South Africa: demographic change, genetic diversity and body condition. *Afr. J. Mar. Sci.* 37(1), 89-98

Klinger, D. and Naylor, R. (2012)- Searching for solutions in aquaculture: charting a sustainable course. *Annual Review of Environment and Resources* 37, 247-276

KMFRI (2010). *Process Framework Kenya Coastal Development Project*. Kenya Marine and Fisheries Research Institute. http://www-wds.worldbank.org/

Lesperance, A.D. (2011). Mariculture development in Seychelles and other Western Indian Ocean Island States: An overview of challenges and prospects. In *Mariculture in the WIO Region "Challenges and Prospects"* (eds. Troell, M., Hecht, T., Beveridge, M., Stead, S., Bryceson, I., Kautsky, N., Ollevier, F. and Mmochi, A.) No 11, pp. 19-22. WIOMSA Book Series

Mirera, D.H.O. (2009). Mud crab (*Scylla serrata*) culture: Understanding the technology in a silvofisheries perspective. *Western Indian Ocean J. Mar.Sci.*8, 127-137

Mirera, D.H.O. (2011). Trends in exploitation, development and management of artisanal mud crab (*Scylla serrata* Forsskal 1775) fishery and small-scale culture in Kenya: An overview. *Ocean Coast. Manage.* 54, 844-855

Mirera, D.O. (2014). Capture-based mud crab (*Scylla serrata*) aquaculture and artisanal fishery in East Africa – Practical and ecological perspective. PhD thesis. Linnaeus University

Mirera, D.O. (2011). Experimental polyculture of milkfish (*Chanos chanos*) and mullet (*Mugil cephalus*) using earthen ponds in Kenya. *Western Indian Ocean J. Mar. Sci.* 10, 59-71

Mirera, D.O. and Ngugi, C.C. (2009). Sustainability and income opportunities of farming milkfish (*Chanos chanos*) to local communities in Kenya: Assessment of initial trials of earthen ponds. *Western Indian Ocean J. Mar. Sci.* 10(1), 153-164

Mmochi, A.J. (2010). *Sustainable milkfish farming: Cost-effective methods to increase food supply, incomes and employment in Mtwara/Lindi, Tanga and Pemba coastal communities.* Report submitted to WIOMSA

Msuya, F.E. (2011). The impact of seaweed farming on the socioeconomic status of coastal communities in Zanzibar, Tanzania. World Aquaculture 42:3 *World Aquaculture Society Balton Rouge, LA*. 45-48

Msuya, F.E. (2013). Social and economic dimensions of carrageenan seaweed farming in the United Republic of Tanzania. In *Social and economic dimensions of carrageenan seaweed farming* (eds. D. Valderrama, Cai, J., Hishamunda, N. and Ridler, N.) pp. 115-146. Fisheries and Aquaculture Technical Paper No. 580. FAO, Rome

Msuya F.E., Buriyo A., Omar I, Pascal B., Narrain K., Ravina J.J.M., Mrabu E. and Wakibia J.G. (2014). Cultivation and utilisation of red seaweeds in the Western Indian Ocean (WIO) Region. *J. Appl. Phycol.* 26,699-705

Msuya, F.E., Shalli, M.S., Sullivan, K., Crawford, B., Tobey, J. and Mmochi, A.J. (2007). *A Comparative Economic Analysis of Two Seaweed Farming Methods in Tanzania. The Sustainable Coastal Communities and Ecosystems Program*. Coastal Resources Center, University of Rhode Island and the Western Indian Ocean Marine Science Association

Mwaluma, J. (2002). Pen culture of the mud crab *Scylla serrata* in Mtwapa mangrove system, Kenya. *Western Indian Ocean J. Mar. Sci.* 1(2), 127-133

National Bureau of Statistics (2011). Tanzania tourism sector survey report. Dar es Salaam, 46 pp

Nehemia, A., Mmochi, A. J. and Mtolera, M.S.P. (2013) Survival and growth of *Tilapia zillii* and *Oreochromis urolepis*

urolepis (Order Perciformes; Family Cichlidae) in seawater. *Western Indian Ocean J. Mar. Sci.* vol. 12, No. 1, 37-45

Omar, I. and Hecht, T. (2011). A synopsis of the current status of mariculture in Mozambique. In *Mariculture in the WIO Region "Challenges and Prospects"* (eds. Troell, M., Hecht, T., Beveridge, M., Stead, S., Bryceson, I., Kautsky, N., Ollevier, F. and Mmochi, A.) No. 11, pp. 13-14. WIOMSA Book Series

Rafael, R. and Ribeiro, F. L. (2002). Shrimp aquaculture in Mozambique. In *Shrimp aquaculture in Africa and the Middle East: the current reality and trends for the future.* Report prepared for the World Bank, Network of Aquaculture Centres. Asia-Pacific, World Wildlife Fund and Food and Agriculture Organization of the United Nations consortium program on shrimp farming and the environment

Responsible Aquaculture Foundation (2013). *Case Study of the Outbreak of White Spot Syndrome Virus at Shrimp Farms in Mozambique and Madagascar: Impacts and Management Recommendations*. Case Study #3 of a series entitled, "Lessons Learned in Aquaculture Disease Management". http://www.gaalliance.org/cmsAdmin/uploads/raf_wssv-report2.pdf

Requintina, E.D., Mmochi, A.J. and Msuya, F.E. (2008). *A guide to milkfish farming in the Western Indian Ocean region*. Western Indian Ocean Marine Science Association, Institute of Marine Sciences and Coastal Resources Center of the University of Rhode Island. WIOMSA book series, 38 pp

Ribeiro, F. (2007*). Inventory of Small-Scale Mariculture in Mozambique*. WIOMSA SUCCESS Programme

Robinson, G. (2011). Community Based Sea Cucumber Aquaculture in Madagascar. In *Mariculture in the WIO Region "Challenges and Prospects"* (eds. Troell, M., Hetcht, T., Beveridge, M., Stead, S., Bryceson, I., Kautsky, N., Ollevier, F. and Mmochi, A.) No 11, pp. 47-52. WIOMSA Book Series

Rougier, A., Ateweberhan, M., and Harris, A. (2013) Strategies for improving survivorship of hatchery-reared juvenile *Holothuria scabra* in community-managed sea cucumber farms. SPC Beche-de-mer Information Bulletin 33, 14-22

Rougier, A. and Razafinama, H. (2013). Public-private partnership on seaweed and sea cucumber community aquaculture in SW Madagascar: An overview of the success, challenges and next steps. In *Community based aquaculture in the Western Indian Ocean: Challenges faced and lessons learned* (eds. Ateweberhan, M., Hudson, J., Rougier, A., Harris, A., Jiddawi N. and Msuya, F.E.) WIOMSA Workshop conducted at Grand Palace Hotel 9 -11 December 2013, Zanzibar, Tanzania

Shipton, T and Hecht, T. (2007). *Coastal Mariculture Assessment Mission*. Report submitted to the Regional Programme for the Sustainable Management of the Coastal Zones of the Indian Ocean Countries (ReCoMaP)

Sullivan K.A., Mmochi, A.J. and Crawford, B. (2010). Food security and poverty alleviation through milkfish farming: Is Tanzania ready? *World Aquaculture*. 50-58

Troell, M., Hecht, T., Beveridge, M., Stead, S., Bryceson, I., Kautsky, N., Ollevier, F. and Mmochi, A. (2011). Mariculture in the WIO region – Introduction and some perspectives. In *Mariculture in the WIO region "Challenges and Prospects"* (eds. Troell, M., Hecht, T., Beveridge, M., Stead, S., Bryceson, I., Kautsky, N., Ollevier, F. and Mmochi, A.) No 11, pp. 1-5.WIOMSA Book Series

Troell, M., Naylor, R.L., Metian, M., Beveridge, M., Tyedmers, P.H., Folke, C., Arrow, K.J., Barrett, S., Crépin, A-S., Ehrlich, P.R., Gren, Å., Kautsky, N., Levin, S.A., Nyborg, K., Österblom, H., Polasky, S., Scheffer, M., Walker, B.H., Xepapadeas, T. and de Zeeuw, A. (2014). Does aquaculture add resilience to the global food system? *Proc. Natl. Acad. Sci. U.S.A.* 111(37), 13257-13263

United Nations Development Programme. *Human Development Reports*. http://hdr.undp.org/en

Vaterlaus, C. and Bumbak, F. (2011). Sponge Farming in Zanzibar, Tanzania. In *Mariculture in the WIO Region "Challenges and Prospects"* (eds. Troell, M., Hecht, T., Beveridge, M., Stead, S., Bryceson, I., Kautsky, N., Ollevier, F. and Mmochi, A.) No 11, pp. 55-56. WIOMSA Book Series

Wakibia, J.G., Bolton, J.J., Keats, D.W. and Raitt, L.M. (2006). Factors influencing the growth rates of three commercial eucheumoids at coastal sites in southern Kenya. *J. Appl. Phycol.* 18, 565–573

Zanzibar Revolutionary Government (2009). *The Status of Zanzibar Coastal Resources: Towards the Development of Integrated Coastal Management Strategies and Action Plan*. Department of Environment, Zanzibar



23

Social and Economic Impacts of Capture Fisheries and Mariculture

Jacob Ochiewo

Opposite page: Improvised fishmarket at landing site, Inhaca Island, Mozambique. © José Paula.

INTRODUCTION

Several countries of the SW Indian Ocean are classified as Least Developed Countries (LDC) by the UNDP, and have a low Human Development Index (HDI) (UNDP 2014). High levels of poverty and rapid population growth is pervasive, and in coastal communities along the mainland (Mozambique, Tanzania, Kenya), Madagascar and on small islands (Comoros, Seychelles, Mauritius) capture fisheries are integral to food security (see Chapter 21) and the functioning of social and economic systems. In recent years, mariculture initiatives have taken root in some areas, such as seaweed farming in Zanzibar, but at a regional scale it is still in an early developmental phase (see Chapter 22).

Fish is rich in essential nutrients for human health (in particular iron, iodine, zinc, calcium, vitamins A and B), and is especially important in the diets of infants, children and pregnant women (Satia 2011). On a worldwide scale, *per capita* fish consumption continues to rise – up from 10 kg in the 1960s to more than 19 kg in 2012, driven by higher demand from a growing population, rising incomes, and more efficient distribution channels (FAO 2014). However, the opposite trend is apparent in the SW Indian Ocean, where *per capita* fish consumption is the lowest in the world, and declining. A decrease in fish availability in coastal waters, increasing poverty levels, and a rapid increase in human population size can partially explain the decline in fish consumption in this region. Another factor is that some species with a higher economic value (namely tuna, prawns and lobsters) are exported, and these species are therefore scarce on local markets, or are prohibitively expensive (FAO 2014).

Environmental degradation caused by fishing and mariculture activities (see Chapters 21 and 22) can reduce potential harvests and food security, affect economic growth and reduce the quality of life in coastal communities. Domestic sewage and agricultural waste runoff, chemical contaminants and microbial run-off increase the risk of disease (see references in European Marine Board 2013). Food safety systems for fish products, such as Standard Sanitary Operation Processes (SSOP) and Hazard Analysis Critical Control Point (HACCP) programmes have been developed in some SW Indian Ocean countries, mainly to comply with export regulations of foreign markets. For instance, the European Union (EU) requires established risk management processes that comply with regulations on food safety and quality control. These measures may safeguard large producers against the impacts of changes to international trading standards, but ignore small-scale producers that deliver to local markets (Satia 2011).

This chapter focuses on the social and economic impacts of capture fisheries and mariculture on coastal communities, their scale and significance for employment, role in social structure, and their contributions to livelihoods.

SOCIO-ECONOMICS OF CAPTURE FISHERIES

Scale of capture fisheries

Trends in capture fisheries have been described in detail in Chapter 21. Estimating the scale of the fisheries sector is notoriously complex, because it employs both fishers and a large number of people involved in related activities, such as fish processing, distribution and marketing. Enumeration is particularly difficult at the community level, where these activities are largely informal. Consequently there are many different estimates of the numbers of artisanal fishers per country and regionally. The actual numbers are difficult to discern because of the highly dynamic nature of fishing activities and data collection limitations. The numbers of fishers can vary seasonally and between years. Fishers often have more than one occupation (for instance fishing and farming) and may switch between them depending on opportunity and perceived gain. Furthermore, women and children also participate in gathering marine organisms in the intertidal zone, but are not generally counted as fishers. Estimating the number of fishers based on the number of fishing licenses issued also has limitations because licensing requirements tend to be weakly enforced. Even where fisheries censuses are conducted, the above constraints can lead to considerable underestimations of the artisanal fisheries sector. Estimates for the comparatively smaller industrial fisheries sector tend to be more accurate than for the artisanal sector, because the number of fishing units and employment is more consistent (van der Elst and others, 2005).

Some estimates of the numbers of fishers by country and their relative importance are as follows (see Figure 23.1):

• Comoros (population est. 850 000 in 2008): There are 127 coastal villages around three habitable volcanic islands. In 2012 and 2013, traditional fisheries comprised 3 961 small wooden boats and 7 922 fishers, catching mainly demersal fishes. Artisanal fisheries, catching mostly tunas, comprised an additional 1 794 boats and 4 062 fishers. Fishing is seasonal, declining during the 'kusi' period of strong SE monsoon winds (June-August), and increasing during the 'kashkasi' period of weak NW monsoon winds (December-April) (Mahamoud 2013).

• Madagascar (population est. 21 million in 2011): Madagascar has a coastline of 5 600 km, and the maritime fisheries sector is structured into traditional fisheries (on foot or using dugout canoes), artisanal fisheries (motorised boats with engines <50 hp) and industrial fisheries (mainly shrimp trawl, with engines >50 hp). Industrial prawn fisheries had 35 vessels in 2013-2014 and about 4 500 fishers. Estimates of artisanal fishers (including traditional) are 55 000-70 000 fishers, using 8 000 boats (with engine) and roughly 22 000 canoes (Soumy 2006; WIOFish 2013).

• Mauritius (population est. 1.3 million in 2010): Mauritius (1 864 km^2) is surrounded by 150 km of fringing reef and small outer islands at Rodrigues, St Brandon and

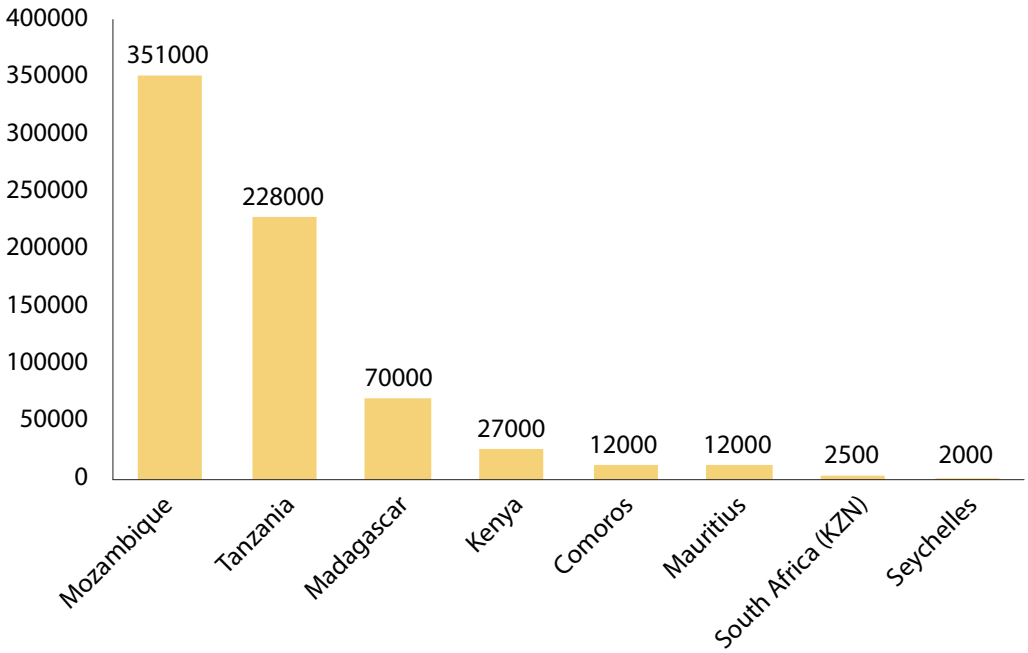


Figure 23.1. Number of commercial fishers per country, including artisanal and industrial sectors.



Figure 23.2. Fisherman scouring intertidal reef in southern Madagascar. © Johan Groeneveld.

Agalega. Fisheries provide employment to about 12 000 people (full-time fishers and employees in processing, for example freezing, salting, smoking, canning and ancillary services). There are about 4 000 artisanal fishers using >2 000 boats, and 700 industrial fishers using 15 boats. Recreational fishing lands a low volume of fish, compared to the other sectors, but 24 000 fishers using >1 000 boats was reported by Jehangeer (2006). Production is insufficient to cover local demand for fish products.

• Seychelles (population est. 88 300 in 2012): Seychelles is an archipelago of 115 tropical islands spread over 1 374 million km^2 of ocean, and is classified as a high-middle-income country. Fisheries are the economic mainstay, contributing more to GDP than tourism. Fish products contribute 90 per cent of all exports. Around 80 per cent of the tuna catch in the Western Indian Ocean is landed or trans-shipped in the Seychelles, where one of the largest tuna canneries in the world is the main employer of locals. Consequently, the Seychelles economy depends heavily on the cannery, which in turn depends on the EU export market. The industrial fleet is foreign owned, comprising purse seiners and longliners. In 2011-2014, licenses were given to 48 purse seiners and >200 longliners, from the EU, Taiwan, China and Japan. Not all vessels were active (Martín 2011). Artisanal and semi-industrial fishing employs about 1 800 local fishers using 417 licensed small boats, and most of the catch is consumed locally.

• Mozambique (population est. 25.7 million in 2015; www.ine.gov.mz): The fishing sector makes up about 1.4 per cent of GDP and has grown by ca. 13.4 per cent per year between 1997 and 2011, through diversification of the species caught. According to the 2012 artisanal fisheries census, 351 000 people are employed, of which approximately 90 per cent are artisanal fishers or involved with fish processing and marketing. Small-scale fisheries are crucial to rural economies, but face pressures from illegal and overfishing, habitat degradation and climate change effects (Benkenstein 2013). Industrial fishing by Mozambican

companies and joint ventures between the state, Japanese and Spanish companies is focused on catching prawns. Fishing ports, storage, boatyards and workshops are located in Maputo, Beira, Quelimane, Nacala and Angoche. Prawns are the principal export product, but other exports are spiny lobster, langoustine and fish (www.mbendi.com).

• Kenya (population est. 42 million in 2011): Fish production is dominated by freshwater fish from lakes (96 per cent of approx. 150 000 tonnes per year), with marine fish contributing only 4 per cent, averaging around 8 800 tonnes. Marine fisheries are divided into industrial, artisanal and recreational fishing sectors, and together they employ around 27 000 people in sea and shore-based activities. The artisanal sector employs over 13 700 fishers (Department of Fisheries 2012), and these fishers remain mainly within or near the fringing coral reef. Limited industrial

BOX 23.1 RESOURCE USER CONFLICT IN KENYA



Boats in Malindi at sunrise. © Xiaojun Deng.

An artisanal fishery has been active in Malindi Ungwana Bay for hundreds of years, and presently comprises about 3 500 fishers and 600 traditional boats that fish in nearshore waters. These fishers compete for finfish and prawn catches with a commercial trawl fishery, active since the 1970s. Trawling takes place close to the coast (within 5 nautical miles, in contravention of the fisheries act) because most prawns occur in shallow waters near river mouths. This brings them into direct conflict with artisanal fishers, when trawling damages artisanal fishing gears, or when retained fish bycatch competes with artisanal catches on local markets. The artisanal fishery targets some of the finfish species caught and discarded overboard by trawlers – these catches include juvenile fish considered to be too small or of low economic value. Therefore artisanal fishers attributed declining catches to the effects of trawling, albeit without direct scientific evidence. Trawling was banned in Malindi Ungwana Bay in 2006, and artisanal catches increased roughly two years after the trawl ban took effect. The trawl fishery resumed in 2011, subject to a Prawn Fishery Management Plan (2010). The plan restricts the fleet to four trawlers that may only operate during daytime, further than 3 nautical miles from the coast, and it includes a closed fishing season between November and March.

prawn trawling in Malindi-Ungwana Bay has resulted in conflict between artisanal and trawl fishers (see Box 23.1). Offshore resources in the Exclusive Economic Zone (EEZ) are exploited by Distant Waters Fishing Nations (DWFN) through a licensing system (FAO 2007a). Essential legislative components are in place, but governance in the offshore sector is limited to collecting licensing fees, without adequate enforcement.

• Tanzania (population est. 51 million in 2014). Marine fishing is concentrated near the mainland shore, within the fringing reef and near estuaries such as the Rufiji delta, and in territorial waters around Zanzibar, Pemba and Mafia islands. Artisanal fishers land >90 per cent of the catch, through foot-fishing and gleaning in the intertidal or using dugout canoes, or dhow-type planked boats (FAO 2007b). Many foot-fishers are women and children. Coastal fisheries are essentially unrestricted, although licenses are theoretically required (Groeneveld and others, 2014). Some species are exported, for instance octopus. Various estimates place the number of fishers between 35 000 (2009 frame survey), and 228 000 (WIOFish 2013). Industrial fisheries include a prawn trawl fishery (presently suspended) and fleets of foreign longliners and purse seiners that target tuna and tuna-like species under license in EEZ waters. Recreational fisheries are restricted to the tourism sector.

• South Africa (KwaZuluNatal province, which forms the southwestern boundary of the SW Indian Ocean; population est. 10 million in 2012): The coastline is exposed with few bays and inlets, and fisheries are less extensive than further north. Twenty-three communities are presently involved in subsistence and artisanal fishing, with approximately 2 500 people participating in five fisheries: estuarine fish traps (Kosi Bay); marine and estuarine rod and line fishing; marine rocky and sandy shore invertebrate harvesting (mainly brown mussels); estuarine sand and mud prawn harvesting (bait harvesting); and traditional spear fishing (handheld spears, at Kosi Bay) (Everett 2014, Goble and others, 2014). Together, these fisheries produced about 150 tonnes of food in 2010. Oyster-gathering in the intertidal, beach seine-netting, industrial trawling for crustaceans, and a line fishery from ski boats form the commercial sector. Between 1999 and 2008, an average of 3 800 to 5 500 people purchased recreational permits to harvest lobster, mussels and other marine invertebrates. Recreational shore angling comprised 55 000 participants in 2009, and a collective 800 000 angler days of fishing. Shore angling effort is high near urban areas, and annual catches range between 250 and 600 tonnes. At least 10 000 recreational boat fishers undertake over 30 000 recreational boat launches per year, reporting annual catches of between 400 and 470 tonnes per year. Many anglers fish in both marine and estuarine environments (Everett 2014).

Role in social structure

Social structure is defined as a system of geographically dispersed rules and practices that influence the actions and outcomes of large numbers of social actors. The importance of capture fisheries in coastal communities as a source of food and economic activity makes it a major determinant of social structure. Key actors are the fishers, mainly men in the formal fishing sectors. Women, and sometimes children, play a significant role in collecting seashells, sea cucumber and octopus in the intertidal for a few hours each day, usually during low spring tides, using hands and sticks or rods (Jiddawi and Ohman 2002). They also use mosquito nets close to the shore to catch shrimps and small fishes. In addition to collecting marine products, women play a prominent role in the processing and marketing of fish (Jiddawi and Ohman 2002; Ochiewo 2004). The 2012 artisanal fisheries frame survey estimates that about 18 per cent of the fishers are women. Other industries that support fishing are artisans that make and repair boats and fishing gear.

Middlemen and traders play an important role in the artisanal fishery, by providing opportunities for fishermen who cannot afford to buy their own gear or vessels (Jiddawi and Ohman 2002; Ochiewo and others, 2010). Middlemen usually own gear (seine or gill nets) or vessels (dhows or boats with engines), which they rent to fishers. The money obtained from the catch is typically divided into three parts: one for the middleman, one for boat and gear maintenance, and one for all fishermen on the boat, regardless of their number. Traders then distribute the fish inland. Consequently the fishermen themselves receive the smallest return.

Fisher migrations along the East African coast is centuries old, and illustrates social adaptation to a complex environment (Fulanda and others, 2009; WIOMSA 2011)(see Box 23.2). Migrations are either temporary or permanent, and patterns vary tremendously, both within and across country borders, and from a few days to several months or years. Drivers are a search for better catches and increased

income. Fisher migrations are seasonal, and associated with social and economic challenges at home and host destinations.

Contribution to livelihoods

To illustrate the dependence on marine resources, an estimated 50 per cent of Mozambicans rely primarily on fish for protein intake. In Tanzania, up to 70 per cent of protein intake may comprise fish from freshwater or marine origin. Population densities along the coast are high (>50 per cent of 21 million people in Madagascar; >20 per cent of 51 million people in Tanzania), and many of them are intimately linked to the sea for food security and jobs. Although precise data are lacking, surveys suggest that 400 000 to 700 000 fishers engaged in marine fishing in the region between 2004 and 2013 (van der Elst and others, 2005, WIOFish 2013), and considering that there is a dependency ratio of about 7: 1 (UNEP 2001), this means that almost 5 million people are directly dependent on fishing for their livelihood. Dependence on fisheries varies among countries, and is highest in Mozambique, Tanzania and Madagascar, and lower in eastern South Africa, where the economy is more diverse.

Economic benefits and contribution to GDP

On a world scale, fish production generally contributes 0.5 – 2.5 per cent of GDP (Bene and Heck 2005). However, the contribution can be much higher in developing countries, where fisheries play a more central role in economic development, poverty reduction and food security (often > 5 per cent of GDP in many west African countries; Bene and Heck 2005). Most assessments measure only the value of fish production, but if processing, trade and services are added (these mostly fall in other sectoral accounts), the overall contribution of fisheries can be much higher (WorldFish Center 2011). Estimates of the contribution of capture fisheries to GDP (without any value adding) show exceptionally high contributions for small island states (30 per cent for Seychelles and 15 per cent for Comoros) and above the world average for Mozambique (4 per cent) and Tanzania (2.7 per cent). Contributions to GDP were much lower for Madagascar (1.4 per cent), South Africa (1 per cent) and Kenya (0.5 per cent).

Fisheries governance

Fisheries co-management and the development of co-management institutions is a promising trend in the SW Indian Ocean region. Beach Management Units (BMU) have recently been established in Kenya and Tanzania to co-manage fisheries within a system with broader stakeholder participation (Oluoch and others, 2009, Japp 2012). Each BMU has jurisdiction over a geographical area that constitutes a fish-landing point, which it manages jointly with fisheries department officials. BMUs are empowered to levy fees against members for services provided, for day-to-day expenses. Although a clear addition to the social structure of fishing communities, it is not yet clear whether BMUs will succeed over the long term. In Mozambique, co-management takes place through Community Fishing Councils (CCPs).

At the international level, SW Indian Ocean countries are signatories to many fisheries agreements, such as the 1982 UN Convention of the Law of the Sea; 1995 FAO Code of Conduct for Responsible Fisheries; 2000 UN Millennium Declaration and Millennium Development Goals; 2002 Johannesburg Declaration on Sustainable Development and Plan of Implementation; 2005 Rome Declaration on Illegal, Unreported and Unregulated (IUU) fishing; and the FAO Ecosystem Approach to Fisheries (EAF). Unfortunately, most countries do not have the capacity or infrastructure to effectively implement the administrative and enforcement tasks brought by these agreements. Most governance issues, at national and regional levels, are explained in Chapter 33 and policy analyses in Chapter 34 of this report.

SOCIO-ECONOMICS OF MARICULTURE

Scale, role in social structure and contribution to livelihoods

Contrary to the global trend in which aquaculture production outstrips that from capture fisheries (FAO 2014), capture fisheries still dominate production in the SW Indian Ocean, with low dependence on mariculture. An exception is seaweed farming in Zanzibar, where the scale, role in social structure, and contributions to livelihoods is substantial. The seaweed sector in Zanzibar has grown continuously since the early 1990s, and now extends over 80 villages, where 23 000 people are involved, of which 90 per cent are women.

About 30 per cent of those directly employed on prawn farms in Madagascar are women who work in the post-harvest operations or administration (FAO 2006). Small-scale seaweed farming in southern Kenya employs

BOX 23.2. MIGRANT FISHERS – ADAPTING TO A CHANGING ENVIRONMENT



Fishing boats waiting for the tide in northern Zanzibar, Tanzania. © José Paula.

From time immemorial, migrant fishers along the coast of East Africa have followed fish movements, to increase catches and income. These fishers often cross geopolitical borders, and their movements are highly variable, the duration ranging from a few days to several years. Migrations are seasonal, mostly in synchrony with the milder sea conditions of the North East Monsoon, when sea travel in wooden boats is easier. Fisher migrations can be seen as a social adaptation to a complex environment of fluctuating resource availability. Migrations have social and economic implications for both home and host destinations. Most migrants are young men, leaving behind wives and children. They tend to increase host populations, placing pressure on village infrastructure and social functioning, through competing for fish resources and market share. Although migrant fishers save part of their earnings to send home, they may also boost host economies through increased clientele for food stuffs, accommodation, provision of social amenities, and increased revenues for Beach Management Units (BMUs) from fish levies, especially in Kenya. On the down side, local fishers may complain that fish markets are flooded with cheap fish, thus reducing the value of their own fish catch. Fisher migrations may in future be affected by shifting fish distribution patterns caused by climate change.

mainly women. Over half of the sea cucumber farmers supported by Blue Ventures in Madagascar are women; they use the income to help pay for their children's school fees and supplement their family's diet (www.blueventures.org). Mariculture therefore contributes to empowering women as owners of farms, or as important actors in the fisheries value chain and marketing; in this way they participate in societal decision-making (Hecht and others, 2006, Wakibia and others, 2011).

Chapter 22 showed that mariculture of most species in the SW Indian Ocean have not progressed past the pilot phase over the past two decades, and apart from the examples above, it only contributes little to livelihoods and economic activity. The lack of growth occurred in spite of technically successful pilot results, and apparently suitable environmental conditions for expansion, such as suitable land and warm productive waters throughout the year. Presumably the constraints imposed by the remoteness of the region, distance from markets, and absence of infrastructure and technological skills were initially underestimated. These constraints need to be overcome before mariculture can expand in scale and economic impact on a more sustainable basis. Furthermore, full development of mariculture in the SW Indian Ocean will require effective governance and strong support from governments and NGOs (Troell and others, 2011).

Marketing and export

The success of mariculture depends heavily on the availability of markets for its products as well as availability of inputs such as quality fish seed, feed and water. Products are generally perishable and require ice plants, cold storage and suitable transport facilities to ensure their quality at the point of sale. These requirements restrict farms to the vicinity of urban centers. An exception is seaweed,

which can be sold and exported dry.

The seaweed harvest in Zanzibar is dried and sold to buyers (middlemen) who deal directly with processing companies in the US, France, Denmark and Spain (Msuya 2009). The buyers have a monopoly and set low prices for seaweed. Farmers can stockpile dry seaweed to increase the price by restricting supply, but villages depend strongly on the income. Value-adding in Zanzibar through processing has often been mentioned as an option to increase the income from seaweed farming.

The principal fish marketing information services in the region are INFOPECHE (Intergovernmental Organization for Marketing Information and Cooperation Services for Fishery Products in Africa) and COMESA (Common Market for Eastern and Southern Africa). These organizations publish a directory of fish importers and exporters annually. Stringent export requirements make small-scale producers less competitive. To overcome potential marketing hurdles, producer associations can be formed to assist farmers with technical and marketing aspects. One such example is provided by the community-based culture of sea cucumbers in Madagascar, where an established network of business and research partners provide assured access to markets, hatchery technology and supply, and technical expertise (see Chapter 22; www.blueventures.org).

Gaps in capacity to engage in socioeconomics of capture fisheries and mariculture

The most obvious gap is a lack of hard information on the importance of capture fisheries and mariculture to the food security and local economies of households near the coast. There is a lack of alternatives to capture fisheries, even when catches from coastal areas are declining, and the populations are increasing.

A common trend across much of the SW Indian Ocean is to provide better boats and gear to enable artisanal fishers to exploit resources further away from the shore. These policies are, however, being promoted without adequate knowledge of deep-water fisheries. A recent study (Everett and others, 2015) suggested that deep-water crustacean stocks may be smaller than formerly thought in Kenya and Tanzania – it is important to investigate their fisheries potential before overcapitalizing on fishing fleets.

Mariculture, as an alternative to capture fisheries, has not taken root as expected, presumably because of the constraints brought by the remoteness of the region, lack of infrastructure and technical know-how. These limitations can only be overcome through a synchronised effort by governments, private operators, and NGOs. What this synchronised effort should entail, and the capacity necessary to implement it, needs to be determined first.

References

Bene, C. and Heck, S. (2005). Fisheries and the millennium development goals: solutions for Africa. *Naga, Worldfish Center Quarterly 28* (3-4), 14-18

Benkenstein, A. (2013). Small-scale fisheries in Mozambique. *SAIIA Policy briefing* 72, 1-4

BlueVentures. *Aquaculture - Pioneering viable alternatives to fishing.* http://www.blueventures.org/conservation/aquaculture.html

Department of Fisheries (2012). *Marine waters fisheries frame survey 2012 Report*. Ministry of Fisheries Development. Republic of Kenya

European Marine Board (2013). *Linking Oceans and Human Health: A Strategic Research Priority for Europe*. Position paper 19 of the European Marine Board. Ostend, Belgium. http://www.marineboard.eu/images/publications/Oceans%20and%20Human%20Health-214.pdf

Everett, B.I. (2014). *Marine and estuarine fisheries along the Kwazulu-Natal coast: An inventory and Brief Description*. Oceanographic Research Institute. Special Publication No. 11. South African Association for Marine Biological Research. Durban

Everett, B.I., Groeneveld, J.C., Fennessy, S.T., Dias, N., Filipe, O., Zacarias, L., Igulu, M., Kuguru, B., Kimani, E., Munga, C.N., Rabarison, G.A. Razafindrakoto H. and Yemane D. (2015). Composition and abundance of deep-water crustaceans in the Southwest Indian Ocean: Enough to support trawl fisheries? *Ocean Coast. Manage.* 111, 50-61

FAO (2006). *State of world aquaculture: 2006*. FAO Fisheries Technical Paper. No. 500. FAO, Rome

FAO (2007a). *Fishery Country Profile - Republic of Kenya*. FAO, Rome

FAO (2007b). *Fishery Country Profile – The United Republic of Tanzania*. FAO, Rome

FAO (2014). *The State of World Fisheries and Aquaculture*, Fisheries and Aquaculture Department. FAO, Rome. http://www.fao.org/3/a-i3720e.pdf

Fulanda, B., Munga, C., Ohtomi, J., Osore, M., Mugo, R. and Hossain, M.Y. (2009). The structure and evolution of the coastal migrant fishery of Kenya. *Ocean Coast. Manag. 52*(9), 459-466

Goble, B.J., van der Elst, R.P. and Oellermann, L.K. (2014). *UguLwethu – Our Coast. A profile of coastal KwaZulu-Natal*. KwaZulu-Natal Department of Agriculture and Environmental Affairs and the Oceanographic Research Institute. Cedara

Groeneveld, J.C., Fennessy, S.T., Everett, B.I. and Robey, J. (2014). *Rapid Assessment of the state of commercial fisheries and main species exploited in Tanzania*. Specialist Report for World Bank Project Development team; SWIOFish Project. Dar es Salaam, Tanzania

Instituto Nacional de Estatística (INE).www.ine.gov.mz

Hecht, T., Moehl, J., Halwart, M. and Subasinghe, R. (2006). *Regional Reviews on Aquaculture Development* 4. *Sub-Saharan Africa – 2005*. FAO Fisheries Circular No. 1017/4 FIRI/C1017/4. Rome

Japp, D. (2012). *Programme for the implementation of a Regional Fisheries Strategy for the Eastern and Southern Africa and Indian Ocean Region*. Kenya Fisheries Governance. http://transparentsea.co/images/e/ed/Kenya-fisheries-Governance2011-Smartfish.pdf

Jehangeer, I. (2006). Country review: Mauritius. In *Review of the state of world marine capture fisheries management: Indian Ocean* (ed. de Young, C.) FAO Fisheries Technical Paper.No. 488. Rome.

Jiddawi, N.S. and Öhman, M.C. (2002). Marine fisheries in Tanzania. *AMBIO 31*(7), 518-527

Mahamoud, K. (2013). *Summary of Fisheries in Comoros*. Ministry of Agriculture, Fisheries, Environment, Industry, Energy and Artisanat. Directorate-General for Fisheries Resources. Comoros.http://www.iotc.org/sites/default/files/documents/2014/04/SWIOFC-IOTC-2014-WoE01-13_-_Comoros.pdf

Martin, J. (2011). *Fisheries in the Seychelles and fisheries agreements with the EU – Note*. Directorate–General for internal policies of the Union Policy: Department B - Structural and cohesion policies. Brussels. http://www.europarl.europa.eu/studies

Mbendi Information Services. *Marine Fishing in Mozambique*. http://www.mbendi.com/indy/agff/fish/af/mz/p0005.htm

Msuya, F. (2009). *Development of seaweed cultivation in Tanzania: the role of the University of Dar es Salaam and other institutions*. Sustainable Aquaculture Research Networks in sub-Saharan Africa (SARNISSA), EC FP7 Project, University of Stirling, UK

http://aquaculturecompendium.wiki.zoho.com/Case-Studies.htmlf

Ochiewo, J. (2004). Changing fisheries practices and their socioeconomic implications in South Coast Kenya. *Ocean Coast. Manag.* 47, 389-408

Ochiewo, J., de la-Torre Castro, M., Muthama, C., Munyi, F. and Nthuta, J.M. (2010). Socio-economic features of the sea cucumber fishery in southern coast of Kenya. *Ocean Coast. Manag.* 53, 192-202

Oluoch, S.J., Obura, D.O. and Hussein, A. (2009). The capacity of fisherfolk to implement beach management units in Diani-Chale. *In Advances in coastal ecology: people, processes and ecosystems in Kenya* (eds. Jan Hoorweg & Nyawira Muthiga) 20, 99-110

Satia, B.P. (2011). *Regional Review on Status and Trends in Aquaculture in sub-Saharan Africa – 2010*. FAO Fisheries and Aquaculture Circular No. 1061/4. Rome

Soumy, M. (2006). Country review: Madagascar. In *Review of the state of world marine capture fisheries management: Indian Ocean* (ed. de Young, C.) FAO Fisheries Technical Paper. No. 488. Rome

Troell, M., Hecht, T., Beveridge, M., Stead, S., Bryceson, I., Kautsky, N., Ollevier, F. and Mmochi, A. (2011). Mariculture in the WIO region – Introduction and some perspectives. In *Mariculture in the WIO region "Challenges and Prospects"* (eds. Troell, M., Hecht, T., Beveridge, M., Stead, S., Bryceson, I., Kautsky, N., Ollevier, F. and Mmochi, A.) WIOMSA Book Series No 11. 1-5

UNDP (2014). *Human Development Report 2014 – Sustaining human progress: Reducing vulnerabilities and building resilience.* United Nations Development Programme. New York

van der Elst, R., Everett, B., Jiddawi, N., Mwatha, G., Afonso, P.S. and Boulle, D. (2005). Fish, fishers and fisheries of the Western Indian Ocean: their diversity and status. A preliminary assessment. *Philos. T. Roy. Soc.* A. 363 (1826), 263-284

Wakibia, J.G., Ochiewo, J. and Bolton, J. J. (2011). Economic analysis of *Eucheumoid* algae farming in Kenya. *Western Indian Ocean J. Mar. Sci*. 10(1), 195-212

WIOFISH (2013). *Western Indian Ocean Fisheries Database: A catalogue of small-scale fisheries*. www.wiofish.org, accessed on 7 October 2014

WIOMSA (2011). *Migrant fishers and fishing in the Western Indian Ocean: Socio-economic dynamics and implications for management*. Final Report of Commissioned Research Project

WorldFish Center (2011). *Aquaculture, Fisheries, Poverty and Food Security*. Working Paper 2011-65. http://www.worldfishcenter.org/resource_centre/WF_2971.pdf



24
Summary of Food Security from Marine Resources

Johan Groeneveld

Opposite page: Fish in the basket at the Palma fish market, north Mozambique. © José Paula.

Capture fisheries have a history of many centuries in the SW Indian Ocean, where they are integral to the food security and culture of coastal communities (see Chapters 21 and 23). Conversely, mariculture is a new sector with few successful commercial ventures, while many initiatives remain at subsistence level and rudimentary (Chapter 22). Demographic pressure along the SW Indian Ocean coastline, coupled with dwindling nearshore fish resources, has emerged as a potential threat to food security in recent decades (Chapter 20). Regional countries, like many developing states worldwide, have limited economic development opportunities, and thus depend heavily on primary natural resources. As a consequence of a low Human Development Index (UNDP 2013), fishing is often a last resort, because people lack other skills or opportunities to earn a living. In Chapter 24, we summarize the outcomes of Part V, with emphasis on critical issues that may affect food security in future. Where possible, ways of alleviating the most pressing issues are suggested, with the hope that governments will be able to use these recommendations to assure sustained food security from marine resources. This will be no easy task, given the great diversity of fisheries in the SW Indian Ocean region, with high complexity in terms of species, user groups, scientific assessment and environmental sustainability.

Overfishing of marine resources is a serious concern when the numbers of fishers, methods used, and harvest quantities are not adequately controlled by authorities. Given the heavy reliance of coastal communities on fisheries for food and economic activity, placing limits on harvests cannot be done without major social, economic and political upheaval, and the provision of alternative livelihood means. Consequently, there is limited political will to effect change, even in the face of strong evidence of overfishing, and this is compounded by limited alternative livelihood options.

Expanding coastal fisheries into deeper waters is frequently tabled as an option to increase harvests from the sea. However, sustainable exploitation of deep-sea bottom fish is notoriously difficult under prevailing economic conditions and governance arrangements, mainly because these species are often slow-growing and have low productivity (Norse and others, 2012). It is therefore important to first conduct surveys of the composition and biomass of potential deep-water resources (see Everett and others, 2015), before investing in fishing fleet or infrastructure expansions. The absence of national research infrastructure with which to assess deep-water fishery resources in most regional countries remains an obstacle to their expansion; this may be overcome by leasing survey vessels.

A minority of species / fisheries have **effective management plans.** In several countries, sector management plans have been developed and even gazetted, but have not been fully implemented after several years. This may reflect a lack of institutional capacity and political will, or in some cases uncertainty in how to translate a plan into active management processes. A review of management plans and practices at a regional level - within distinct fish-

ing sectors - might be an option to identify best-practice methods for similar fisheries at a regional scale, instead of individually trying to address complex issues with stand-alone management plans.

Nearly all countries bordering on the SW Indian Ocean lack sufficient data and expertise to fully describe their fisheries and the anthropogenic pressures on stocks. **Basic information on fished species is incomplete**, and more data is required to describe distribution patterns, biological characteristics and reference points, stock status, and the effects of fishing. Recent projects at regional level (e.g. SWIOFP, WIOFish, ASCLME, WIOLab) have made good progress in compiling existing fisheries information (see van der Elst and Everett 2015) and supporting studies on key exploited species. These studies should be continued, and the information that they generate need to be incorporated into fisheries management strategies.

The **linkage between science and management** is often suboptimal, with the result that crucial studies, such as those to estimate stock status, or to provide solutions to recent or longstanding management issues, are not prioritized. In some cases studies have been done, but their conclusions are not effectively communicated or implemented. The science / management linkage can be strengthened within a governance setup, for instance through regular meetings between managers and scientists to communicate management needs and help direct research initiatives. Regional and national mechanisms of assessing integration of scientific findings into management may be a necessary link.

Modest monitoring, control and surveillance (MCS) capacity make enforcement of national and international laws and regulations patchy and ineffective in most SW Indian Ocean countries. Consequently **IUU fishing** is common in artisanal (nearshore) and industrial (further offshore) fisheries, where it is responsible for considerable economic, social and ecological losses. Successful prosecutions are needed to deter or reduce IUU fishing – possibly at a regional level, through collaborative processes. Financial and technological support for expanding and maintaining MCS systems, need to be sought from international development agencies.

Co-management of artisanal fisheries, through Beach Management Units (BMUs) empowered to manage fisheries in specific areas on behalf of fisheries departments, is a promising development in Kenya, Tanzania and Mozambique. BMU objectives are to strengthen the management of fish landing stations, facilitate broad stakeholder participation in decisions, and prevent or reduce user conflicts (see Chapter 23). Although the requirements of running BMUs are quite demanding, it remains the most promising management approach in remote areas. In Madagascar, the first seascape-scale traditional, artisanal and industrial fisheries co-management plan, for Antongil Bay, was signed by the Ministry of Fisheries in 2013.

The growing awareness and implementation of an **ecosystem approach to fisheries management** (EAF) is a notable positive development in the SW Indian Ocean. Using **ecological indicators** for evaluating and comparing the status of exploited marine ecosystems (e.g. Indiseas project) is also promising. Both systems are relative newcomers to the region and are supported by governments (see Chapter 20) – nevertheless, their implementation can be accelerated and entrenched over a broader base, by making them popular among coastal communities. The positive spin-offs of EAF management will need to be demonstrated to stakeholders, especially in the artisanal fishing sector, to encourage its acceptance and support at community level.

Transboundary fish stocks in the SW Indian Ocean range from highly migratory tunas and billfishes that move long distances through high seas and EEZ waters, to more sedentary species, such as benthic crustaceans, that are distributed across geopolitical borders. International fisheries for large pelagic species in the Indian Ocean are managed by the Indian Ocean Tuna Commission (IOTC 2014), of which most SW Indian Ocean countries are members (see Chapter 21). Benthic stocks (such as prawns) are also potentially shared across geopolitical boundaries, through alongshore migrations or larval dispersal in ocean currents. Therefore the harvesting activities of one country may impinge on the opportunities of another (Gulland 1980). Genetic studies of several crustacean species with wide distribution were recently undertaken, and showed a surprising tendency towards highly structured populations over relatively short distances; this implies that several distinct stocks exist, and that they are not necessarily shared by neighbouring countries (Groeneveld and Everett 2015).

Cooperative management of shared fish stocks among neighbouring countries may confer many ecological and economic advantages, but it is also a complex political process (see Payne and others, 2004). A move from national to regional fisheries management strategies should therefore be subject to strong and broad-based evidence that it

would be advantageous to all parties, and that it would be justified based on stock identity and boundaries, genetic diversity, exploitation patterns and management objectives. The recently concluded SWIOFP project (van der Elst and Everett 2015) showed that combining resources among countries provided a clear forward impetus, especially for transboundary stocks, compared to struggling along individually with little infrastructure and scarce logistical support.

There is a **scarcity of skilled manpower** (i.e. fisheries researchers, scientific observers, fisheries managers, surveillance technologists, hatchery and grow-out systems operators) in the region, and this is presently being addressed through the capacity-development initiatives of several regional programmes (i.e. WIOMSA, SWIOFP, SWIOFish, SmartFish). Whether the uptake of these graduates into fisheries management and research positions is successful, needs to be seen. A weakness of the present system is that skilled workers easily become isolated, without the logistical and infrastructure support that their skills might warrant. When this happens, skills erode, or are lost because individual workers leave.

Mariculture is encouraged by governments as an alternative activity to generate fish protein and wealth. It is an important emerging issue with high complexity, extending from land and sea-use planning, to finding the right species and culture technology, and to encouraging responsible practises. It requires improved governance systems to encourage and support prospective farmers.

To date, demonstration projects and **donor-driven mariculture initiatives have been generally short-lived**, with modest uptake, except for seaweed farming in Zanzibar. Whereas the impediments to sustainability may differ (i.e. lack of skills, technology, infrastructure, marketing etc.), a common problem appears to be the remoteness of most of the region from large urban centers and foreign markets. Without access to markets for cultured products, or efficient distribution networks, local marketing remains as the main driver for mariculture – and it is less attractive than capture fishing.

A more **integrated approach to mariculture** is required, as illustrated at sea cucumber farms in southwest Madagascar, where collaboration between farmers (rearing), NGOs (technology) and business (marketing) has proved successful over several years. In such a system, donor and / or private sector investment would be needed over an extended period, with a gradual transfer of skills.

Mariculture can play an important role in **empowering women** in culture and business aspects. This has been clearly demonstrated by seaweed farming in Zanzibar, and is likely to expand across the region with the further development of mariculture projects. Mariculture undoubtedly has **high growth potential** in the region over the next decade, as it starts from a relatively low base, and is generally supported by local communities, investors, NGOs and governments. Constraints to the growth of this sector (i.e. lack of skills, technology, infrastructure; access to markets; unwieldy governance systems; planning) need to be identified and addressed, to allow for the expansion of the sector. It is also important to learn lessons from collapsed intensive commercial enterprises from other parts of the world, especially shrimp farming in mangrove ecosystems, which occurred at great environmental cost (Kautsky and others, 1997, Spalding and others, 1997).

Ironically, the high biodiversity of this tropical region and multiplicity of methods used to exploit the coastal and marine environment for food and economic activity is the source of many governance headaches. Only modest governance resources are generally available to address these complex issues. Nevertheless, good progress has been made over the past decade: governance systems are in place; capacity building is progressing; governments are signatories to international treaties; a shift towards EAF instead of single-species management; co-management through development of BMUs; regionalization of research and management; and the realization that mariculture will be key to food security and social and economic systems in the near future. Finding and implementing a long-lasting solution to the conundrum of declining coastal fish stocks and increasing human populations along the coast needs to be high on the agenda of governments in the SW Indian Ocean region.

References

Everett, B.I., Groeneveld, J.C., Fennessy, S.T., Dias, N., Filipe, O., Zacarias, L., Igulu, M., Kuguru, B., Kimani, E., Munga, C.N., Rabarison, G.A., Razafindrakoto, H. and Yemane, D. (2015). Composition and abundance of deep-water crustaceans in the Southwest Indian Ocean: Enough to support trawl fisheries? *Ocean Coast. Manag.* 111, 50-61

Groeneveld, J.C. and Everett, B.I. (2015). Crustacean deep-water trawl fisheries: A retrospective analysis of their status in the Southwest Indian Ocean. In *Offshore fisheries of the Southwest Indian Ocean: their status and the impact on vulnerable species* (eds. van der Elst, R.P. and Everett, B.I.) Special Publication No 10. Durban: South African Association for Marine Biological Research

Gulland, J.A. (1980). *Some problems of the management of shared fish stocks*. FAO Fisheries Technical Paper

IOTC (2014). *The Commission*. http://www.iotc.org/about-iotc Accessed 09 May 2014

Kautsky, N., Berg, H., Folke, C., Larsson, J. and Troell, M.. (1997). Ecological footprint for assessment of resource use and development limitations in shrimp and tilapia aquaculture. *Aquacult. Res.* 28, 753-766

Norse, E.A., Brooke, S., Cheung, W.W., Clark, M.R., Ekeland, I., Froese, R., Gjerde, K.M., Haedrich, R.L., Heppell, S.S., Morato, T., Morgan, L.E., Pauli, D., Sumaila, R. and Watson, R. (2012). Sustainability of deep-sea fisheries. *Marine Policy* 36(2), 307-320

Spalding, M.D., Blasco, F. and Field, C. (1997). *World Mangrove Atlas*. International Society of Mangrove Ecosystems, Okinawa

Payne, A.I.L., O'Brien, C.M. and Rogers, S.I. (2004). *Management of shared fish stocks*. CEFAS. Blackwell Publishing, UK

UNDP (2013). *Human Development Index and its components*. Human Development Report 2013 Media Toolkit. https://data.undp.org/dataset/Table-1-Human-Development-Index-and-its-components/wxub-qc5k

van der Elst, R.P. and Everett, B.I. (2015) *Offshore fisheries of the Southwest Indian Ocean: their status and the impact on vulnerable species* . Special Publication No 10. Durban: South African Association for Marine Biological Research

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Assessment of Other Human Activities and the Marine Environment

Louis Celliers

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25
Maritime Activities

Lynn Jackson

Opposite page: Evening in Port Louis, Mauritius. © Peter Kuchar.

INTRODUCTION

Shipping is essential to the global economy, providing the most cost-effective means of transporting bulk goods over long distances. Around 80 per cent of global trade by volume and over 70 per cent by value is carried by sea and is handled by ports worldwide, with these shares being even higher in the case of most developing countries (UNCTAD 2014). Despite some decreases since the onset of the slowdown in the global economy in 2009, the volume of seaborne trade increased by 3.8 per cent during 2013 (UNCTAD 2014). Moreover, Lloyd's and others (2013) projected that – driven by increases in global population and GDP - it will rise from 9 000 million tonnes to between 19 and 24 000 million tonnes by 2030.

In January 2014, the global fleet of merchant ships of 100 Gross Tonnes had a combined tonnage of just over 1 690 million Gross Tonnes (UNCTAD 2014). This was an increase of 4.1 per cent over January 2013, which in turn was more than double that of 2001 (UNCTAD 2013). The capacity of the fleet is expected to increase by some 50 per cent by 2020 (DNV 2012).

Around 90 per cent of these vessels are cargo vessels comprising general cargo ships (4.9 per cent of tonnage), oil tankers (28.5 per cent), gas carriers (2.7 per cent), chemical tankers (1.4 per cent), bulk carriers (42.9 per cent), offshore (4.3 per cent), ferries and passenger ships (0.3 per cent) and containerships (12.8 per cent). This reflects an increase in the relative percentage of bulk carriers and container ships – at the expense of general cargo vessels and oil tankers (UNCTAD 2013, UNCTAD 2014). In contrast, oil tankers now make up some 80 per cent of the Western Indian Ocean (WIO) fleet – the majority registered in Tanzania - compared with 14.5 per cent in 2004 (see Figure 25.1).

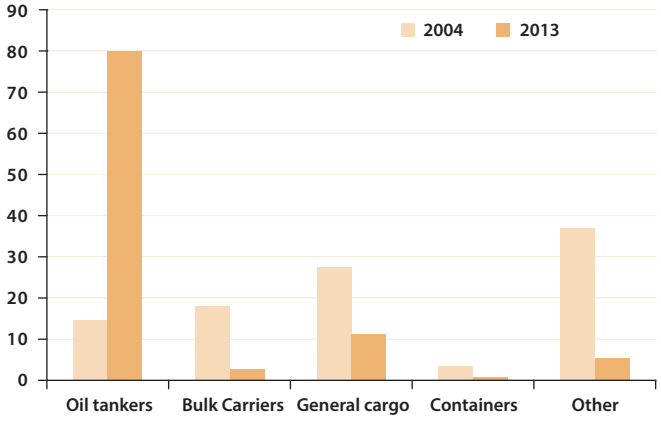


Figure 25.1. The makeup of the WIO fleet with the various vessel types shown as a percentage of the total fleet (based on data from UNCTAD reports).

The global fishing fleet numbers 21 589 ships with a Gross Tonnage of 9.438 million. Other fishing-related vessels (fish carriers, support vessels etc.) number 1 242 with a Gross Tonnage of 1.233 million (IMO 2012).

Some 6 per cent of the world trading fleet travels to ports in the Indian Ocean (UNCTAD 2006). In addition, vessels such as oil tankers frequently travel through the

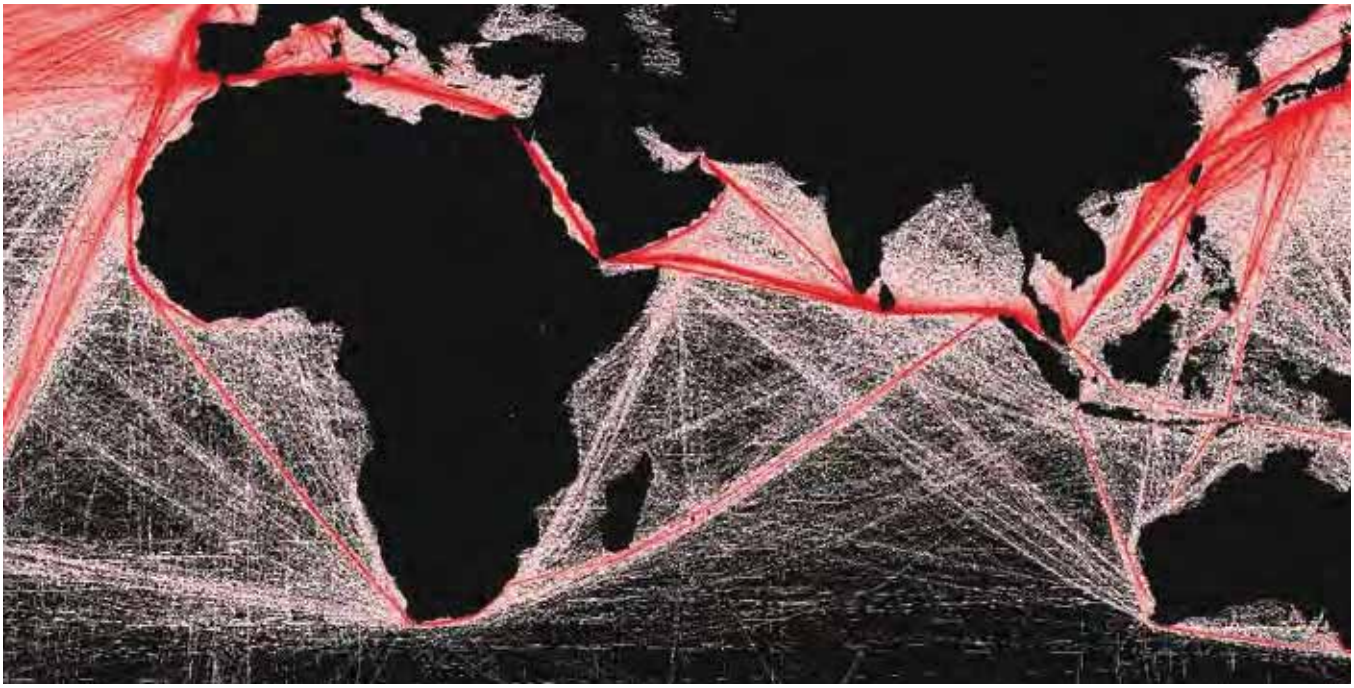


Figure 25.2. Relative commercial shipping density, at a scale of 1 km. © University of California, National Center for Ecological Analysis and Synthesis.

Western Indian Ocean (WIO) because it forms part of the route between the major oil-producing countries and their markets (see Figure 25.2). Other challenges in the region include piracy, the illegal dumping of toxic waste and potential impacts of climate change as a result of more frequent storm events and rising sea levels.

While ships are essential to the global economy, they have a variety of negative environmental impacts. These include:

- Pollution resulting from the ship's day-to-day operational activities;
- Pollution as a result of accidents;
- Impacts related to ship recycling; and,
- Translocation of invasive alien species primarily via ballast water and hull-fouling.

Internationally, operational pollution is regulated by the International Convention for the Prevention of Pollution from Ships (MARPOL 1973/78) which has a number of Annexes, each dealing with a specific type of ship-related pollution, including oil, garbage, sewage and air pollution. Accidental pollution, liability, and invasive alien species are covered by a number of other conventions and guidelines – all administered by the International Maritime Organisation (IMO).

Although the number of major oil spills has declined in recent years, vessels also carry a wide range of cargoes – including hazardous chemicals – which also pose significant risks in the event of accidents. It is estimated that the annual seaborne chemical trade will grow from some 151 million tonnes in 2005 to 215 million tonnes by 2015 (OSC 2006). Moreover, the growth of the world fleet has led to shipping lanes becoming more and more congested, thereby increasing the risks of accidents – particularly around ports. The risk of accidents is also likely to be further exacerbated by an increase in adverse weather conditions as a consequence of climate change.

Although passenger ships make up a very small proportion of the global fleet, the cruise industry has seen rapid growth in the past few years with over 20 million passengers cruising globally during 2012 (F-CCA 2013). It is estimated that cruise ships – which can carry up to 5 000 passengers and crew – can discharge around 100 000 litres of sewage a day. This excludes greywater such as laundry, shower, and galley sink wastes, which are produced in even higher volumes and which may include oils, nutrients, detergents, heavy metals, pesticides and even medical and dental wastes. This is of particular concern in that cruise ships frequently dock very close inshore in sheltered coastal environments.

With respect to invasive alien species, an analysis by Molnar and others (2008), drawing on information from over 350 databases and other sources, showed that for the 329 marine invasive species considered, shipping was the most common pathway (69 per cent), with others being aquaculture (41 per cent), canals (17 per cent), the aquarium trade (6 per cent), and live seafood trade (2 per cent).

Of the 205 species introduced via shipping – and for which sufficient information was available – 39 per cent were introduced by hull-fouling, 31 per cent via ballast water, and the remainder by either or both.

While there can be many direct and indirect impacts of invasive marine species, the principal consequences can be grouped into three main categories:

• Ecological impacts occur when the local biodiversity of the area and/or the ecological processes are altered by the invasive species;

• Economic impacts, including losses as a consequence of reduced productivity, and costs incurred for the prevention and management of invasive species; and

• Public health impacts: ballast water can transfer a range of species including bacteria, viruses and microalgae such as those that cause harmful algal blooms (HABS) with consequential health impacts.

In light of the likely increase of shipping in the region – and the heightened environmental risks – consideration needs to be given to developing policies on a number of issues including:

• The strengthening of Port and Flag state controls, particularly taking into account the fact that one of the objectives of the African Union's 2050 AIM Strategy is to increase African ownership of ships;

• Development of a regional maritime surveillance system;

• Pollution monitoring and reporting;

• Building awareness and addressing sources of marine litter;

• Adequacy of waste reception facilities in ports;

• Development of a regional approach to the management of ships as vectors of alien and invasive species; and,

• A coordinated response to potential impacts of climate change on the maritime sector.

STATUS OF MARITIME ACTIVITIES IN THE WIO

While developing countries continued to increase their contribution to seaborne trade during 2012, Africa only accounted for 787 million tonnes of global goods loaded (8.58 per cent) and 407 million tonnes unloaded (4.44 per cent), much of it from West Africa (UNCTAD 2013). Trends in key products for Eastern Africa are shown in Table 25.1.

While there has been a general increase in both imports and exports over the years, the most significant change has been in the African export of crude oil since 2006 and an associated decline in crude oil imports since 1990. With the recent discovery of additional reserves of oil and especially

Table 25.1. Seaborne trade volumes in Eastern Africa, excluding South Africa (millions of tonnes)*.

	Goods loaded				Goods unloaded			
Year	Crude oil	Hydrocarbon products	Dry cargo	TOTAL	Crude oil	Hydrocarbon products	Dry cargo	TOTAL
1970	0	1.2	16.1	17.3	5.5	2.6	8.3	16.4
1980	0	0.9	6.3	7.2	6.2	2	9.9	18.1
1990	0	0.6	9.3	9.9	6.4	2.6	16	25
2000	0	0	7.2	7.2	0.7	4.8	19	24.5
2005	0	0	9.3	9.3	0.7	5.2	20.5	26.4
2006	11.8	1.1	29	41.9	2.1	7.7	18.2	28
2007	13.6	1.2	23.3	38.1	2.1	8.3	19.8	30.2
2008	19.7	0.8	27.8	48.3	1.8	7.9	23.8	33.5
2009	19	0.6	18.3	37.9	1.7	9.2	24.4	35.3
2010	19	0.5	29.5	49	1.9	8.6	26.3	36.8
2011	20	1	16.7	37.7	1.4	9.6	39	50
2012	22	1.1	16.8	39.9	1.5	10.4	42.1	54
Global								
1970	1 108.9	232.5	1 162.4	2 503.8	1 101	297.5	1 130.9	2 529.4
2012	1 785.4	1 050.9	6 329	9 165.3	1 928.7	1 054.9	6 200.1	9 183.7

*Data extracted from UNCTAD reports, noting that only regional data is available, and that South Africa is not included in this group. Global figures are included for comparative purposes.

gas in the WIO countries, the contribution of East Africa to oil and hydrocarbon products (especially methane) exports will likely grow in future (see Chapter 26).

African ports currently handle 6 per cent of global water borne cargo and 3 per cent of containers (AU 2012). According to the African Development Bank (2010), this will increase from 265 million tonnes in 2009 to more than 2 000 million tonnes in 2040, while transport volumes will increase six- to eightfold, with a particularly strong increase of up to 14 times for some landlocked countries (UNCTAD 2013).

There are 13 existing commercial ports in the region with several others either in the planning phase or under construction. The port at Lamu (Kenya), for example, is

BOX 25.1. LAMU PORT



Waterfront of Lamu old town, Kenya. © Kiunga Kareko.

The development of a port at Manda Bay in Lamu is a key component in Kenya's Vision 2030 Strategy for Growth and Development (http://www.lapsset.go.ke/lamu). It is intended to accelerate development of trade routes linking the Northern part of Kenya to South Sudan and Ethiopia. A feasibility study carried out by the Japan Port Consultants Ltd in 2010 found that the development of a port in Lamu would have "extensive irreversible environmental, social, and cultural impacts on what is a unique and culturally sensitive area". In terms of Kenya's Environmental Management and Coordination Act, 1999, the Ministry of Transport therefore commissioned an Environmental and Social Impact Assessment (ESIA) to determine in more depth the likely impacts of the first phase of the proposed development, establish a baseline, and advise on mitigation measures.

The ESIA anticipated a number of major impacts that included:

- Loss of water quality;
- Loss of mangrove habitat, degradation from pollution and changes in tidal flushing, and increased use as a resource;
- Displacement of artisanal fishers, reduction in accessibility to fishing grounds and landing sites, reduction of stocks;
- Negative effects on archaeological, historical and cultural impacts. It is predicted that the port is likely to alter the character of the Old Town of Lamu - a UNESCO Heritage Site;
- Human health and safety issues relating to the port construction work and the associated influx of migrant workers.

The ESIA report proposed the following in mitigation of the impacts:

- Practice less intensive dredging techniques;
- Development of an oil spill preparedness and response plan;
- Limit a loss of mangrove habitat by reducing the footprint of the port. Restoration of an equivalent area of mangroves at another appropriate site;
- Implementation of monitoring programmes for all relevant aspects of the port and port environment;
- Empowerment of local fishers to operate in deeper waters. This can only be achieved through the provision of fisheries equipment and infrastructure;
- Development of protocols for the preservation of artefacts found during the construction process;
- Significant expansion of local health facilities.

Some sources criticised the ESIA citing issues relating to inadequate research methods and public consultation, incomplete baseline information and description of impacts, insufficient assessment of project alternatives, and impractical and even harmful recommendations on measures to mitigate impacts as contained in the ESIA (www.savelamu.org).

Reference:

Extracted from Ministry of Transport: Kenya (2013). ESIA Study Report for Construction of the First Three Berths of the Proposed Lamu Port and Associated Infrastructure. Final Report. 216 pp.

Table 25.2. Container port throughput (TEU's)*.

	2003	2004	2010	2011	2012
Kenya	331 000	404 000	696 000	735 672	903 000
Madagascar	95 000	105 000	141 093	149 135	155 101
Mauritius	381 000	290 000	332 662	350 624	417 467
Mozambique	Not available	Not available	254 701	269 219	279 988
Reunion	Not available	Not available	Not available	Not available	224 000
South Africa	237 4000	2 670 000	380 6427	3 990 193	4 424 254
Tanzania	204 000	256 000	429 285	453 754	471 904
TOTAL	3 385 000	3 725 000	5 660 168	5 948 597	6 875 714
Global	299 280 432	336 858 116	540 816 751	580 022 280	601 722 123
% of global	1.131%	1.105%	1.047%	1.026%	1.14%

*Data from UNCTAD Reports, with the exception of Reunion, which is from Simon (*pers. com.*). NOTE: Figures for South Africa include all ports, not just those on the east coast.

under construction, while construction on that proposed for Bagamoyo (Tanzania) is expected to start before the end of 2015. The ports serve as hubs for traffic emanating from, and destined for Europe, Asia, the Americas and the east and west coasts of Africa. In addition, there are a number of smaller ports and harbours.

Trade in containerized goods has grown rapidly over the past few decades and comprised 16 per cent of global seaborne trade by volume (155 million TEU's) in 2012 (UNCTAD 2013). Of this only around 1 per cent is handled by ports in the WIO region (see Table 25.2). The top container ports in the region include Durban, Mombasa, Port Elizabeth, Port Louis, Dar es Salaam, Toamasina and East London. Several of these have become important as regional trans-shipment hubs resulting in significant increases in throughput.

ENVIRONMENTAL IMPACTS OF MARITIME ACTIVITIES IN THE WIO

Operational pollution from ships

The majority of countries in the region are Party to MARPOL and most of its Annexes (see Table 25.3 below) with the exception of Annex VI which deals with air pollution. The majority are also Party to the Conventions dealing with liability for oil spills as well as the International Convention on Oil Pollution Preparedness, Response and Co-operation (OPRC) which deals with cooperation in case of oil spills. On the other hand, only two countries are presently Party to the Ballast Water Management Convention.

There is effectively no data available on any form of operational pollution from ships in the region. Moreover, an assessment of national marine pollution monitoring in the region under WIOLaB (which focussed on land-based sources) (De Mora 2006) reported that none of the countries in the region has a comprehensive national marine pollution monitoring programme with most monitoring that does take place being linked to specific projects or sites (eg outfalls).

Similarly, there has been no specific assessment of litter from vessels. However, an assessment of marine litter in the WIO Region (UNEP and others, 2008) concluded that:

- Marine-based sources of litter do not appear to be as significant as land-based sources although the WIO is heavily trafficked by commercial shipping and fishing vessels. However, loss of fishing gear and dumping of garbage from fishing boats is widespread;
- None of the islands or coastal states can afford to effectively police their territorial waters or exclusive economic zones;
- Because of the nature of the ocean currents, litter dumped almost anywhere in the Indian Ocean can be transported for thousands of kilometres;
- The major constraints to effective waste management, and thus to reducing marine litter, are inadequate awareness about impacts and/ or a shortage of funds to deal with it.

Apart from impacts on human health and tourism, marine litter affects biodiversity as a result of ingestion, entanglement (especially of turtles, seabirds and mammals) and smothering – for example, on coral reefs. Some countries do keep records of, for example, animals found entangled while Kenya has produced a Sea Turtle Strategy which identifies marine litter as a threat (Kenya Wildlife Service 2009).

Table 25.3. Membership of WIO countries to relevant IMO Conventions (X = Party)

Convention	Country								
	Com	Kenya	Mad	Maur	Moz	Sey	Som	SA	Tanz
MARPOL 73/78 + Annexes I (oil) & II (bulk noxious liquids)	X	X	X	X	X	X		X	X
MARPOL Annex III (packaged goods)	X	X	X	X	X			X	X
MARPOL Annex IV (sewage)	X	X	X	X	X				X
MARPOL Annex V (garbage)	X	X	X	X	X			X	X
MARPOL Annex VI (air pollution)		X							
CLC Protocol 1992 (liability)	X	X	X	X	X	X		X	X
FUND Protocol 1992 (liability)	X	X	X	X	X	X		X	X
OPRC 1990 – response cooperation	X	X	X	X	X	X		X	X
Ballast Water Management Convention - 2004		X						X	

Shipping accidents

The International Tanker Owners Pollution Federation (ITOPF) maintains a database of spills from tankers going back to 1967. The only major oil spill listed by ITOPF in the WIO region since 1967 is the Katina P, a Greek tanker which spilled an estimated 13 000 tonnes of #6 heavy fuel oil in the Mozambique Channel after suffering hull damage on passage from the Persian Gulf in 1992 (www.itopf.org).

The IMO has a database on shipping casualties but it relies on reports from the countries, and for the majority of WIO countries there are either no reports, or reports which provide minimal information. Table 25.4 below summarises the information from a report prepared for the Agulhas Somali Current Large Marine Ecosystem project (ASCLME) (Jackson 2011).

Invasive alien species (IAS)

Information on marine invasive alien species and harmful algal blooms (HABs) in the WIO region is fairly limited largely due to the fact that it is a relatively new field and only a few assessments targeting alien species have been conducted. One exception is the marine invasive species survey conducted in Port Victoria during 2005, under the SCMRT-MPA, IUCN and NIWA (see Bijoux and others, 2008). The study found four species that were non-native, out of about one hundred identified, and provided a sound baseline from which future monitoring can be undertaken.

The majority of alien species that have been recorded in the WIO region are thought to have been introduced either via bio-fouling on ships, or as deliberate introductions for mariculture purposes. Of the alien species identified, only a few are thought to have significant invasion potential. These include the Asian mussel (*Musculista senhausia*), the oyster (*Crassostrea gigas*), the European Green crab (*Carcinus maenas*), and a barnacle (*Balanus glandula*). The Crown-of-thorns Starfish (*Acanthaster planci*) is considered to be cryptogenic and is impacting on coral reefs in the region (Awad 2011).

HAB events have been reported from Kenya, Mauritius (including Rodrigues), Somalia, South Africa and Tanzania. However red tides and other HAB events are known to occur throughout the region usually associated with the beginning of the northeast monsoon season in East Africa (Awad 2011).

Table 25.4. Shipping casualties in the WIO region (as reported to IMO).

Country	IMO database	Other Sources
Comoros	0	0
Kenya	0	Abuodha and Kairo (2001) - Mombasa Kenyan National Oil Spill Response Contingency Plan (2007) – around 30 spills in and near Port of Mombasa
Madagascar	1 (2001)	0
Mauritius	2 (2001/2003)	0
Mozambique	4 (2000/2001/2002)	0
Seychelles	1 (2008)	0
Somalia*	9 (1990 – 2009)	0
South Africa	9 (2001 – 2006)	Jackson (2011)
Tanzania	0	Mohammed and others (2008) – spill from Single Buoy Mooring near Dar es Salaam

*Many of these were incidents of piracy.

Environmental impacts of port activities

Ports are the interface between maritime and land-based activities and are generally located in sheltered environments such as bays and estuaries in close proximity to urban complexes. Such locations are invariably environmentally sensitive and can be negatively affected both by port construction and operations depending on the proximity to natural resources and the nature of the adjacent activities.

Although there is limited specific information on pollution in ports for most countries in the WIO region, the majority of the pollution hotspots identified during the WIO-LaB project were in or adjacent to ports. Dar es Salaam harbour, for example, was listed as a pollution hotspot, with sediments containing high levels of heavy metal and organophosphates (Mohammed and others, 2008). Similarly, Port Victoria was identified as a Category 2 hotspot for metals, microbiological pollutants and nutrients (Antoine and others, 2008). Studies conducted in Mozambique have shown the presence of heavy metals, particularly lead (Pb), in the Port of Maputo from discharges of the Matola and Maputo Rivers, as well as in Nacala Bay (Fernandes 1996, Anon Mozambique 2007). And, as mentioned above, the majority of oil spills reported in Kenya are in and around the port of Mombasa. A contributing factor is that many ports in the region lack adequate waste reception facilities for calling vessels.

Dredging takes place during both port construction and operational phases with the greatest long-term concern being the disposal of the dredged material. The dumping of waste at sea – including dredged material – is regulated under the London Convention/Protocol. Globally, dredged material from ports and waterways is the most common waste dumped with annual amounts of between 150 and 400 million tonnes. Of this, about 66 per cent arises from regular maintenance dredging, with the balance from capital dredging. Much of this is relatively clean, but around 10 per cent is heavily contaminated with toxic chemicals such as trace metals and hydrocarbons. Moreover, the disposal of large volumes of dredged material can cause physical smothering of benthic species and habitat alteration (http://londonprotocol.imo.org).

Although a number of the WIO countries are party to the London Convention/Protocol, only South Africa reports on the dumping of dredged material with volumes ranging from around 2 million to 24 million tonnes per annum between 2001 – 2009 (data provided by Y.Petersen, DEA).

The WIO-LaB project did, however, generate some general information on dredging activities. For example:

- Munga and others (2006) reported that the dredged material from the port and channels of Kilindini Harbour in Mombasa is disposed of in the adjacent deep waters beyond the reef. These sediments contain significant amounts of particulate material and associated chemicals such as nutrients, heavy metals and persistent organic contaminants;
- Dredging in Port Louis, is undertaken on an *ad hoc* basis in existing channels for maintenance purposes, as well as for strategic port development (Anon Mauritius 2009);
- The four most important ports in Mozambique are Maputo, Matola, Beira and Nacala. Poor land-use practices result in high levels of sedimentation in coastal environments and, as a result, frequent dredging of these harbours

and their entrance channels is needed. Surveys from 10 years ago showed that between 1.2 x 106 m^3 and 2.5 x 106 m^3 of sediments need to be dredged annually from the ports of Maputo and Beira respectively (FAO 1999).

SOCIO-ECONOMIC CONCERNS

The African Union's 2050 Integrated Maritime (AIM) Strategy identifies the African Maritime Domain as an opportunity for the growth and development of a maritime economy whilst acknowledging that this must be done in a sustainable manner. In addition to potential environmental impacts, there are a number of other challenges including piracy, the illegal dumping of toxic waste and potential impacts of climate change on shipping and port infrastructure.

Piracy

Piracy emerged as a problem in the region from around 2005, initially primarily off the coast of Somalia, but subsequently spreading into the Gulf of Aden, Red Sea, Arabian Sea and the Indian Ocean as far south as Mozambique (OBP 2012a, OBP 2012b). The number of attacks in the region peaked at 237 in 2011 – 54 per cent of the global tally – but dropped significantly in 2012/13 (see Table 25.5) as a result of efforts on the part of a number of organisations, including various United Nations agencies, the African Union, an European Union Naval Force and the governments in the region.

These activities have affected trade routes, fishing and tourism in the region, as well as affecting seafarers. Papers by Oceans Beyond Piracy (OBP is a project of the One Earth Future Foundation, the International Maritime Bureau (IMB) and the Maritime Piracy Humanitarian Response Programme (MPHRP)) have analysed both economic and human costs over the past few years. It was estimated that the cost of piracy was nearly $7 billion in 2011 with over 80 per cent of the costs being borne by the shipping industry, while governments accounted for 20 per cent of the expenditures associated with countering piracy. This fell to around US$ 6 000 million in 2012, but given the drop in the number of incidents, this actually represents a higher "per incident" cost (OBP 2012a).

In addition to the economic cost of piracy, it imposes significant hardships on seafarers, fishermen and their families as a consequence of physical and psychological trauma during and after attacks and/or periods of captivity as well as loss of wages (OBP 2012b).

Hostages are not limited to seafarers and fishermen but, in 2012, for example, included a journalist and three aid workers. There have also been costs to the Somali community such as the death of fishermen mistaken as pirates, involvement of disaffected youth in piracy, impacts on livelihoods, increased levels of alcohol and drug abuse, prostitution and decreased levels of development aid and investment.

On the positive side, recent initiatives have expanded the scope of co-operation around piracy from just heightening security against piracy to increasing investment in the creation of economic opportunities for Somali communities (OBP 2012b).

Illegal dumping

Since the collapse of the Somali regime in 1991 there have been numerous reports of illegal dumping activities off of the Somali coastline, some allegedly involving European companies. These resurfaced after the Asian Tsunami in December 2004, during which a number of containers of toxic waste were broken open and/or deposited onto the

Table 25.5. Numbers of attacks by Somali pirates*.

Location	2009	2010	2011	2012	2013
Gulf of Aden	117	53	37	13	6
Kenya	1	0	1	1	1
Mozambique	0	0	0	2	2
Red Sea	15	25	39	13	2
Somalia	80	139	160	49	7
Tanzania	5	1	0	2	1
Arabian Sea	1	2	0	0	0
Indian Ocean	1	0	0	0	0
TOTAL	220	220	237	80	19

*Data from the International Maritime Bureau's Piracy Reporting Centre: www.icc-ccs.org

shore. The 2005 UNEP Report "After the Tsunami" contains the following extract: "*Somalia is one of the many Least Developed Countries that reportedly received countless shipments of illegal nuclear and toxic waste dumped along the coastline. Starting from the early 1980s and continuing into the civil war, the hazardous waste dumped along Somalia's coast comprised uranium, radioactive waste, lead, cadmium, mercury, industrial, hospital, chemical, leather treatment and other toxic waste. Most of the waste was simply dumped on the beaches in containers and disposable leaking barrels which ranged from small to big tanks without regard to the health of the local population and any environmentally devastating impacts.*"

Further reports (Hussein 2010, Greenpeace 2010) contains statements suggesting that some 400 containers of toxic waste were "buried" in the quays of El Ma'an Port during its construction in the late 1990s.

The matter was raised again at a meeting in February 2010, on counter-piracy strategies coordinated by the United Nations Political Office for Somalia and Department of Political Affairs. It was subsequently raised in the UN Security Council in the context of discussions on piracy leading to the adoption of UN Resolution 1976 (April, 2011) which, amongst other things requested: "… *the Secretary-General to report within six months on the protection of Somali natural resources and waters, and on alleged illegal fishing and illegal dumping, including of toxic substances, off the coast of Somalia, taking into account the studies on this matter previously conducted by the United Nations Environmental Programme and other competent agencies and organizations, and expresses its readiness to keep the matter under review.*"

The toxic waste off Somalia is reportedly impacting on the health of local people, animals and the environment and any containers remaining in coastal waters pose a significant threat to the WIO region as a whole.

Climate change

The global fleet is estimated to contribute some three per cent of global carbon emissions (UNCTAD 2012, Wright 2013). At the same time, climate change is likely to have significant impacts on maritime activities as a consequence of, for example, increased frequency of storm events and rising sea level. Impacts may include more frequent shipping accidents, increased costs of port maintenance and disruption of port operations from both the seaward-side and hinterland supply chains (McEvoy and Mullett 2013). These concerns need to be factored into plans to expand maritime activities in the region.

CAPACITY

Given the potential environmental impacts of shipping, it is important for the WIO countries – in addition to monitoring the impacts themselves - to have the capacity to regulate ships, provide them with appropriate maritime services (such as navigational aids) and respond to shipping accidents.

Port and Flag State Control

Comoros, Kenya, Mauritius, Mozambique, Seychelles, South Africa and Tanzania are now parties to the Indian Ocean Memorandum of Understanding for Port State Control which was finalised on 5 June 1998. The Memorandum came into effect in April 1999, and as of September 2013 has 17 members (www.iomou.org). Madagascar and Somalia are not currently parties to the agreement.

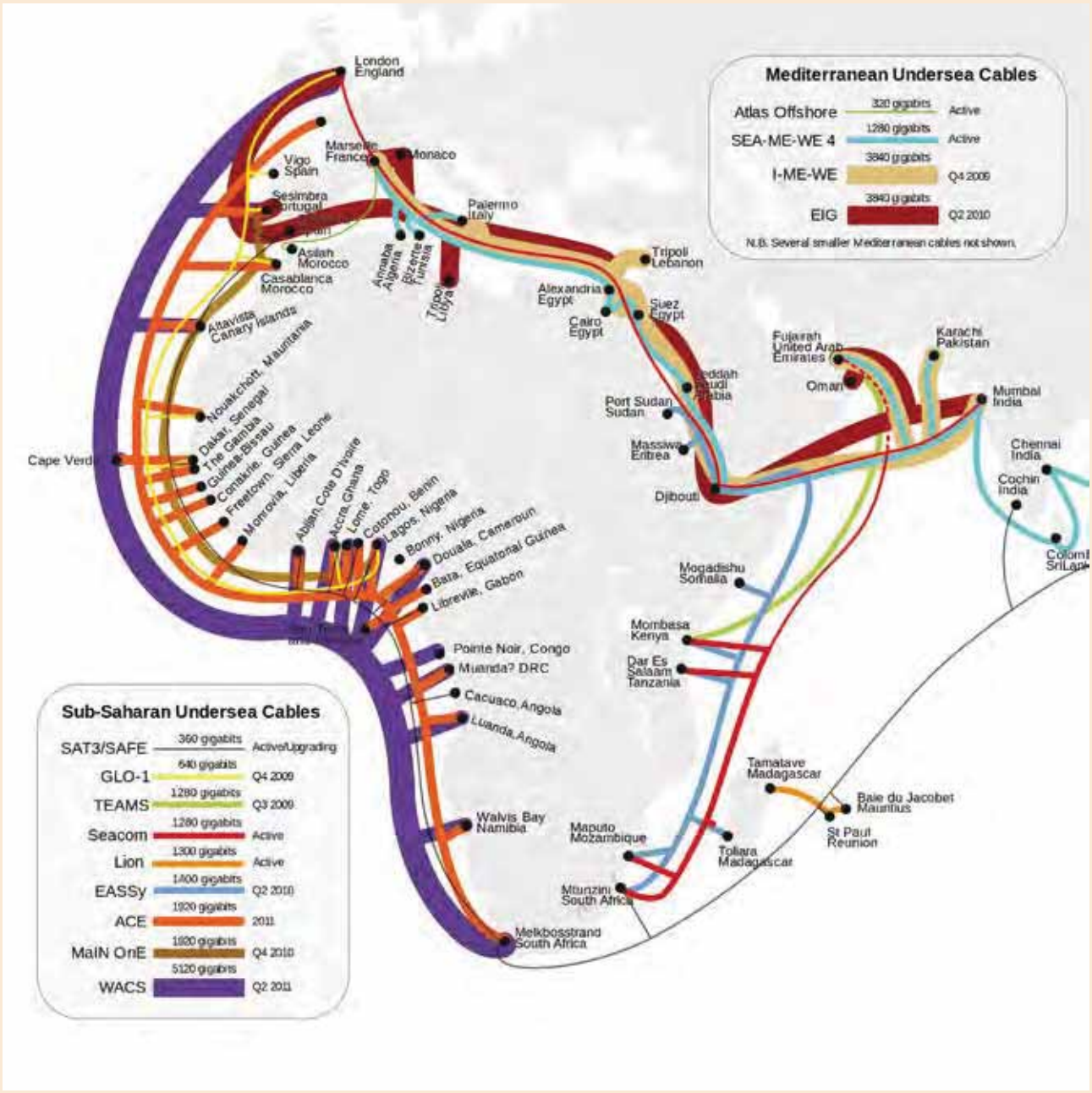
Of the WIO countries, only South Africa has implemented a comprehensive port state control system, which aims to verify whether foreign flag vessels calling at the ports of the state comply with applicable international conventions and with national laws. This issue was addressed to some extent through the WIO Marine Highway project which ran training courses on various aspects of Port State Control (Guy 2013). Training courses have also been organised by the Secretariat of the Indian Ocean MoU.

This does seem to have led to an improvement, with

Table 25.6. Port State control inspections in selected WIO countries.

Country	No. of inspections in 2003	No. of inspections in 2012	No. of deficiencies in 2012	No. of detentions in 2012
Kenya	0	123	328	6
Mauritius	1	2	0	0
South Africa	264	222	294	7
Tanzania	0	2	8	0

BOX 25.2. SUBMARINE CABLES



Network of submarine cables along the East African coast. © Shuttleworth Foundation.

Submarine communications cables are laid on the sea bed between land-based stations to transmit telecommunication signals across stretches of ocean, often between continents. The installation of submarine fibre optic cables significantly enhances opportunities for international connectivity through increased bandwidth and higher transmission speeds. Moreover, they are significantly cheaper than satellite. They therefore offer major socio-economic benefits while the environmental concerns can be addressed through improved planning and mitigation.

The past few years has seen a proliferation of submarine telecommunications cables servicing the region from the original SAT 3 which was laid in 2001 but which only connected to Mtunzini on the South African coast, Reunion and Mauritius. Since then the following cables have been added to the network that connects Africa with the world:

- SEACOM – 2009 (www.seacom.mu);

- The East African Marine System (TEAMS - 2009) (www.teams.co.ke)
- Lower Indian Ocean Network (LION – 2009)
- Eastern African Submarine Cable System (EASSy – 2010)
- Seychelles East Africa Submarine Cable (SEAS – 2011)
- LION 2 – 2012 (www.lion-submarinesystem.com).

Submarine cables are landed onshore while the cable itself is laid on the seafloor. The cable traversing the intertidal zone is generally buried before connecting to land-based telecommunications networks. There are potential environmental concerns relating to the deployment of the cable, as well as the presence of the cable within the ecosystem it traverses. Some of the concerns include:

- Potential damage to coral reefs and associated organisms as a consequence of the movement of inadequately secured cables. Movement may occur as a result of currents and storms, or when cables are snagged by fishing gear or anchors;
- Sedimentation and turbidity caused during cable-laying operations;
- Their impacts on resource-use as a result of:

o The imposition of exclusion zones to protect the integrity of the cables which may be damaged as a result of, for example, trawling activities;

o The dissection of, for example, trawling grounds, into sections which are too small to be viably trawled. Telkom SA, for example, required an exclusion zone of one nautical mile on either side of the EASSy cable in the Mtunzini area of the east coast of South Africa which led to objections from the prawn fishers with quotas in the area (Scherzer, 2009); and

- Impacts on other activities and infrastructure in the vicinity of the cable route including mariculture activities, fish aggregating devices, archaeological resources, anchorage facilities and recreational activities (CSIR, 2000).

To a large extent, these impacts can be mitigated by investigating alternatives during the Environmental Impact Assessment process and selecting those which are optimal. For example:

- In the case of the EASSy cable, a route was selected in consultation with the prawn fishers which had limited impact on the trawling ground;
- In the case of the SEAS cable between Seychelles and Tanzania, the cable was buried in the shallow water section (0 – 1000m) to limit impacts to the construction period (and prevent snagging of the line) (African Development Bank, 2010).

Approvals granted for cable installation can also include a requirement for repair and/or restoration in cases where damage has occurred.

A regional approach should be taken to the planning of submarine telecommunications cables in future with a view to limiting the number of cable lines while at the same time enabling access to the benefits they provide.

References

African Development Bank (2010). Summary of the Environmental and Social Impact Assessment for the Multinational Seychelles Submarine Cable Project. 20 pp.

CSIR (2000). Environmental Impact Assessment of the Installation of a Fibre Optic Cable in Reunion: Main Report. CSIR Report ENV-S-C 2000-095

Scherzer,P. (2009). Impact Assessment Case Studies from Southern Africa: Routing of the EASSy Submarine Cable, South Africa. SAIE Report. 9pp.

Sultzman,C. (2002) A Professional Jury Report on the Biological Impacts of Submarine Fiber Optic Cables on Shallow Reefs off Hollywood, Florida. Report to PEER.

an increase in the number of countries undertaking inspections, as shown in Table 25.6 (data from the 2012 Annual Report of the Indian Ocean MoU/ www.iomou.org).

Surveillance of shipping lanes

As far as can be ascertained, South Africa is the only country in the region with an active surveillance programme for oil spills at sea. This is focussed on the shipping lanes although there is also provision for reconnaissance flights during incidents as well as *ad hoc* flights for other purposes eg research.

Munga and others (2006) reported that the responsibilities of the Kenyan Navy include the patrolling of Kenyan waters, while those of the Oil Spill Mutual Aid Group (OSMAG) under the Ministry of Transport and Communications include overseeing oil spill surveillance. However, it is unclear whether there is an active surveillance programme.

In Mozambique, the Marine Arm of the Ministry of National Defence is responsible for surveillance of the maritime area, although other institutions such as the Police, Fisheries and Maritime Authorities, also play a role in surveillance activities (Gove 2011). The extent of such surveillance is unknown.

Similarly, in terms of the Maritime Zones Act, 1977, the Seychelles Coast Guard is responsible for surveillance in the EEZ. This includes oil spill surveillance although the Coast Guard have no planes and have to utilise the planes from the Island Development Company (Nageon de Lestang and Carolus 2011, Nageon de Lestang *pers. comm*).

Provision of Navigational Aids

Although all the countries in the region have some charts and other aids to navigation, part of the rationale for the GEF-World Bank Western Indian Ocean Marine Highway project (World Bank 2003) was that many of the charts were out of date as a consequence of underground seismic activity in the area. Moreover, the technology used to compile the charts and for other aids was obsolete in a number of cases. These issues were addressed by the project and the development objective was to "*... increase the safety and efficiency of navigation…by establishing a demonstration marine highway to guide ships around environmentally sensitive areas and through selected busy sea lanes and by supporting widening the regional agreement on port state control and implementation of its provisions*" (World Bank 2003).

Although the project concluded that the establishment of a marine highway in this area was not feasible, it did contribute significantly to the improvement of navigational aids in the region through the following activities:

- Surveys of various shipping routes including port approaches;
- Updated information included into various nautical charts;
- Provision of training on hydrography, marine cartography and electronic navigational charting;
- Repairs to various aids to navigation; and
- Training on aids to navigation and maintenance thereof (Guy 2013).

Oil spill response

The Nairobi Convention includes a Protocol concerning Co-operation in Combating Pollution in Cases of Emergency in the Eastern African Region the main objective of which is to facilitate the development of regional arrangements for the effective combating of major spillages of oil or other harmful substances from ships. Other obligations in terms of the Protocol include:

- The development of national contingency plans and pollution response capabilities;
- The distribution of information to the other Parties regarding their national organization and their competent national authorities;
- Informing the other Parties of all pollution incidents; and
- The provision of assistance to a Party which so requests.

A draft Regional Contingency Plan was developed under the WIO Marine Highway Project (World Bank 2013). According to the draft plan: "*The purpose of the Regional Contingency Plan is to establish, within the framework of the Emergency Protocol and according to the obligations of the Contracting Parties under this Protocol, a mechanism for mutual assistance, under which the competent national Authorities of the countries concerned will co-operate in order to co-ordinate and integrate their response to marine pollution incidents either affecting or likely to affect the territorial sea, coasts and related interests of one or more of these countries, or to incidents surpassing the available response capacity of each of these countries alone.*"

The plan hinges on the establishment of a Regional Coordination Centre (RCC) for Marine Pollution Preparedness and Response in the Western Indian Ocean. The Centre will act as the Secretariat for the plan and be responsible for its ongoing maintenance. The Centre has been designed, but is yet to become operational (World Bank 2013).

All countries in the region – with the exception of Somalia - have National Oil Spill Contingency Plans. In the majority of cases these were either developed and/or updated by the Regional Oil Spill Contingency Planning Project or the WIO Marine Highway Project (World Bank 2013).

CONCLUSIONS AND RECOMMENDATIONS

The recent discovery of significant additional oil and especially gas resources in the WIO region, together with a more general increase in trade and the AU 2050 AIM Strategy, suggests that it is highly likely that maritime activities are set to increase significantly in the region. This, together with factors such as climate change, heightens the environmental risks and points to the need to urgently develop

regional policies on:

• The implementation of Flag and Port state controls and the need to develop capacity in this regard;

• Regional co-operation around maritime surveillance which could be extended from the current co-operation around combatting piracy to include illegal, unregulated fishing, oil spills and other ship-related pollution, amongst others;

• Scientific monitoring and reporting of pollution levels and incidents;

• Prevention and control of alien and invasive species introduced by ships;

• The provision of adequate waste reception facilities at ports;

• Building awareness of the impacts of marine litter and increasing capacity to address the sources thereof;

• Response to the potential impacts of climate change on the maritime sector including, for example, the inclusion of climate change concerns into risk assessments and the development of Climate Adaptation Plans for ports;

• Financial mechanisms to provide for the required management activities.

References

Abuodha, P.A.W. and Kairo, J.G. (2001). Human-induced stresses on mangrove swamps along the Kenyan coast. *Hydrobiologia 458*(1-3), 255-265

African Development Bank (2010). *Summary of the Environmental and Social Impact Assessment for the Multinational Seychelles Submarine Cable Project*. Oxford University Press, USA

AU (2012). *2050 Africa's Integrated Maritime Strategy*. African Union. http://www.au.int/maritime

Anon Mozambique (2007). *Mozambique national summary report on land-based activities, sources of pollution and pollutant levels in water and sediment*. Draft report submitted to WIO-LaB PMU. Nairobi, Kenya

Anon Mauritius (2009). *National summary report on land-based activities, sources of pollution and pollutant levels in water and sediment: Mauritius*. Unpublished Report submitted to UNEP/WIO-LaB Project/Nairobi Convention Secretariat. Nairobi, Kenya

Antoine, H., Carolus, I., Naya, N., Radegonde, V. and Sabury, E. (2008). *The status of coastal and marine pollution in Seychelles*. Unpublished Report submitted to UNEP/WIO-LaB Project/Nairobi Convention Secretariat. Nairobi, Kenya

Awad, A. (2011). *Report on the Invasive Species Component of the MEDA's, TDA and SAP for the ASCLME Project*. Cape Town, South Africa

Bijoux, J.P., Decomarmond, A. and Aumeeruddy, R. (2008). Status of the Marine Environment Report Seychelles. UNEP-GEF WIO-LaB Project Addressing Land Based Activities in the Western Indian Ocean

De Mora, S. (2006). *An Assessment of the National Capabilities for Marine Pollution Monitoring in the Western Indian Ocean Region and Recommendations for Regional Capacity Building and Training Needs*. Report to UNEP and WIO-Lab by the International Atomic Energy Agency: Marine Environmental Laboratory. Monaco

DNV (2012). *Shipping 2020*. DNV Report, Executive Summary. Oslo

FAO (1999). *Land-based sources and activities affecting the marine, coastal and associated freshwater environment in Comoros, Kenya, Mozambique, Seychelles and United Republic of Tanzania*. EAF/5 (Waruinge D. and Ouya D., eds). Nairobi, Kenya

Fernandes, A. (1996). Pollution in Maputo Bay: Contamination levels from 1968 to 1996. *Revista Médica de Mozambique* 6(34). Instituto Nacional de Saúde

F-CCA (2013). *Cruise Industry Overview – 2013*. Florida-Caribbean Cruise Association. 20th Annual Cruise Conference and Tradeshow. 30 Sept. – 4 Oct. Cartagena, Colombia

Gove, D.Z. (2011). *Mozambique National Policy and Governance Assessment for Management of Coastal and Marine Resources*. Report prepared for the ASCLME Project

Greenpeace (2010). *The Toxic Ships: The Italian hub, the Mediterranean and Africa*. Greenpeace Report

Guy, N.R. (2013). *WIO Marine Highway Development and Coastal and Marine Pollution Prevention Project: Draft Project Completion Report (Components A and D)*. Unpublished report

Hussein, B.M. (2010). *The Evidence of Toxic and Radioactive Wastes Dumping in Somalia and its Impact on the Enjoyment of Human Rights: A Case Study*. Paper presented at

the United Nations Human Rights Council 14th Session: Panel discussion on Toxic Wastes

IMO (2012). *International Shipping Facts and Figures: Information Resources on Trade, Safety, Security, Environment*. International Maritime Organization

Jackson, L.F. (2011). *Marine Pollution in the Agulhas and Somali Currents Large Marine Ecosystem*. ASCLME Project: GEF/UNDP/UNOPS

Kenya Wildlife Service (2009). *Conservation and Management Strategy for Sea Turtles in Kenya: 2010 – 2014*. Nairobi: KWS

Lloyd's, QinetiQ and University of Strathclyde (2013*). Global Marine Trends 2030*. Brochure

McEvoy, D. and Mullett, J. (2013). *Enhancing the resilience of seaports to a changing climate: Research synthesis and implications for policy and practice. Work Package 4 of Enhancing the resilience of seaports to a changing climate report series*. National Climate Change Adaptation Research Facility. Gold Coast

Mohammed, S.M., Machiwa, J., Njau, K.N. and Ram, R. (2008). *Tanzania National Summary Report on Priority Land-based Activities, Sources of Pollution, and Pollutant Levels in Water and Sediment*. Unpublished Report prepared for WIO-LaB

Molnar, J.L., Gamboa, R.L., Revenga, C. and Spalding, M. (2008). Assessing the global threat of invasive species to marine biodiversity. *Front. Ecol. Environ. 6*(9), 485-492

Munga, D., Mwangi, S., Kamau, J., Nguli, M.M., Gwada, . PO., Daudi, L.N., Ong'Anda H., Mwaguni, S.M., Massa, H.S., Tole, M., Onyari, J.M., Makopa, J., Gachanja, A., Opello, G., Kheir, A. and Machua, S. (2006). *Land-based activities, pollution sources and levels in water and sediment in the coastal and marine area of Kenya*. Draft report submitted to WIO-LaB PMU. Nairobi, Kenya

Nageon de Lestang, J. and Carolus, I. (2011). *Seychelles National Level Policy and Governance Assessment for Marine and Coastal Resources*. First draft of Report prepared for the ASCLME Project

OSC (2006). *Chemical Carriers and Product Tankers: Demand, Supply and Profitability to 2015*. Ocean Shipping Consultants. England. http://www.OSClimited.com

OBP (2012a). *The Economic Cost of Somali Piracy: Working Paper*. Oceans Beyond Piracy. http://www.oceansbeyondpiracy.org

OBP (2012b). *The Human Cost of Maritime Piracy: Working Paper*. Oceans Beyond Piracy. http://www.oceansbeyondpiracy.org

UNCTAD (2006). *Review of Maritime Transport 2006*. United Nations publication. NY. Geneva

UNCTAD (2012). *Review of Maritime Transport 2012*. United Nations publication. NY. Geneva

UNCTAD (2013). *Review of Maritime Transport* 2013. United Nations publication. NY. Geneva

UNCTAD (2014). *Review of Maritime Transport 2014*. United Nations publication. NY. Geneva

UNEP (2005). *After the Tsunami. Rapid Environmental Assessment*. United Nations Environmental Programme

UNEP, Nairobi Convention Secretariat, WIOMSA (2008). *Marine Litter in the Eastern Africa Region: An Overview Assessment*. United Nations Environmental Programme

United Nations Security Council (2011). *Resolution 1976*. United Nations. New York

World Bank (2003). *Concept Note*: *GEF Western Indian Ocean Marine Highway Development and Marine Contamination Prevention Project*. Africa

World Bank (2013). *Implementation Completion and Results Report: GEF Western Indian Ocean Marine Highway Development and Marine Contamination Prevention Project*. World Bank Report No. ICR 2568. Africa

Wright, P. (2013). Impacts of climate change on ports and shipping. *MCCIP Science Review 2013*. pp. 263 – 270


Statoil
Transocean

26
Oil, Gas and Renewable Energy

Matthew D. Richmond

Opposite page: Ultra-deepwater drillship active in waters 2 000 m deep, off Tanzania. © Matthew D. Richmond.

INTRODUCTION

This chapter describes the status of development and utilisation of the various energy sources present in or accessed from the marine environment. For over ten years, natural methane gas extracted from below the seabed has been used to produce energy in some countries, famously in Tanzania and Mozambique. However, there are other less obvious alternatives to energy available in the sea, notably from tides, currents and waves and the thermal properties of waters from the deep ocean.

With the exception of Reunion and Mayotte (France), all countries in the WIO region are exempt from reducing greenhouse gas emissions under the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC). Consequently, there is no international obligation to reduce emissions from the burning of coal, oil or gas. The realisation is that these countries need energy to develop and reduce poverty and that their contributions to climate change are insignificant. However, they are still committed under the treaty to reduce their emissions. Actions taken to reduce emissions include support for renewable energy, improving energy efficiency, and reducing deforestation.

A common feature of the eastern Africa countries of Kenya, Tanzania and Mozambique, as well as Madagascar, is the generally poor coverage and irregular availability of electricity, infrastructure shortcomings that affect people's businesses, education and well-being. In Tanzania for example, with a population now exceeding 40 million, results from the 2010/11 National Panel Survey show that access to electricity had increased from 13 per cent to 17 per cent between 2008/09 and 2010/11, but that in rural areas access to electricity was only 5.3 per cent (NBS 2013).

This chapter considers the sources, impacts and potential of energy derived only from the marine environment, yet it is important to note that a number of land-based, renewable energy sources are being explored within the region. For example, Kenya is exploring benefits from geothermal energy (CDKN 2013) while Madagascar has identified significant small and micro-hydropower potential (Liu and others, 2013); solar and wind sites are considered on Reunion and Comoros (African Energy 2013), and the expanded use of biofuels on Mauritius (Republic of Mauritius 2014). In Tanzania and Mozambique, sugar cane and cassava projects to produce ethanol and biomass to fuel power generators are gaining support (Arndt and others, 2010, Wiggins and others, 2011). These are all land-based sources of energy.

Seychelles has plans for renewable sources to contribute at least 15 per cent to power needs by 2030 (Vannier 2013) mainly using wind and solar energy. Currently there are eight recently-installed windmills generating 6 MW of power (about 2.5 per cent of the total demand) (Vannier 2013), on reclaimed coastal land. The French island of Reunion is targeting renewable energy contributing 50 per cent of local electricity needs by 2020 and a further goal of 100 per cent of all energy use by 2030 (IEA-RETD 2012),

mainly through wind and solar, as well as marine-based cold water energy (see OTEC below).

The need for energy by WIO countries

At present, all nine countries in the WIO region rely on the importation of oil to fuel power stations to generate electricity. For some, fossil fuel is the main source of energy, notably for the smaller island states like Mauritius, Comoros, Seychelles and France (Mayotte and Reunion), but also Madagascar and even some of the larger mainland Africa states like Kenya. In Mozambique and South Africa, coal is the predominant source of energy for power stations, with hydropower also contributing significantly. The latter source is also important in Tanzania, contributing 49 per cent of energy needs (Kihwele and others, 2012).

The main *driving force* for increased energy supply in most WIO countries is to supply electricity to local industry, commerce and their citizens. In most countries, population growth remains significant, between 1-3 per cent *per annum*, with Tanzania having the highest growth rate (World Bank 2014), thus the needs increase each year. Added to population growth is the desire to reduce the dependence on imported fuel (for power stations, vehicles, plastic industries and other consumers of oil and gas). Over the last decade, the electrical power demand in Mauritius has increased at an average rate of 4 per cent *per annum* (AFD 2012). This implies a doubling time of about 18 years. Similar consumption/usage apply to mainland African countries. If local energy options exist, these countries could potentially eliminate the costs of importation of oil, often one of the largest items on the domestic budget. For example, in Kenya, oil imports are the second largest item, accounting for 25 per cent of imported commodities (Mengo 2014). Over the first quarter of 2012, Tanzania spent US$ 842.4 million on imported oil, equivalent to 33.7 per cent of the cost of all imported good (BoT 2012), whilst in Seychelles, oil imports in 2009 amounted to US$ 205 million, or 25.4 per cent of total imports (Reegle 2012).

One common realisation by most countries in the WIO region is that energy diversification is key to addressing the growing needs of the expanding populations and industries (African Energy 2013). It is recognised that not all energy systems are large scale nor can they all be integrated into national power grids which themselves are often lacking and extremely costly to install. A more realistic approach is to consider a range of power generating systems of varying sizes to reduce risks and maximise coverage, while also involving the private sector (Kihwele and others, 2012). All countries are already benefitting from the use of solar photovoltaic systems, from the domestic, mainly at the single household level, making a valuable contribution to rural livelihoods (Hammar and others, 2009).

The status of marine-based energy sources in the WIO region

This section presents the status of energy use and describes the potential for future use of renewable and non-renewable (fossil fuel) energy sources from the sea in the WIO region. Although wind and solar energy technologies can be installed in the marine environment, and wind towers are present for example in the Irish Sea, off the coast of Denmark and many other parts of the world, the design and challenging maintenance issues result in significant additional costs compared to installations on land. As such, their use in the WIO region is not considered here.

Fossil fuels from the coastal zone and offshore

Nations whose landmasses and maritime EEZ are of volcanic origin have little to be optimistic about in terms of the likelihood of making discoveries of fossil fuels (hydrocarbons), unlike those nations that comprise sedimentary basins. The latter are a feature of the Kenya, Tanzania, Madagascar, Mozambique, Seychelles and South Africa territorial seas, as well as those surrounding the Comoros. For hydrocarbons to develop, the following four factors or criteria need to be present: (i) there needs to be deposition of an organic-rich source rock, typically derived from phytoplankton and algae; (ii) there needs to have been a means whereby this organic material became buried and trapped under layers of sediment rapidly enough to avoid oxidation (decomposition); (iii) the trapped organic material must experience appropriate heat and pressure over time, to crack the organic compounds into oil and gas - a process generally requiring burial of several hundred (ideally thousands) of meters; and, (iv) 'traps', such as anticlines or fault blocks, need to be present to create a reservoir into which hydrocarbons will accumulate, and to seal it - such traps for oil and gas are generally found at depths of 2 000 to 4 000 m below the seabed. The composition of natural gas varies depending on source and processing, but typically consists of over 90 per cent methane and small amounts of ethane and other hydrocarbons as well as nitrogen, carbon dioxide and trace amounts of water vapour (Demirbas 2010).

The US Geological Survey (USGS) has identified four

geological provinces in the WIO region (Figure 26.1) for undiscovered, technically recoverable conventional oil and gas resources. The USGS study, by Brownfield and others (2012), revealed estimated mean volumes, for all four provinces combined, of 27 632 million barrels of oil (mmbo), 441 051 billion cubic feet of gas (bcfg) and 13 772 million barrels of natural gas liquid (mmbngl). To put the estimated volumes into perspective, the conversion rate of gas units to oil barrels is one barrel of oil (200 litres) being equivalent to 6 000 cubic feet of gas (cfg).

Recent discoveries and developments

The primary offshore discoveries recently made in East Africa (between 2010 and 2014) have been off the southern coast of Tanzania and northern coast of Mozambique, where combined estimates indicate the presence of at least 150 trillion cubic feet (tcf) of natural gas. This is based on Tanzania Petroleum Development Corporation's confirmation that the country's natural gas deposits are now estimated at 50 tcfg. Nellist (2014) and Deloitte (2013) report of at least 100 tcf of confirmed recoverable natural gas for Mozambique. Gas volume estimates change rapidly though, as more wells are drilled and existing wells are re-evaluated, but it is safe to say that at present, the above volume is the minimum found to date in this region.

The existing combined discoveries from the Ruvuma and Mafia basins (150 tcfg) is roughly equivalent to 25 000 million barrels of oil. The top African proven gas reserves are Nigeria (181 tcfg), Algeria (159 tcfg) and Mozambique (100 tcfg), with "east Africa deepwater" ranked overall third, according to Hanner (2014). Returning to the USGS estimates above, clearly there is potentially a great deal more gas (and oil) to be found in the provinces of the WIO that cover mainland Africa, western Madagascar and the Seychelles Plateau.

Both Tanzania and Mozambique have been benefitting from domestic gas supplies for the last ten years. Investment in development and production of the few methane reserves discovered in the 1970s, namely, in central and southern Tanzania, at Songo Songo and Mnazi Bay respectively, took place at the start of the new millennium. The Songo Songo field then began production in 2004, providing gas to Dar es Salaam for electricity, with the southern districts of Mtwara and Lindi now supplied with gas-generated electricity from the Mnazi Bay fields (Figure 26.2). The two producing gas fields (Songo Songo and Mnazi Bay) have a life expectancy of 25 to 30 years.

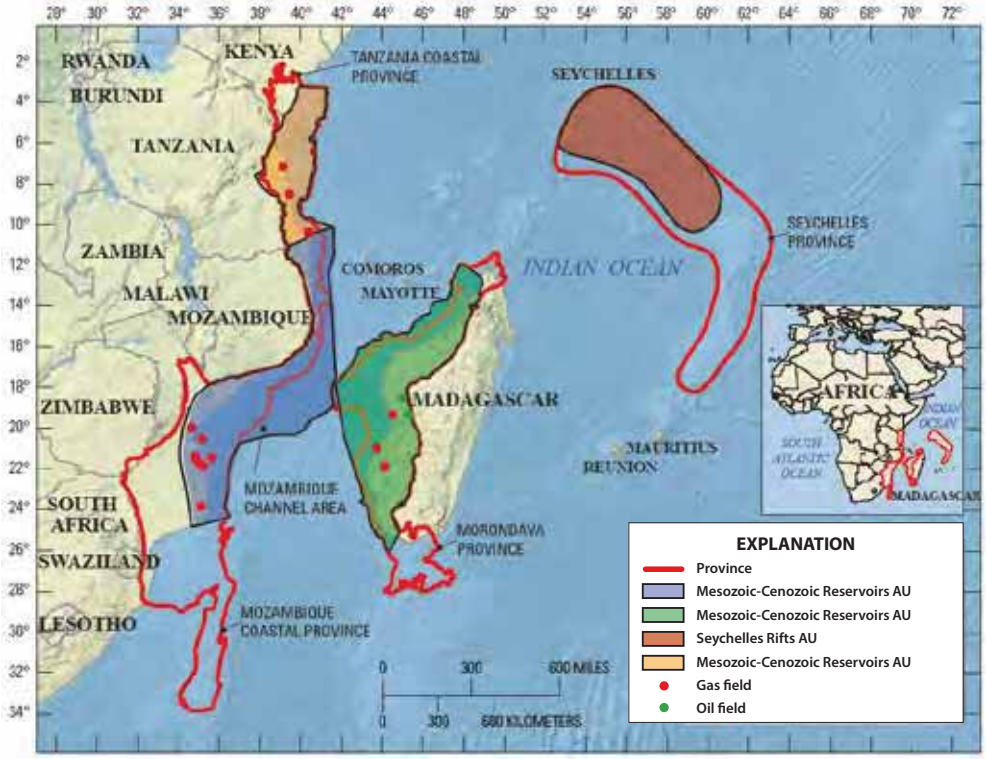


Figure 26.1. Locations of the four assessed geologic provinces and assessment units (AU) in the WIO region. Source: Brownfield and others (2012).

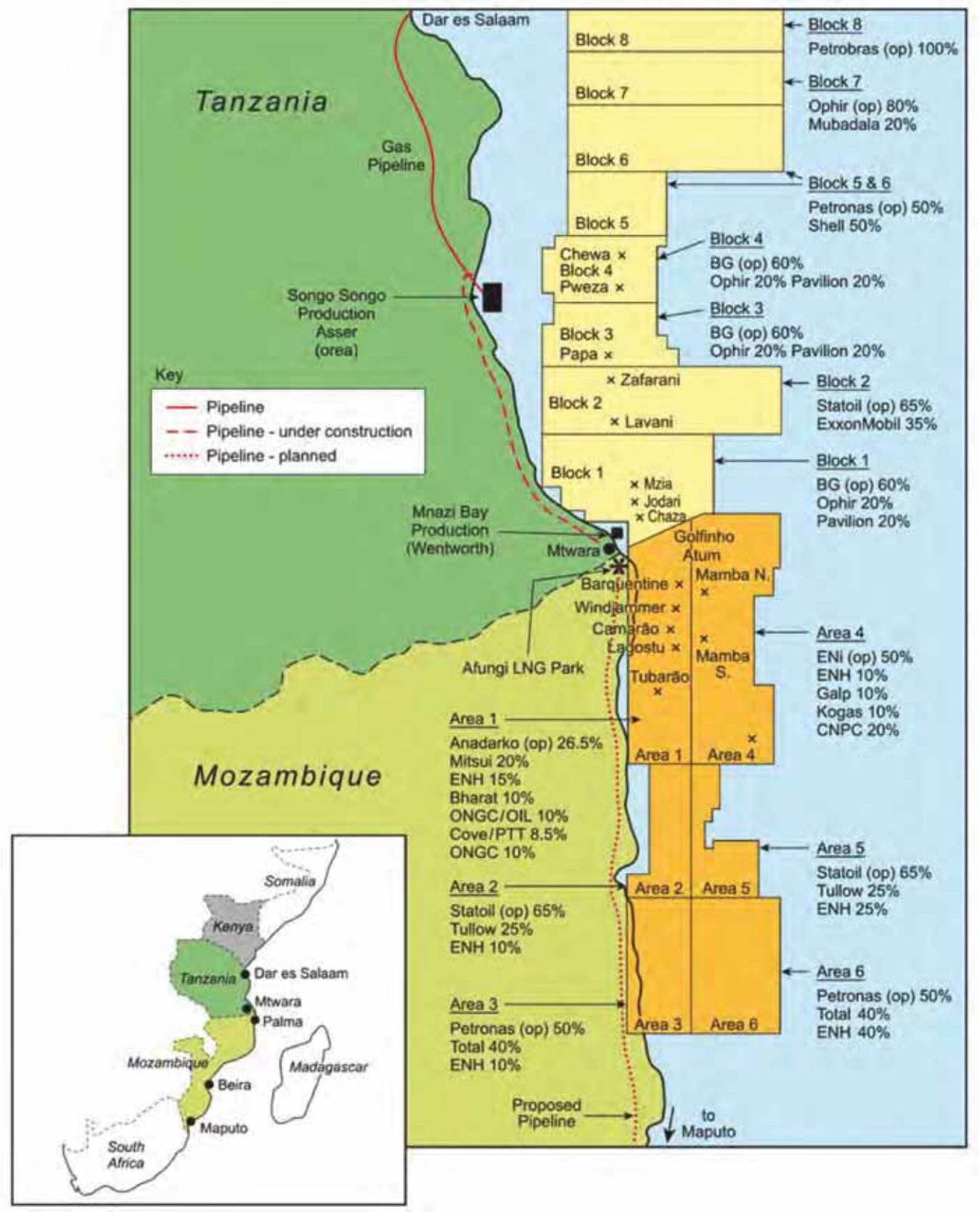


Figure 26.2. Southern Tanzania and northern Mozambique, showing most of the offshore exploration blocks, gas wells drilled (x), operator and other exploration companies involved, the locations of the Songo Songo and Mnazi Bay gas fields, various gas pipeline infrastructure and the site of Mozambique's Afungi LNG plant (under construction). Source: Wood Mackenzie (2014).

A number of industrial and commercial customers in the Dar es Salaam area already uses gas, and the soon to be completed additional gas infrastructure will boost usage. Expansion includes a 785 million cubic feet per day (mmcfpd) capacity, 542 km, 36" pipeline extending from Mnazi Bay to Dar es Salaam (see Figure 26.2) plus two new gas processing plants, on Songo Songo Island with a 140 mmcpfd capacity and at Madimba (Mtwara) with a 210 mmcfpd capacity (23 333 and 35 000 barrels of oil, respectively). The pipeline will provide gas transportation access to smaller discoveries by other gas exploration companies both on land and offshore. Two new gas-fired power stations to receive the processed gas are now under construction close to Dar es Salaam. The estimated completion of the entire expansion project is the end of 2015.

Similar developments also occurred in southern Mozambique, at the Pande and Temane gas fields, inshore of Vilanculos, near Bazaruto Archipelago (Figure 26.3). The gas supplies the Sasol Natural Gas Project in South Africa, a project that also included the construction of a central processing facility to clean the gas as well as the 865 km cross-border gas pipeline to Secunda in South Africa supplying gas to a petrochemical plant. The project started in March 2004 relying on wells located close to shore and in shallow water, with a combined volume of 5.5 tcfg, and an estimated lifespan for the production wells of approximately 25 years.

In Kenya, oil and gas exploration are on-going, with mixed results from offshore, though successful drilling and discoveries on land have been made in the Turkana Basin (Deloitte 2013). A recent exploration well drilled offshore, close to the EEZ border with Tanzania has intersected an oil column – the first-ever oil discovered off the East African coast, with high prospects for finding commercial quantities of the commodity in the area called the Lamu Basin (Pancontinental 2014). There are no commercial finds from exploration so far in Madagascar other than of minor heavy tars at Tsimiroro, 100 km inland. In Somalia there was past support for drilling operations but recent instability has precluded further development.

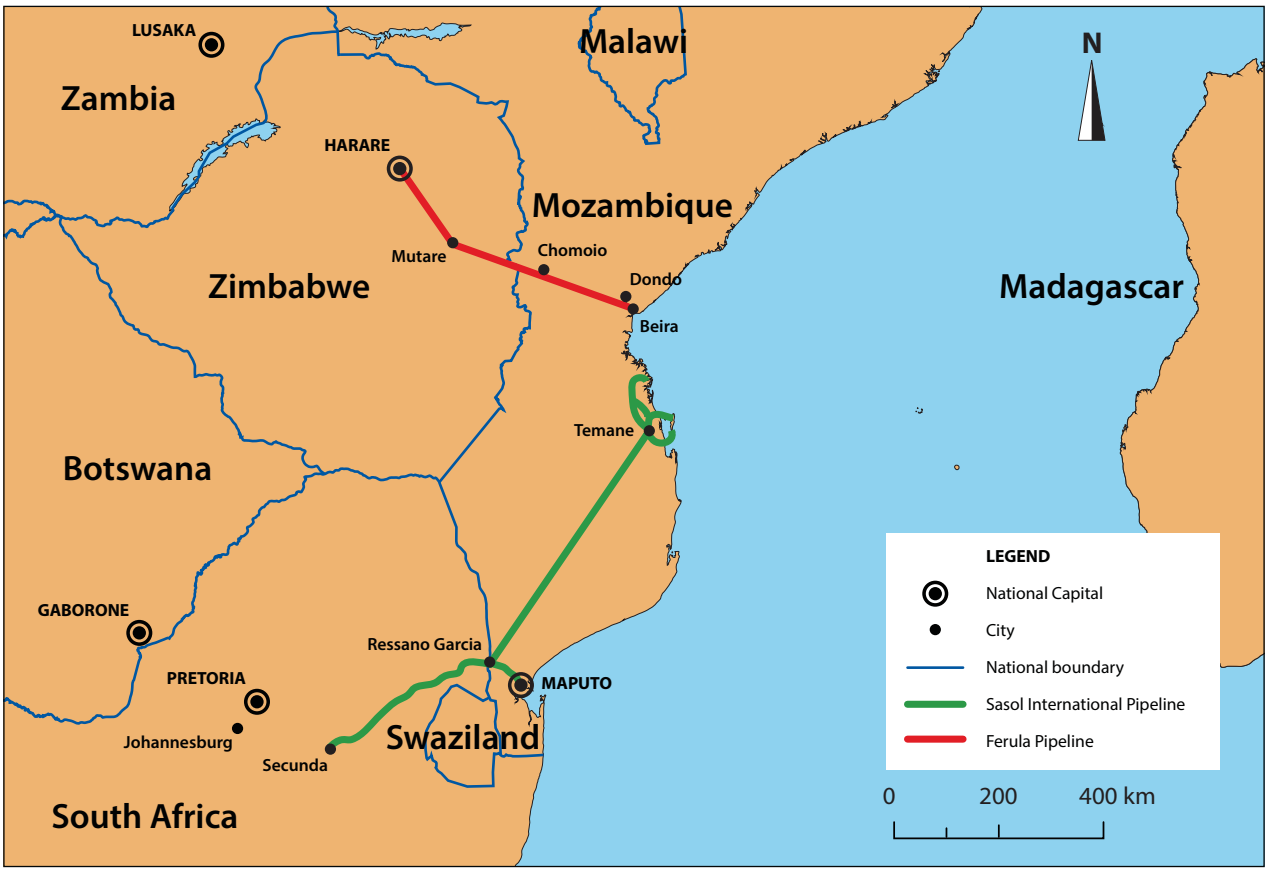


Figure 26.3. The Sasol Natural Gas project map, showing pipeline extending from the coastal gas fields of Temane and Pande to the industrial hub at Secunda in South Africa. Note: the Feruka pipeline, built in 1966, is 408 km long and supplies fuel oil to Harare, Zimbabwe. A similar pipeline exists in Tanzania, the Tazama pipeline, commissioned in 1968, extending 1 710 km from Dar es Salaam, supplying oil to Ndola, Zambia. Modified from: Wildcat International FZ-LLC 2013.

The East Africa discoveries have fuelled interest in the EEZs of neighbouring islands of Comoros, as well as around the islands of Europa, Juan de Nova and Bassas de India, all in the Mozambique Channel. In the Comoros, exploration is beginning in the western portion of its EEZ, in the Mozambique Channel, with expectations of discoveries linked to those of neighbouring Mozambique with possible similar geological features. Seismic surveys are soon to commence (Spectrum 2014).

Seychelles conducted 2-D seismic surveys across much of the Seychelles Plateau in the 1970s with the first exploratory wells drilled in the early 1980s. Though no commercial quantities were encountered, the presence of oil and gas "shows" proved that a "working hydrocarbon system" was present (Petro Seychelles 2014). The fourth exploration well was drilled in 1995 and 3-D seismic surveys completed in 2012. The near future includes additional exploration drilling with participation of four international oil and gas exploration companies.

Drilling and costs

The only way to really confirm the presence of oil and gas and fully understand the geology of the various sedimentary strata is to drill an exploratory well. On land, the cost (in Tanzania), to drill a single exploratory well, in an area from which only seismic data was gathered, can reach US$ 38 million, an example being SS-11 on Songo Songo Island, where additional costs are incurred for transportation by sea of all equipment and materials (Orca Exploration 2012). Deepwater drilling is much more expensive. For example, the day rate for a drillship from Transocean, for ultra-deepwater drilling such as recently taking place offshore Mozambique and Tanzania, is typically above US$ 500 000 (Forbes 2013), while Fred Olsen ASA, another supplier of deepwater drilling platforms, including the "Bedford Dolphin" to Anadarko, also in Mozambique, charged a day rate of US$ 484 000 (Fred. Olsen-Energy 2014). Combined with the cost of two supply boats, one anti-pirate gunboat, two service helicopters, plus technical personnel aboard and shore base personnel and equipment, the overall day rate for such as operation was US$ 1.2 million in Tanzania (Hoole 2012). A typical single well drilling program, assuming no unforeseen delays, lasts 45-60 days (Pancontinental 2013), hence the total costs amount to some US$ 50-70 million. Even with very good quality seismic data, the worldwide success rate for an exploratory well in a new region (a 'wildcat'), is usually much less than 20 per cent. From well-drilling to final production of oil in barrels (or gas in pipes, or compressed into liquid and in tanks on ships) requires large investment, rapidly amounting to thousands of millions of dollars. For most countries in the WIO region, local investors are unable to match the costs of exploration and are not prepared to take the risks, hence the need for participation of the large independent and major companies in the oil and gas industry.

Other than the supply to local gas-fired power stations and large industries (eg cement plants, bottling companies, glass manufactures, fertilizer and chemical factories), large gas discoveries need large consumers. These are also not present in the region. However, the gas finds have generated a marked interest, due to not only their size, but also their placement in proximity to Asia. The discoveries have placed East Africa in the running to supply major Asian Liquefied Natural Gas (LNG) importers, putting them in competition with the USA and Australia (see Box 26.1).

The second *driving force* behind fossil fuel exploration is the potential to export to energy-hungry consumers such as India and China. Over the last ten years, the USA changed from being a net importer of oil and gas to a net exporter of gas and only a minor importer of oil (see Zuckerman 2013). The dramatic change in fortune within the USA, largely due to new technologies applied to extracting oil and gas using hydraulic fracturing (or "fracking") of oil- and gas-bound shale rock, demonstrates the unpredictable nature of the industry and production.

Deep Ocean Water Application

Deep Ocean Water Application (DOWA) is the name for the use of the deep bottom seawater with temperature of 5° C or colder, found at a depths below 1 000 m that, when brought to the surface, can be used for a variety of energy-related applications. Its most useful property is its low temperature. Deep ocean water makes up about 90 per cent of the volume of the oceans. The profile of the deep-water changes little seasonally, and therefore, cold water is always available.

A temperature differential indicates energy potential. Where there is an energy gradient there is potential for productive use by humans. Assuming the extraction of deep ocean water is environmentally friendly and the source is replenished by natural mechanisms, it creates the potential for cleaner energy than that derived from fossil-fuels. The simplest use of cold water is for air conditioning: using the cold water itself to cool air saves the energy that

BOX 26.1. THE NEED FOR LIQUEFIED NATURAL GAS (LNG) IN TANZANIA AND MOZAMBIQUE



Testing a new methane gas well, Songo Songo Island, Tanzania. © Matthew D. Richmond.

It is important to note that not all the gas is recoverable, that estimates vary and change considerably, and, more importantly, if the gas is to be liquefied so that it can be exported overseas, then 40 per cent of the gas is consumed in order to liquefy the remaining 60 per cent. Consequently, natural gas is not as desirable as oil because it is harder to extract and takes much longer to get to market (especially when in remote areas). On an energy equivalency basis it sells at a deep discount to oil mainly because there are fewer applications (at present) for its use, requiring more complex infrastructure.

In Tanzania, the construction of the joint venture LNG plant between Statoil (from Norway) and the BG Group (UK) is expected to begin at Lindi in 2016. The costs are expected to range from US$ 20 000 million to 40 000 million (IMF 2014). These include construction of the liquefaction plant, feeder pipelines from source wells sited at depths of 500 to 2 500 m to shore, delivering gas to processing plants (perhaps two) that then feed the gas to the refrigeration trains (usually multiple trains which reduce the temperature to approximately -160°C, shrinking the gas to 1/600th of its original volume). Storage facilities are needed and a docking facility for loading onto up to three specialized liquid gas carrier vessels, each 200 m in length. At the peak of the development phase, the annual investment would amount to 19 per cent of GDP (IMF 2014).

An almost identical but larger project is close to start on the Afungi Peninsula, near Palma, Cabo Delgado Province, in northern Mozambique (Figure 26.2), coordinated by the American company Anadarko. The other major exploration company in the area is Eni (previously Agip) who are considering a floating LNG facility (or FLNG), as an option to a land-based installation. Whether there will be two separate operations or a combined single investment, the total is expected to exceed US$ 50 000 million (Reuters 2014). By the next millennium, Anadarko (2014) estimates that Mozambique will have the third largest gas liquefaction capacity, after Australia and Qatar. Both the Lindi and the Afungi terminals aim for completion to coincide with an expected shortage of LNG in Asian markets between 2018 and 2022.

Standard Bank (2014) estimated that the Afungi LNG facility, once operational, will result in large and unprecedented economic gains for Mozambique. Six trains of LNG will add an additional US$ 39 000 million to the Mozambican economy by 2035 over a baseline growth case. As such, GDP *per capita* will grow from approximately US$ 650 in 2013 to US$ 4 500 by 2035 in real terms. It is also estimated that after 2020, at full production, the Tanzanian government could receive annual revenues of between US$ 3 000 million and US$ 6 000 million depending on the scale of production, equivalent to 10-20 per cent of (2012) GDP. These would have a transformational impact on the debt outlook, as by way of comparison, the country's national debt stock at the end of June 2013 was $ 17 690 million (URT 2013). However, in both countries, uncertainty remains about aspects of the fiscal regime under which such projects would operate. Negotiations continue and the final investment decision, for Tanzania at least, is unlikely to be taken until late 2015 (IMF 2014). Finally, it is important to note that increasing *per capita* GDP does not guarantee equitable wealth sharing. The history of the oil sector in West Africa is a clear demonstration of how benefits tend to accrue to a tiny minority while the majority remain in poverty. A more appropriate measure would be median income, which would reflect changes that actually affect the people as a whole.

would be used by the compressors for traditional refrigeration (Barrero and Gómez 2012) which in general, consume about 40 per cent of total electrical output (Hurd 2012). Usage could increase ten times by 2050 (Isaac and van Vuuren 2009). Seawater-based air conditioning is not technically complex nor does it involve a high technical risk. This application is currently being developed in Mauritius (see Box 26.2). Ideally, the DOWA technology must be near its intended use-area (eg airport, business or industrial centres) so as to reduce energy loss as the cold water warms up. In the WIO region there are several locations with steep temperature gradients close to shore, for example around Comoros, off the narrow continental shelf of some mainland African countries and off South Africa's east coast, but the latter in a high-energy area with heavy shipping activity (Retief 2007).

Another use could be to replace expensive desalination plants. When cold water passes through a pipe surrounded by humid air, condensation results. The condensate is pure water, suitable for human consumption or irrigation (Summerhayes 1996, PMO 2013). There are also significant secondary applications for the cold deep water. It is rich in nutrients and minerals and when oxygenated at the surface can support a wealth of sea-life. The extra nutrient content provides unique opportunities for mariculture (Nakasone and Akeda 1999) and can boost growth and quality of a variety of natural organisms such as shrimps and sea grapes (green macroalgae) of the *Caulerpa* genus (Martin 2012). Other downstream business activities include cosmetics and pharmaceuticals from shampoos to mineral gels, agrochemicals and thalassotherapy.

Finally, via a technology called ocean thermal energy conversion (OTEC), the temperature difference can be converted into electricity; however, numerous technical challenges persist that have delayed development beyond government-funded trials (IRENA 2014).

Tidal energy

There are two forms of energy derived from tidal changes. The first utilised fixed turbines inserted into tidal streams. This form of tidal energy potential exists along the coast of African countries (Kenya, Tanzania, Mozambique and South Africa) and the west coast of Madagascar thanks to an approximate 4 m spring tidal range. Other parts of the WIO region experience too small a tidal range to create the necessary water velocities needed to operate the submerged turbines that require water currents of 1.0 to 2.5 m/s (EPRI 2005). Though no sites have tested tidal stream energy, in South Africa, two potential sites have been identified, with depth-averaged currents of about 1m/s and water depths of 6 to 7 m, at Langebaan Lagoon and Knysna Heads, both in the Western Cape (Retief 2007). In the USA, several tidal and in-stream current turbine applications are now close to commercialisation, taking advantage of the daily tidal cycles in near-shore ocean environments, or steady water flow from freshwater rivers (MMS 2007).

The second form of tidal energy is obtained by storing water behind a barrier, or barrage, after high-tide, and releasing it through tunnels and turbines once there is a substantial height differential after the ebb has started. It is generally accepted that a minimum tidal range of 5 m (preferably >10 m) is required for economic viability in barrage schemes (Retief 2007). However, the localities where such structures could be constructed in the WIO region without negatively affecting the local marine habitats and the communities that depend on them are rare.

Ocean currents

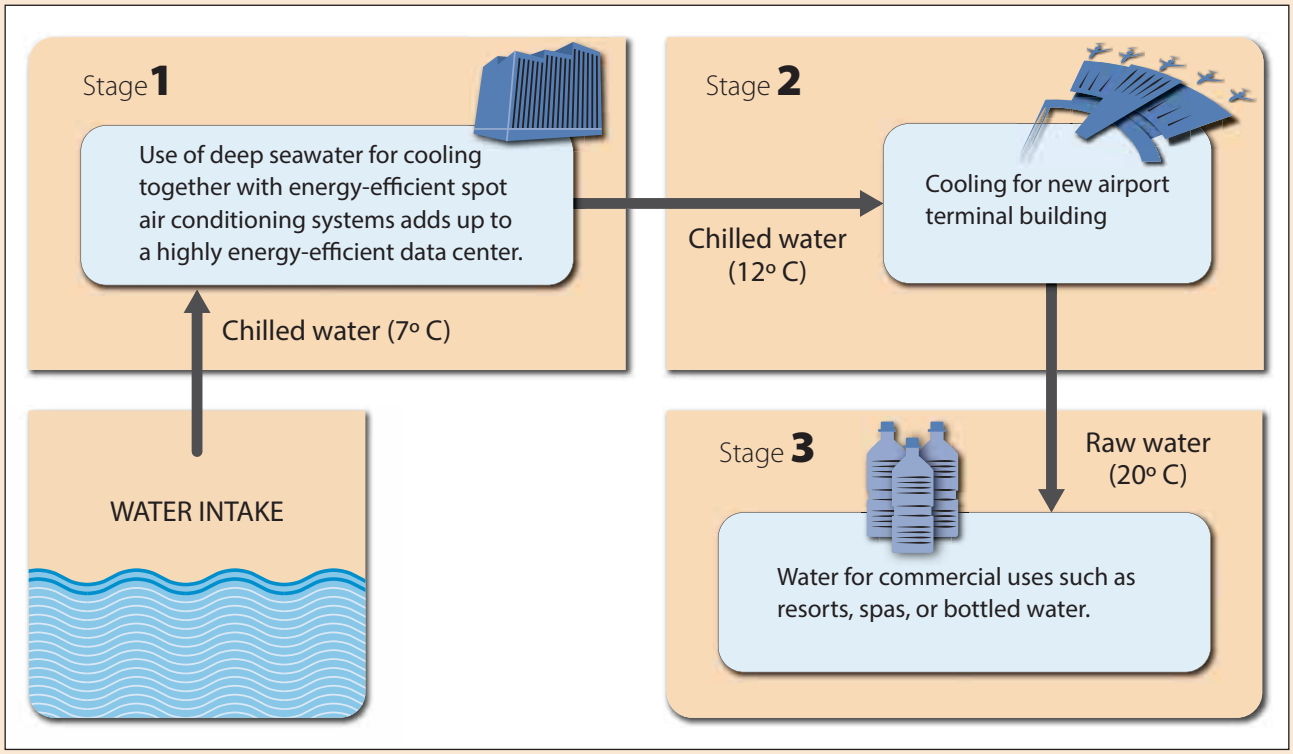
Ocean currents in the WIO region vary from weak in mid ocean to up to 4 or 5 knots along the east African coast (Lutjeharms and others, 1981, Ngusaru 2000, Benny 2002, Tomczak and Godfrey 2003), and unlike tidal current streams, are usually constant and unidirectional. A common feature of the ocean current energy prototypes tested to date is submerged turbines held in place by cables anchored to the seabed (DBEDT 2002).

The USA and other developed countries are pursuing ocean current energy; however, marine current energy is at an early stage of development and the only appropriate site so far identified in the USA is within the Florida Current (MMS 2007). Relative to wind, wave, and tidal resources, the energy resource potential for ocean current power is the least understood, and its technology is the least developed. It is widely acknowledged that the power of the ocean's currents is in general too diffuse to harness easily by conventional means (Summerhayes 1996). In the ocean area from Port Edward to Bashee River, south of Durban in South Africa, potential sites for testing current energy have been identified (Retief 2007).

Wave energy

The principle of harnessing wave energy is to use the energy stored in the motion of waves (namely the rise and fall of waves, or the rocking and heaving), or by focusing

BOX 26.2. DEEP OCEAN WATER APPLICATION (DOWA) IN MAURITIUS by Sachooda Ragoonaden



Business model for Mauritius. The rich mineral content of the deep seawater has the potential for a variety of commercial uses. Modified from: Hitachi Review 2014.

The concept of using deep cold water to cool the air in buildings is already being applied at diverse sites worldwide. At the Natural Energy Laboratory of Hawaii Authority since 1990, standard titanium heat exchangers and cold sea water provide air-conditioning of its main laboratory buildings, saving the facility nearly US$ 4 000 per month in electricity cost, since there is no need for the chiller which is the primary energy consumer for conventional air-conditioning systems (Craven and Daniel 2001). In Toronto, Canada, the system is meeting up to about 40 per cent of the city's cooling needs for office towers, sports and entertainment facilities and waterfront developments (Institute of Science in Society 2014). Others are planned for Curacao, Nassau, Reunion and Maldives.

Tropical countries consume a large proportion of their energy budget, mostly derived from fossil fuels, for air conditioning. Many are however ideally located close to deep cold ocean water and can therefore exploit the benefits of sea water air conditioning and take advantage of other deep sea water applications. Mauritius is planning the utilisation of the pure, nutrient-rich and cold deepsea water to develop DOWA projects. Two upstream projects are planned for implementation as from 2015 (Government of Mauritius 2014). The first one will be in the capital Port Louis whereby about 20 MW energy reduction is expected in the short term for cooling of offices and industrial buildings, with downstream activities following in a second phase. The other one will be implemented in the south of the island, in the vicinity of the international airport (Government of Mauritius 2014).

wave energy through refraction or diffraction. This source of energy has been investigated in some locations (eg Mauritius (NIO 1988) and South Africa (Joubert and van Niekerk 2013)), but it is generally accepted that of all countries in the WIO region, only South Africa has significant wave energy potential. Even there, potential sites are only south of the 30° S latitude (GESAMP 1984, Retief 2007), hence beyond the boundaries of the WIO region. Furthermore, wave energy generation reliability is low in most nearshore locations since the source is wind dependent, which is generally less inshore (Hammar and others, 2009). Despite these general conclusions, Tanzania is pres-

ently undertaking a feasibility study of wave energy at three sites, in cooperation with experts from Waveroller in Finland (WavePowerLab 2014).

Summary of energy options

Despite huge gas discoveries in Mozambique, and the start of gas flows to South Africa in 2004, gas contributes only 1 per cent to Mozambique's energy needs, and 2 per cent to those of South Africa. In Tanzania, present day gas supplies from the two coastal gas fields contribute over 40 per cent of national energy needs (MEM 2014). For Tanzania at least, the gas reserves are extremely important, helping secure power supplies in a country plagued for decades with power outages and a massively inadequate power supply infrastructure.

Kenya, Tanzania and Mozambique are at the start of what potentially could be a new and highly significant industry, located in the coastal and marine zone. In the latter two countries, there are already measurable economic benefits. If the projected oil and gas reserves continue to yield even a small portion of the results expected, then most countries of the WIO region will benefit from an income and saving on fuel imports that will significantly alter their economies, and with it contribute to eliminating poverty. However, the reality is that not all WIO countries have such resources, with Mauritius potentially being one of those that may not benefit from domestic fossil fuel reserves. South Africa is likely to exploit some, though from areas beyond the WIO boundaries, while Somalia's territorial waters remain largely unexplored due to the political instability.

Based on the information presented above, lack of development and uncertainties associated with all non-fossil fuel options at present reflect the meagre status of significant marine-based sources of energy in the region (Table 26.1). Aside from oil and gas, of the other three potential marine-based energy options presently available to WIO countries only cold, deep ocean water applications are seeing any development. This source of energy has the potential to expand and contribute meaningfully to reductions in the use of fossil fuel. Whether countries choose to explore its potential depends on the outcome of the oil and gas boom and the success of trials in Mauritius and Reunion.

IMPACTS FROM EXPLORATION, DEVELOPMENT AND PRODUCTION OF ENERGY FROM THE SEA

Impacts common to all structures placed in the marine environment

The presence of any structure placed in the ocean is likely to have some environmental and social impacts, even if only indirect ones. In the offshore oil and gas sector, likely structures include seismic survey and drillships, floating LNG plants, offshore oil and gas production platforms and seabed feed pipelines. Physical obstruction and interference with access for navigation or fishing activities, similarly affecting the movement of marine mammals and fish are the most obvious impacts. There is little by way of

Table 26.1. Current **(C)** and potential **(P)** marine-based energy exploration in WIO countries.

Countries	Oil & gas		Deep ocean water		Tidal streams		Ocean currents	
	C	P	C	P	C	P	C	P
Comoros	-	?	-	?	-	-	-	-
France (Reunion)	-	?			-	-	-	-
France (Mayotte)	-	?	-	?	-	-	-	?
France (Îles Ésparses)		?	-	?	-	-	-	?
Kenya		?	-	?	-	?	-	
Mauritius	-	-			-	-	-	?
Mozambique			-	?	-	?	-	
Seychelles		?	-	?	-	-	-	?
Somalia	-	?	-	?	-	?	-	
South Africa	-	?	-	?	-	?	-	?
Tanzania			-	?	-	?	-	

Status of exploitation:	None -	Beginning trials	Some	Significant	Major

effective mitigation, yet the impact is small in terms of the physical size of the obstruction compared to the available wider open water.

Wave energy devices located close to shore are likely to affect sediment transport and distribution and could result in erosion in some areas and accretion in others. This could affect inshore reefs and impact on other uses of the coastal zone. They could also be a hazard to shipping. Tidal barrages are also likely to cause changes to sediment transportation, water circulation and biological communities. However, over time, an increasingly diverse flora and fauna is likely to become established, indicating a degree of biological adjustment to the new environmental conditions. Related to the physical structures described above, the *pressure indicators* are the use of rock, gravel and sand for their construction.

Impacts from fossil fuel exploration and their mitigation

The initial seismic surveys use compressed air to generate explosive sound waves that penetrate the seabed. These acoustic sound waves, reflected back as echoes from each geological layer penetrated (to 10 km into the earth's crust), are recorded using hydrophones. The sound generated close to the 'air gun' does affect sea life in close proximity (a few metres) and can affect marine mammals such as whales up to 20 km distant or even further (McCauley 1994, Richardson and others, 1995, Gausland 2003, Huelsenbeck and Wood 2013). Avoidance of whale migratory seasons and known whale or dolphin breeding or feeding areas are necessary mitigation measure in most countries. More often than not, seismic surveys include a Marine Mammal Observer (MMO) on board, specifically to address encounters with mammals and to guide mitigation procedures, usually following Joint Nature Conservation Committee guidelines (JNCC 2009). These guidelines include soft start procedures, minimum safe distances from marine mammals and constant monitoring and vigilance during operations.

Deep-water exploration drilling, though expensive and likely to consume between 1 500 and 3 000 tonnes of compounds per well is generally a clean operation. Many benign substances, such as water, bentonite and various salts, comprise the bulk weight of the compounds used (Patin 1999). Some cuttings (the sand and bedrock drilled out) will be discarded back to the seabed after cleaning, resulting in local smothering. This physical impact, measurable in terms of tonnes of waste materials covering given areas, together with noise levels from seismic surveys represents the most recognizable *pressure indicators* during the exploration phase (excluding accidental events).

Waste chemicals, surplus cement, and some oils are usually collected, stored and properly disposed of or recycled ashore. Drilling mud, a lubricant the viscosity of thin honey, is needed to lubricate and cool the drill bit. It also binds the cuttings with which it returns to the surface, in a 'closed' mud system. Cuttings are separated and the drilling mud re-used. For deepwater drilling, low toxicity, biodegradable oil is currently considered the safest compound to use as the binding element, combined with the weighing agent, usually bentonite (also regularly used on land for standard bore-holed drilling). Disposal of waste drilling muds in the deep sea or open water, may have widespread impacts, affecting marine mammals, turtles, birds and fish, though toxicity is typically rapidly diluted by the receiving environment.

Mangrove forests are particularly sensitive to oil pollution. Accidental oil spills or blow-outs during exploration drilling pose the most significant threats to the coastline of eastern Africa. Coral reefs, mangrove forests, seagrass beds, lagoons, turtle nesting beaches, marine protected areas with valuable biodiversity, fishing grounds and tourist facilities, dolphins, dugongs, whale sharks and humpback whales are common features of the region. All would potentially be impacted to varying degrees by a massive oil spill.

In most countries of the WIO region, oil and gas exploration is required by law to be preceded by an Environmental and Social Impact Assessment (or ESIA). ESIAs should identify the likely impacts of activities and the affected areas and stakeholders, and design mitigation measures and monitoring plans to address these. Associated with ESIA is the need for oil spill contingency plans. So far, oil has not been found in viable quantities in the WIO region but with large discoveries of more methane gas confirmed, there is a growing optimism that oil discoveries are only a matter of time. Other than from an extremely unlikely accident (like a crude oil blowout), disturbance to marine life from drilling, including to migrating Humpback whales, should be negligible. While EIAs are generally project-specific, a Strategic Environmental Assessment (SEA) is strongly recommended in cases where a new major resource is being developed, such as the gas industry in countries like Tanzania and Mozambique. An SEA considers the broader scenario, including legislation

likely to have an effect on the management, conservation and enhancement of the local environment (including coastal tourism and security) and the sustainable management of natural resources (like fisheries), as well as any relevant regulations, policies, programs and development plans, and helps plot the development of the whole sector.

The *state indicators* associated with exploration for oil and gas include the noise levels that impacts on migrating species such as whales, turtles, tuna and whale sharks; the amounts of discharged drilling muds and fluids at the well locations, on the seabed and into the water column; and, the resulting degraded seawater quality around drilling platforms. Meanwhile, *impact indicators* related to exploration (and at times, production) include reduction in migrating marine species.

Impacts from fossil fuel production

Once gas or oil reserves are identified and production commences, the transportation of fossil fuels is vulnerable to poor maintenance, weak infrastructure and accidents, resulting in potential threats to the coastal and marine environment. Impacts from methane leaks are not well-documented, but impacts on the marine environment from crude oil are much better understood (eg Gilbert 1982, Patin 1999, IPIECA 2000). Consequently, *impact indicators* related to oil and gas production (and at times, exploration) include the loss of mangrove forest and seagrass beds from oil spills.

Social impacts associated with the developing industry in Tanzania and Mozambique have already been felt. Some are positive, like increased local employment associated with the industry, benefits from corporate social responsibility initiatives (often linked to training and education) and increased tax revenues from the spurred business at locations such as Cabo Delgado and Pemba in Mozambique and Mtwara in Tanzania. *Impact indicators* related to these socio-economic aspects include tax revenues, figures of employment and trained and skilled workforce. Negative aspects have, unfortunately, also manifested themselves, particularly in Mtwara where riots developed after rumours circulated that the 542 km gas pipeline (mentioned earlier) would transport "local" gas to Dar es Salaam without benefits to the local inhabitants. Relevant *impact indicators* might be the number of incidences of unrest where police where involved, or the costs of housing and basic foodstuff - inflationary consequences of the rapid development of any industry.

Before natural gas can be utilized, it must be processed (cleaned) to remove impurities and water. The resulting "produced water" is usually discharged to sea after removal of hydrocarbons and other chemicals, though low levels remain. Though the quantities of produced water are generally low, the contaminants (which can usually be removed) do nevertheless present pollution threats which can be measured and thus classified as *pressure impacts*.

Cumulative impacts from methane leaks is a potential major negative aspect of its use as an energy source and represents another *pressure indicator*. As the utilisation of methane increases, there are concerns that leaks of this gas, a far more potent contributor to climate change than carbon dioxide, will offset any gains from reductions in use of more dirty hydrocarbons like coal and oil. Odourless and clear, tracking leaks from pipelines and drilling is very difficult. Even in the USA, where natural gas is increasingly contributing to energy supplies, the Environmental Defence Fund has not yet determined how much gas is escaping to the atmosphere (Zuckerman 2013).

LOCAL PARTICIPATION IN MARINE-BASED ENERGY OPTIONS

The governments and business sectors of most countries in the WIO region have limited capacity to engage in the development of the marine-based energy options described above. Clear weaknesses in capacity include a lack of a maritime sector in the first place, combined with inadequate safety and security considerations, and limited technical skills (in the geological, petrochemical, technological sectors) as well as in engineering, construction, logistics and supplies, health and safety capabilities. There are also inadequacies among national regulators and ESIA consultants.

The gaps are slowly being addressed by international NGOs such as WWF, some companies under their corporate social responsibility (CSR) mandates, Oil for Development (Norway), financial institutions (eg World Bank) and other initiatives. Engaging in capacity building is vital for national buy-in and participation, critical to building confidence, transparency and maintaining long-term sustainability.

With environmental and social issues associated with oil spill response extensively covered in the media following the 2010 Gulf of Mexico spill, oil spill preparedness remains as important as ever. In many WIO countries, gov-

ernment institutions tasked with management of the environment, and ensuring compliance of mitigation measures and monitoring procedures associated with such large projects as deep-sea drilling, are often lacking in technical capacity. Fortunately, there is support from donors, the industry and NGOs, to assist local governments to better manage an activity that may become a significant presence in the region in the years to come.

In additional to national lack of capacity, the development of renewable energy options (including marine-based options) are hampered by a number of issues, as described by Hammar and others (2009), and include the following:

- Absence of long-term hydrological and meteorological data;
- Weak transport infrastructure;
- The need to include local participation in order to develop acceptance;
- Lack of locally-available spare parts;
- Insufficient electricity grid coverage;
- Theft and vandalism, notably in Tanzania; and,
- High dependence of rural communities on ecosystem services (mangrove forests, coral reefs, intertidal flats).

TRAJECTORY AND CONCLUSIONS

The USA and the companies involved in the 2010 Gulf of Mexico Macondo spill demonstrated that they have sufficient capacity to handle the logistics and costs of a rapid and comprehensive response and clean-up, though much of the oil remains unaccounted for. A similar event in coastal East Africa would however be more complex, less certain in outcome and thus potentially a lot more damaging to the local economy and the sensitive coastal and marine environment. There are many lessons from the recent Gulf of Mexico's oil spill that are relevant to the WIO region. These include recognizing the need for governments, industry and NGOs to work together during an accident, but more importantly, before any accident in order to reduce the likelihood that such an accident could occur. The highest technical standards must be applied and monitoring should be thorough. This includes for example, ensuring that well casings have proper seals and are set at proper depths to avoid drilling chemicals leaking into underground aquifers.

Added to the risk of oil spills are the vagaries of the energy market, regional and national politics, social and development issues, and the impacts of changing technology on fossil fuel discoveries. On the latter for example, the recent discovery of shale gas in the USA, among which is the Marcellus gas resource, the same size as the oil and gas resource of the North Sea, with 500 tcfg, equivalent to 83 000 million barrels of oil, becomes a "game changer" (Zuckerman 2013). The USA can now consider itself a net gas exporter, something not imaged a few years back.

Whether China and other Asian countries manage to explore their own enormous reservoirs of natural gas will likely influence the demand for natural gas from sources such as those in the WIO region, where costs of exploration and production are high, even though extraction costs are relatively low because the gas is readily extracted. The projected demand will significantly impact the profitability of the industry in the region, where massive investments are required to explore, liquefy and export the gas. At the very least, if local energy needs are met, the region will significantly benefit, but that will depend on the relationships between the exploration companies and national governments who presently do not have the financial or technical capacity to undertake exploration alone. While some large companies such as the BG Group, Petrobras, Statoil AS, Shell, Exxon, Anadarko and Eni are presently engaged in exploration in the WIO region, there are no guarantees for future involvement. These companies require stability of gas demand and security of their investment, two factors that the countries in the WIO at present cannot guarantee. As described above, the demand for natural gas from the WIO is influenced by factors beyond control of regional governments. Depending on discoveries within the various (often multi-country) assets held by such companies, their presence in any one country can change without notice. Farm-ins, by-outs, mergers, and go-slow are common terms in the industry were companies often come and go within a few years, especially in the early days of exploration and development. Security of their investments at the national level is also somewhat unpredictable, as local politics jostle with issues of ownership, transparency, "local content" and national revenues. The experience from West Africa and the "resource curse" where large proportions of the revenues from oil production that started in the 1960s ended up in the private accounts of politicians, while the citizens remained below the poverty line, is a reminder than young African democracies are not always the safest places to invest (Shaxson 2007). The vision of a gas-powered economy as proposed by some politicians may and hopefully will become a reality, while the "gas bonanza" hoped for by

some is subject to many more *driving forces* beyond the influence of the region's governments.

There exists the risk that if the major companies hesitate to invest in the WIO region, smaller companies will partner with local governments to fill the gap. While such a scenario may help fulfil the expectation to exploit local resources, it also potentially increases the possibility of accidents since the mega-companies usually have more stringent technical, environmental and social standards, and the experience and financial means to address associated issues. These standards are mainly driven by the corporate social responsibility targets that are increasingly a requirement of shareholders of major companies in developed nations. Smaller companies often are not pressed to maintain such standards and also do not have the financial base to compensate in the event of a major accidental event such as an oil blow-out at sea. However, the 2010 Macondo well blow-out in the Gulf of Mexico showed how in some instances companies like BP, Haliburton and Schlumberger fail to perform as planned, and accidents still happen.

In Tanzania, the draft Natural Gas Policy includes the following statement: "A Natural Gas Revenue Fund will be established and managed to ensure transparency and accountability over collection, allocation, expenditure and management of all natural gas revenues." A similar gas policy is being drafted in Mozambique. Whether these have come about due to influence from Norway where a special fund ensures that riches from fossil fuels are screened from political interference is not clear, but such policies if implemented may indeed secure the mineral wealth for the population at large and over the long term, avoiding the well-known "resource curse" typical of so many other countries in Africa. It is hoped by many that such policies will bear fruit, but only time will tell. The need for transparency, national dialogue and sound fiscal management of the natural gas revenue cannot be over-emphasized. There is also concern that countries like Tanzania and Mozambique are not "ready" for oil and gas, or natural energies based on the development of new policies and legislation. This is a major part of the response required by governments.

Based on the regional energy opportunities described above, the following are recommended:

- The development of awareness and capacity building in all areas associated with energy exploration are desperately needed in most countries in the WIO region. This particularly includes the environmental regulators (responsible for SEAs and ESIAs) and those charged with developing contracts and agreements with energy sector investors.
- Promote effective management and good governance of the extractive sector, as suggested by the Extractive Industries Transparency Initiative (EITI) and establish a rigorous fiscal regime with transparent tracking of both incomes generated and the fate of that income. Establish ring-fencing of revenues from the profitable sectors (eg oil and gas) to avoid politicising the resource and its benefits and ensure transparent and wise use of the same. Encourage participation of civil society watchdog organisations to help ensure equitable distribution of benefits.
- Protect the marine environment (including migratory species) and ensure oil pollution preparedness and that oil and gas companies have adequate insurance (eg US$ 10 000 million) in the event of a spill and can cover clean-up costs and compensation for loss of livelihoods.
- Sign and ratify all International Maritime Organisation (IMO) conventions relevant to oil and gas exploration, shipping, transportation of oil etc.
- Review legal mandates to ensure that compensation for damages caused by marine-based energy companies are streamlined.
- Adhere to the conditions of the Nairobi Convention. The most relevant articles, among others, are: 5 (pollution from ships), 8 (pollution from seabed activities, including oil and gas exploration), 12 (co-operation in combating pollution in cases of emergency) and 16 (liability and compensation).
- Develop and promote alternative, renewable energy alternatives.
- Promote regional coordination on planning of transboundary issues such as oil spill contingency, piracy and security, as well as cross-border developments to minimize negative impacts and maximize benefits from marine-based energy sources.

References

AFD (2012). *AFD and Mauritius - Sustainable Island. A partnership for a sustainable societal project*. Agence Française de Développement/Agence de Port-Louis/FFEM

African Energy (2013). *Indian Ocean power update report: diversification is key*. Issue 257. Cross-border Information

Anadarko (2014). *Mozambique Fact Sheet 081814*. Available at http://www.anadarko.com

Arndt, C., Pauw, K. and Thurlow, J. (2010). *Biofuels and Economic Development in Tanzania*. IFPRI Discussion Paper 00966. Development Strategy and Governance Division. International Food Policy Research Institute

Barrero, E.M. and Gómez, F.S. (2012). *Comparison of a conventional split cooling system with sea water district cooling and solar cold triple absorption cycle systems*. MSc Thesis in Energy Systems. University of Gävle. Faculty of Engineering and Sustainable Development

Benny, P.N. (2002). Variability of Western Indian ocean currents. *Western Indian Ocean J. Mar. Sci.* 81 (1), 81–90

BoT (2012). *Economic Bulletin for the Quarter Ending March, 2012*. Vol. XLIV No 1. Bank of Tanzania. Dar es Salaam

Brownfield, M.E., Schenk, C.J., Charpentier, R.R., Klett, T.R., Cook, T.A., Pollastro, R.M. and Tennyson, M.E. (2012). *Assessment of Undiscovered Oil and Gas Resources of Four East Africa Geologic Provinces*. No 2012-3039. U.S. Geological Survey's (USGS). World Petroleum Resources Project

CDKN (2013). Harnessing geothermal energy: The case of Kenya. *In Inside stories on climate compatible development* (eds. P. Kollikho and B. Rivard) Climate and Development Knowledge Network

Craven, J.P. and Daniel, T.H. (2001). *The Current Status of Deep Ocean Water Applications: Meeting the Okamura-Craven Challenge*. 24th Meeting of the UJNR Marine Facilities Panel: 4-12 November. Honolulu, Hawaii, USA

DBEDT (2002). *Feasibility of Developing Wave Power as a Renewable Energy Resource for Hawaii*. Department of Business, Economic Development, and Tourism. Honolulu

Deloitte (2013). *The Deloitte Guide to Oil and Gas in East Africa. Where potential lies*. 2013 edition. Deloitte and Touche

Demirbas, A. (2010). *Methane Gas Hydrate*. Green Energy and Technology. Springer-Verlag London

EPRI (2005). *Ocean Tidal and Wave Energy. Renewable Energy Technical Assessment Guide – TAG-RE: 2005*. No 1010489. EPRI. Palo Alto, California

Forbes (2013). *Transocean Bubbles To $55 On Ultra-Deepwater Demand*. Investing. 24 june. Trefis Team. Contributor. http://www.forbes.com/sites/greatspeculations/2013/06/24/ultra-deepwater-demand-helps-transocean-bubble-to-55/ Accessed at 19 November 2014

Fred. Olsen-Energy (2014). *Presentation 2Q 2014*. Fred. Olsen Energy. 11th July. Oslo. http://fredolsen-energy.com/?nid=198740andlcid=1033andiid=278815andpid=FredOlsenBasic-ReportYear-QuarterReports.Fred-OlsenBasic-QuarterReport-QPresentation Accessed at 19 November

Gausland, I. (2003). *Seismic surveys Impacts on fish and fisheries*. Report for Norwegian Oil Industry Association (OLF). Stavanger

GESAMP (1984). *Marine Pollution Implications of Ocean Energy Development*. Report and Studies GESAMP (20). GESAM_-IMO/FAO/UNESCO/WMO/WHO/IAEA/UN/UNEP/ Joint Group of Experts on Scientific Aspects of Marine Pollution

Gilbert, J.T.E. (ed.) (1982). *Environmental Planning Guidelines for Offshore Oil and Gas Development*. East-West Centre. University Press, Hawaii

Government of Mauritius (2014). *Board of Investment eNewsletter. Investment, Trade and Renewable energy*. Issue 67. National Investment Promotional Agency

Hammar, L., Ehnberg, J., Gullström, M. and Molander, S. (2009). *Ocean energy in combination with land-based renewable energy sources: appropriate technology for smaller electricity grids in Africa?* Proceedings of the 8th European Wave and Tidal Energy Conference. Uppsala, Sweden

Hanner, I. (2014). *Top 10 African Oil and Gas Hotspots*. Exploration World. 1 August. http://explorationworld.com/top10/79/INFOGRAPHIC-Top-10-African-Oil-and-Gas-Hotspots. Accessed at 19 November

Hitachi Review (2014). *Treasure in the Depths of the Ocean - Multi-stage Deep Seawater Utilization System*. Visionaries 2014. Vol. 63. No 3, 24-29

Hoole, L. (2012). *Mud, pirates, jellyfish and gas. The Mtwara Story*. Ophir Energy

Huelsenbeck, M. and Wood, C. (2013). *A Deaf Whale is A Dead Whale. Seismic Airgun Testing for Oil and Gas Threatens Marine Life and Coastal Economies*. Oceana

Hurd, D. (2012). *The high cost of air conditioning*. Small

Islands States Foundation. 5 November. Available at http://www.smallislandstates.org/the-high-cost-of-air-conditioning/

IEA-RETD (2012). *Renewable Energies for Remote Areas and Islands (REMOTE)*. International Energy Agency - Renewable Energy Technology Deployment. Paris, France.

IMF (2014). *United Republic of Tanzania Selected Issues*. IMF Country Report No 14/121

Institute of Science in Society (2014). *The Blue Revolution: Air Condition and Energy from Deep Waters of Lakes and Oceans*. Available at http://www.i-sis.org.uk/DeepWaterEnergy.php

IPIECA (2000). *A Guide to Contingency Planning for Oil Spills on Water*. 2nd edition. International Petroleum Industry Environmental Conservation Association. London. Available at http://www.ipieca.org

IRENA (2014). *Ocean Thermal Energy Conversion. Technology Brief*. IRENA Ocean Energy Technology Brief 1

Isaac, M. and van Vuuren, D.P. (2009). Modeling global residential sector energy demand for heating and air conditioning in the context of climate change. *Energy policy* 37(2), 507-521

JNCC (2009). *Guidelines for minimising acoustic disturbance to marine mammals from seismic surveys*. JNCC, Aberdeen

Joubert, J.R. and van Niekerk, J.L. (2013). *South African Wave Energy Resource Data. A Case Study*. Centre for Renewable and Sustainable Energy Studies

Kihwele, S., Hur, K. and Kyaruzi, A. (2012). Visions, Scenarios and Action Plans Towards Next Generation Tanzania Power System. *Energies*, 5(10), 3908-3927

Liu, H., Masera, D. and Esser, L. (eds.) (2013). *World Small Hydropower Development Report 2013*. United Nations Industrial Development Organization; International Center on Small Hydro Power. Available at www.small-hydroworld.org

Lutjeharms, J.R.E., Bang, N.D. and Duncan, C.P. (1981). Characteristics of the currents east and south of Madagascar. Deep Sea Res. A 28(9), 879–899

Martin, B. (2012). *More things Japanese*. Available at http://morethingsjapanese.com/deep-sea-water-uses/

McCauley, R.D. (1994). The environmental implications of offshore oil and gas development in Australia – seismic surveys. In *Environmental Implications of Offshore Oil and Gas Development in Australia - The Findings of an Independent Scientific Review*. (eds. Swan, J.M., Neff, J.M. and Young, P.C.) pp. 19-122. Australian Petroleum Exploration Association, Sydney

MEM (2014). *Joint Energy Sector Review 2012/13*. Updated final report. Ministry of Energy and Minerals (MEM) and Pöyry SwedPower AB. Tanzania

Mengo, B. (2014). *Kenya's oil import bill dips amid drop in fuel use*. http://www.coastweek.com/3649-latest-news-Kenyan-oil-import-bill-dips-amid-drop-in-fuel-use.htm Accessed at 14 November

MMS (2007). *Programmatic Environmental Impact Statement for Alternative Energy Development and Production and Alternate Use of Facilities on the Outer Continental Shelf. Final Environmental Impact Statement*. OCS EIS/EA. U.S. Department of the Interior, Minerals Management Service

Nakasone, T. and Akeda, S. (1999). *The application of deep sea water in Japan*. UJNR Technical Report No 28. Japan

NBS (2013). *Tanzania in Figures 2012*. National Bureau of Statistics. United Republic of Tanzania, Ministry of Finance

Nellist, R. (2014). *Energy and Minerals*. Tanzanian Affairs. Business and the Economy. Issue 109. 1 September. http://www.tzaffairs.org/2014/09/energy-minerals-3/ Accessed at 18 November 2014

Ngusaru, A. (ed.) (2000). *The Present State of Knowledge of Marine Science in Tanzania: Synthesis Report*. Tanzania Coastal Management Partnership (TCMP) Support Unit and the Science and Technical Working Group. Working Document: 5047. Dar es Salamm, Tanzania

NIO (1988). *Annual Report 23 (1987-88)*. National Institute of Oceanography

Orca Exploration (2012). *Orca Exploration Group Inc. Updates Status in Tanzania and Italy*. 4 July. Available at http://www.orcaexploration.com/news_12_4_july.asp

Pancontinental (2013). *Quarterly Activities Report March 2012*. Pancontinental Oil and Gas NL. http://pancon.com.au/wp-content/uploads/2014/03/Quarterly-Activities-Report-31-March-2012.pdf. Accessed at 19 November 2014

Patin, S. (1999). *Environmental Impact of the Offshore Oil and Gas Industry*. EcoMonitor Publishing, USA

Petro Seychelles (2014). *Hydrocarbon Indicators*. Available at http://www.petroseychelles.com/index.php/geotechnical/petroleum-system/hydrocarbon-indicators

PMO (2013). *The Ocean Economy. A Roadmap for Mauritius*. Prime Minister's Office. December 2013

Reegle (2012). *Seychelles*. http://www.reegle.info/policy-

and-regulatory-overviews/SC Accessed at 13 November 2014

Republic of Mauritius (2014). *National Report of the Republic of Mauritius. Third International Conference on Small Island Developing States (SIDS)*. UNDESA/UNDP

Retief, D. (2007). *Ocean energy in South Africa*. Presentation. Centre for renewable and sustainable energy studies. Wave power seminar. 8 June. Prestedge Retief Dresner Wijnberg (Pty) Ltd. Consulting Port, Coastal and environmental Engineers

Reuters (2014). *Italy's Eni invites design proposals for Mozambique LNG plant*. 16 April. Available at http://www.reuters.com/article/2014/04/16/eni-mozambique-lng-idUSL6N0N84A720140416

Richardson, W.J., Greeve, C.R., Malme, C.I. and Thomson, D.H. (1995). *Marine Mammals and Noise*. Academic Press, Inc

Rigzone (2014). *Pancontinental Confirms Oil Discovery at Sunbird-1 Well Offshore Kenya*. Pancontinental Oil and Gas NL. http://www.rigzone.com/news/oil_gas/a/133604/Pancontinental_Confirms_Oil_Discovery_at_Sunbird1_Well_Offshore_Kenya#sthash.dFBxQPWd.dpuf Accessed 19 November 2014

Shaxson, N. (2007). *Poisoned Wells: the dirty politics of African oil*. Palgrave Macmillan, NY

Spectrum (2014). *New seismic agreement with Madagascar's OMNIS*. Press Release 3 October 2014. http://www.spectrumasa.com/press-release/new-seismic-agreement-with-madagascars-omnis Accessed at 19 November 2014

Standard Bank (2014). *Mozambique LNG: Macroeconomic Study*. 31 July 2014. Standard Bank. Coningarth Economists

Summerhayes, C.P. (1996). Ocean resources. In *Oceanography - An Illustrated Guide*. (eds. C.P. Summerhayes and S.A. Thorpe) pp. 314-337. Manson Publishing, London

Tomczak, M. and Godfrey, J.S. (2003). *Regional Oceanography: an Introduction*. 2nd edition. Daya Publishing House, Delhi

URT (2013). *Tanzania National Debt Sustainability Analysis*. Ministry of Finance, The United Republic of Tanzania

Vannier, R. (2013). *Winds of change as Seychelles embraces green power*. PhysOrg. http://phys.org/news/2013-06-seychelles-embraces-green-power.html Accessed at 12 November 2014

WavePowerLab (2014). *Waveroller to carry out feasibility study on Tanzania's wave power potential*. http://wavepowerlab.weebly.com/news/waveroller-to-carry-out-feasibility-study-on-tanzanias-wave-power-potential 5/10/2014 accessed at 13 November

Wiggins, S., Keane, J., Kennan, J., Leturque, H. and Stevens, C. (2011). *Biofuels in Eastern Africa: dangers yes, but much potential as well*. Project Briefing No 66. Overseas Development Institute. Bioenergy in Africa

World Bank (2014). *Data: Population Growth (annual %)*. http://data.worldbank.org/indicator/SP.POP.GROW . IBRD. IDA. Accessed at 12 November

Zuckerman, G. (2013). *The Frackers*: The outrageous inside story of the new billionaire wildcatters. Portfolio/Penguin Group. USA



27

Coastal Mining and its Influence on Coastline Stability

Laurie Barwell

Opposite page: Artisanal sand mining near Mombasa, Kenya. © Laurie Barwell.

INTRODUCTION

In UNEP/ Nairobi Convention Secretariat (2009) it is reported that the coastal regions of Sub-Saharan Africa are generally endowed with non-renewable mineral resources such as pyrochlore, gypsum, barites, iron ore, clay, apetite, galena, manganese and semi-precious stones. These occur where geological processes have contributed to concentrating certain deposits with examples being the rich diamond fields off the southern African west coast and the titanium-rich dune fields and sandy shores of various parts of East Africa including Madagascar. It is further reported in UNEP/ Nairobi Convention Secretariat (2009) that the geological exploration of the WIO region is far from comprehensive so that unknown deposits are likely to exist. In cases where mining for minerals is indeed undertaken, there are reported examples of major environmental changes.

As denoted in UNEP/ Nairobi Convention Secretariat (2009) the central drivers of the economy of the coastal areas and the countries of the WIO, in general, include maritime trade, tourism, fisheries, agriculture, mining and other industries and a large percentage of the GDP (see Chapter 1) of the WIO region is generated within the immediate vicinity of coastal towns and cities. The local, national and regional economy is often associated with the infrastructure required by tourism and the ports that form the trade links to international markets.

Infrastructural development results in heavy dependence on natural resources, including the basic components of building material, namely cement, sand and coarse aggregate (stones) for concrete and mortar, and clay for bricks (ASCLME 2012a–i). Dune fields and beaches located closer to river deltas consist of quartz sand and may contain other minerals, more frequently heavy minerals. In other areas, many of the beaches are composed of shell and coral fragments that are of organic origin and are known as carbonaceous sands. DHI and Samaki (2014) report that both live coral rock in shallow waters and onshore fossil coral limestone occur along large stretches of the WIO coastline and are seen as a useful source of building material where the larger boulders sizes are used as building bricks / stones and when broken, can be mixed into concrete as stones and sand. The traditional practice of baking coral rock and crushing the residue to be used as cement is also widely practiced in areas in the WIO region especially in the southern Tanzania coastal region as reported on in DHI and Samaki (2014).

Collectively, the sand and coarse aggregate (stones) material is known as aggregates and further categorized as fine aggregates (grains smaller than 1 cm) and coarse aggregates when larger. The availability of such aggregates along the coast is often seen as a 'free' resource along with the demand from the construction industry offer opportunities for entrepreneurs in both the formal and informal sectors along the whole supply chain (Pikey undated). This is especially noticeable in the Small Island Developing

States (SIDS) where, even though sand and limestone deposits exist, there are inherent challenges in formally sourcing building materials for the building industry (UNEP/ Nairobi Convention Secretariat 2009).

Sediment washed down rivers during floods is deposited within the coastal system and thereby contributes to the coast's natural ability to buffer against sea surges and erosion during storms. In untransformed systems, accretion processes balance the coastal erosional processes and the coastline exists in a state of dynamic equilibrium (Tinley 1985). Transformational pressures in the form of overexploitation, modification and loss of habitats and uncontrolled development or encroachment onto the dynamic beach and coastal system have resulted in environmental degradation including a reduction of the natural dampening effect against sea surges during storms that coral reefs, beaches and dunes have (Roger 2002). The total sum of these factors has a negative impact on coastal communities and often on the countries at large (Masalu 2002).

Some of these impacts include catchment degradation due to poor land-use practices including agriculture and uncontrolled mining activities such as sand excavation from rivers and the destruction of riverine habitat for solar salt production (DHI and Samaki 2014). This can result in increased sediment and silt load in rivers, causing coastal accretion and in places the smothering of habitats such as coral reefs UNEP/ Nairobi Convention Secretariat (2009). The die-off of coral results in a reduction of the protection that such reefs offer to the adjacent coastline against the forces of the sea. On the other hand, coastal erosion has occurred in places due to the coastal system being starved of its sources of sand. This is often due to anthropogenic activities. Such activities include the construction of dams in river courses (which trap sediments); aggregate mining in rivers and from foredunes, beaches and the shoreface; and the sterilisation of the littoral sand source located in dune cliffs and foredunes due to development encroachment (Tinley 1985). In many cases, the construction of harbour infrastructure including breakwaters and/or the dredging of shipping entrance channels has interrupted, reduced or totally changed the natural alongshore sand transport system (USACE 1984).

Natural and human derived driving forces

Since it is implied that coastal mining may have a contributory effect on the stability of the coastline as observed in the form of either coastal erosion or accretion in places (UNESCO 2000, Government of Kenya 2009, ASCLME 2012a–i, DHI and Samaki 2014), this chapter focuses on coastal mining within the context of the physical (abiotic) part of the coastal system. In particular, the influence of coastal mining on the coastal sand system, as an anthropogenic driving force, is assessed as a proxy of the state of the coast in this context. Note that the biotic, economic and societal components of the coupled coastal system are described in other sections of this book.

The types of coastal mining activities in the WIO countries considered in the context of the chapter are:

- Quarrying of coral rock and limestone for cement manufacturing and course aggregates for concrete and road building;
- Artisanal sand mining from the catchment, floodplains, river banks, estuaries and lagoons;
- Informal removal of sand from beaches and foredunes;
- Formal mining of minerals from titaniferous sands; and,
- The production of sea salt from saltpans typically located on estuary flood plains (ASCLME 2012a–i, DHI and Samaki 2014).

The coastline erosion and accretion can result in significant shoreline change (UNEP/ Nairobi Convention Secretariat 2009). Even though coastal erosional trends can be part of the normal coastal processes, the observed erosional trend in parts of the WIO countries is thought to be as a result of anthropogenic activities, as well as episodic storms (which are in part thought to be driven by climate change). The resultant impact on critical habitats, coastal infrastructure, agricultural land and human settlements have been shown to be significant in places, with the impact being accentuated where the shoreline is characteristically low lying and highly erodible such as where dune cliffs and sandy beaches occur. A comprehensive study in Mozambique has confirmed the vulnerability of low lying and erodible coastlines to the effect of episodic storms under existing and future projected climate scenarios (Theron and others, 2012).

DHI and Samaki (2014) report that, in Tanzania, coastal mining at community level is mainly focused on sand and gravel mining, salt production and coral mining. They further report that sand and stone quarrying along beaches, coastal water- courses and other areas are considered important livelihood activities to a point that infor-

mal (un-regulated) sand mining has become a big local industry. As confirmed in research undertaken by Masalu (2002), these informal activities create a range of jobs and local income with resultant socio-economic opportunities and challenges. However the activities can, and often do, result in localised accelerated and / or severe coastal erosion, extensive environmental degradation and an increase in the risk from the forces from the sea on coastal properties which in turn can lead to decreased economic activities, job losses and extensive long-term costs to the local economy.

Changes in accretion to the coast occur as a result of either a change in sediment loads from rivers and estuaries, due to poor land-use and management practices; changes in nearshore processes (such as engineering structures) and/or the re-suspension of sediments in the nearshore by rough seas, often associated with cyclonic conditions (Tinley 1985). As shown in Box 27.1 the natural driving forces that influence the stability of the coastline are: (1) alongshore sand transport; (2) cross-shore sand transport; (3) wind-blown sand transport; and, (4) river flow transporting sediment and silt. The underlying condition is the existence of suitable sand supplies. A further consideration is the effect of future climate change on the wind regime and the sea level.

Human actions directly influence the stability of the coastline

As depicted in Box 27.1, all the sand sources and sinks are linked to one another and thereby form a coastal sand system that is in a natural state of ever-changing equilibrium (USACE 1984). This implies that if a removal from or addition of sand to a system component occurs, it affects all of the other parts of the system and a new equilibrium is formed. Anthropogenic actions, defined as Pressures (in the DPSIR framework), are shown as A to E in Box 27.1 and can influence the stability of the coastline in the short-, medium- and long-term.

In this chapter the state of the coast and the impact and significance of coastal mining activities on the short- and long-term shoreline dynamics are assessed in the context of the coastal sand system as it exists in the WIO coastal belt. This area has large stretches where sediment (sand) occurs along coastal shorelines where it exists in dynamic equilibrium with wave, current and wind-driven processes to form the coastal sand system (USACE 1984, USACE 2004), as depicted in Box 27.1.

Criteria for assessing the state and level of impact on the integrity of the coastal sand system

Building onto the assessment approach followed by Theron and others (2012), in Mozambique, and responding to the typical DPSIR framework (Kristensen 2004) as applied in the context of coastal mining activities in the WIO region, an assessment framework for reflecting the state and level of the residual impact on the integrity of the coastal sand system due to coastal mining is here defined and depicted in Table 27.1. The focus of the assessment is on the residual impact of coastal mining on the integrity of the coastal sand system as a regulating ecosystem service and an integral component of the social-ecological system that prevails within the coastal belt of WIO countries. Seven key elements of the complex system were crystallized from the work reported by Masalu (2002) and the Box 27.1, and are shown in Table 27.1, where the associated criteria for assessing the residual impact are also shown. The qualitative rating and associated numeric score are included.

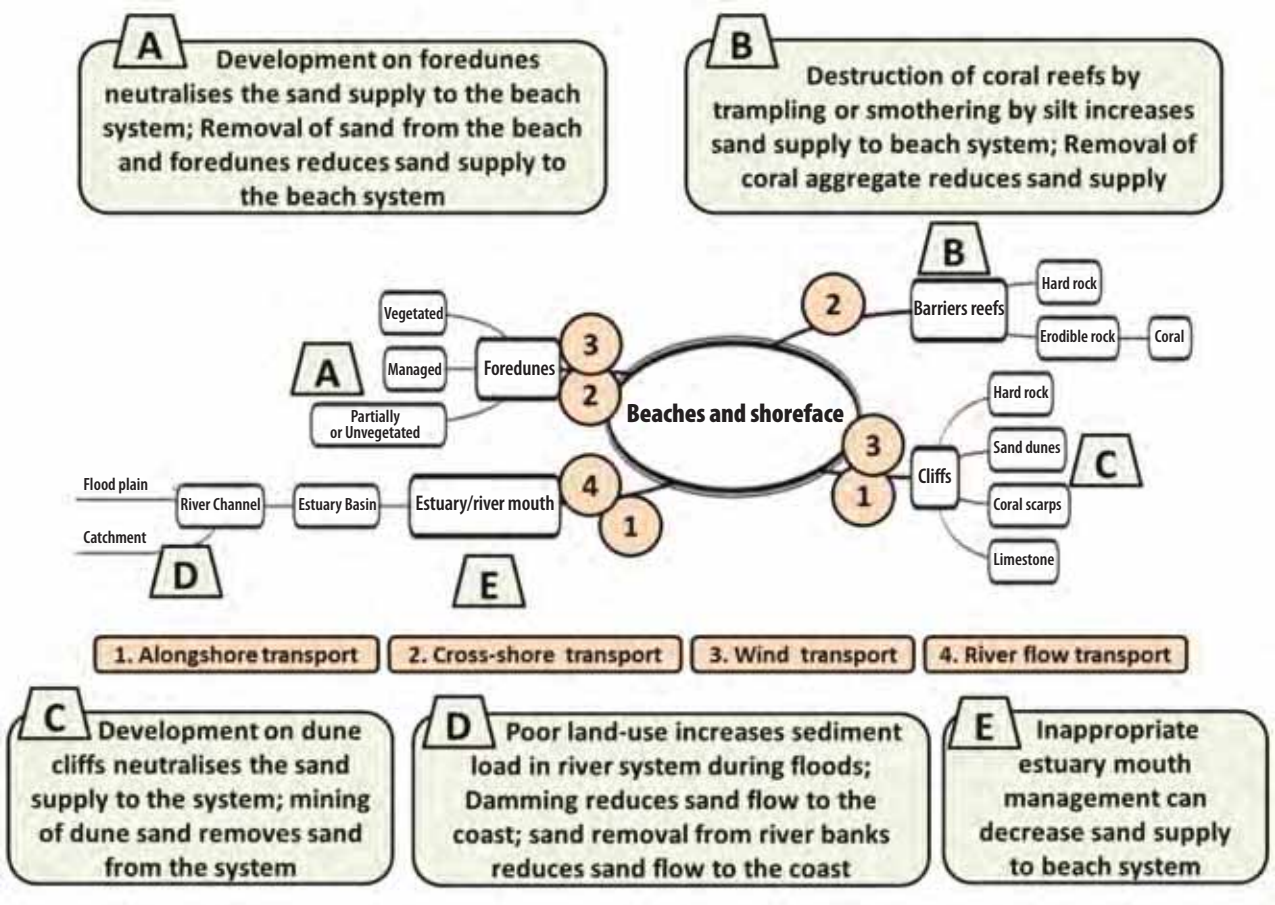
ASSESSMENT OF THE STATE OF THE COASTLINE

Although the National Marine Ecosystem Diagnostic Analysis (NMEDA) series of country specific reports prepared by the UNDP (ASCLME 2012a–i) include basic summaries of the available information on mining activities in the WIO countries under consideration, very little quantitative data are available on coastal mining. This necessitated the use of a similar method to the tried-and-tested assessment approach followed in Mozambique where a qualitative approach was employed for the assessment of the risk and vulnerability to climate change in data- and information-poor contexts (Theron and others, 2012).

The qualitative assessment method, as adapted from the Theron and others (2012) approach, consisted of the following steps:

- No field research, site visits or new data gathering activities were carried out;
- As evidence on which the assessment is based, recent country specific literature (scientific, consultancy and management papers, books and reports) was sourced using the Internet. For the WIO countries the most useful was found to be the ASCLME series published by UNDP (ASCLME 2012a–i). It was impossible to limit the literature to only peer-reviewed work as this would have made no sense given the lack of this qualitative research work;

BOX 27.1. A TYPICAL COASTAL SAND SYSTEM



Elements of the typical coastal sand system and the main natural mechanisms and anthropogenic activities that cause sand to be moved within the system (adapted from Tinley 1985)

Key:

A, 1 & 2: Sand is fed into the littoral zone when high seas erode coastal dune cliffs and then moved alongshore and cross-shore by nearshore currents. Another source of sand arises through the continuous abrasion of boulders and pebbles through wave action impacting on erodible rocky cliffs, reefs and pebble beaches.

A, 2 & 3: Where onshore winds dominate, sand is blown off the beach and foredunes into dunefields. In places, it is moved beyond the reach of storm-waves into the area landwards of the primary dune system, hence it is removed from the coastal sand system. Figure 27.1 illustrates this typical transversal profile of a naturally developing sandy coast. The sand 'stored' in the beach and foredune areas provide a natural buffer against the forces of the sea whereas the sand in the central dune area is important as a reserve under future sea level rise scenarios. Where the geomorphology is suitable, sand from these dune fields bypasses a headland to, in time, join the littoral system either directly into an adjacent bay or into a river. In places, a portion of the sand budget is drained from the shoreface into submarine canyons and thereby removed from sand system.

B, 1 & 2: Coral reefs grow under suitable conditions and coral sand is formed when corals die-off or are broken by wave action thereby forming a source of sand to adjacent beaches. The coral sand is moved across-shore and alongshore. In the nearshore area (seaward of the barrier reefs when present) the sand typically forms a shoreface stretching from the beach (or reef) to about 10 m water depth. Sand in the nearshore area is reworked by waves, currents and wind to form connected environments such as beaches and foredunes. At accreting shorelines, the foredunes mature (through the ongoing establishment of a succession of vegetation) and in time form central and backdune areas that show little change. Where the coastline is in an eroding state, the foredune forms a steep scarp with little or no hummock dune zone.

D, 4: Alluvial (mainly siliceous) sand originating in river catchments is washed downstream during river floods to be deposited in river and tidal deltas at the coast.

• Each document was subjected to keyword-based searches using each of the five identified coastal mining activities as keywords;

• The search results were rated in terms of the published content and significance of data and/or information. The ratings were thus derived for the seven elements and associated state / impact descriptors listed in Table 27.1;

• In many cases there is a lack of information in the published documentation and the specific cells in the tables are consequently shown blank;

• A qualitative rating / score was determined against the scale depicting the state of impact ranging from Very Low (VL) to Very High (VH) with associated scores of 1 to 5 to allow for a comparative analysis across countries and for mining activity type; and,

• The scores are reflected in Tables 27.2 to 27.7 and a *normalized* score (given out of a maximum of 5) was calculated for each element. This allows comparative deductions to be carried out across the countries, mining activities and mining activities.

Ideally, given the data-poor environment, the rating criteria and descriptors depicted in Table 27.1 should be defined and the rating (Step 4) achieved by consensus within a panel of experts representing the various components of the coastal socio-ecological system assessment as well as the various mining activities. Furthermore, the rating / score should be agreed to after observing the actual activities on site.

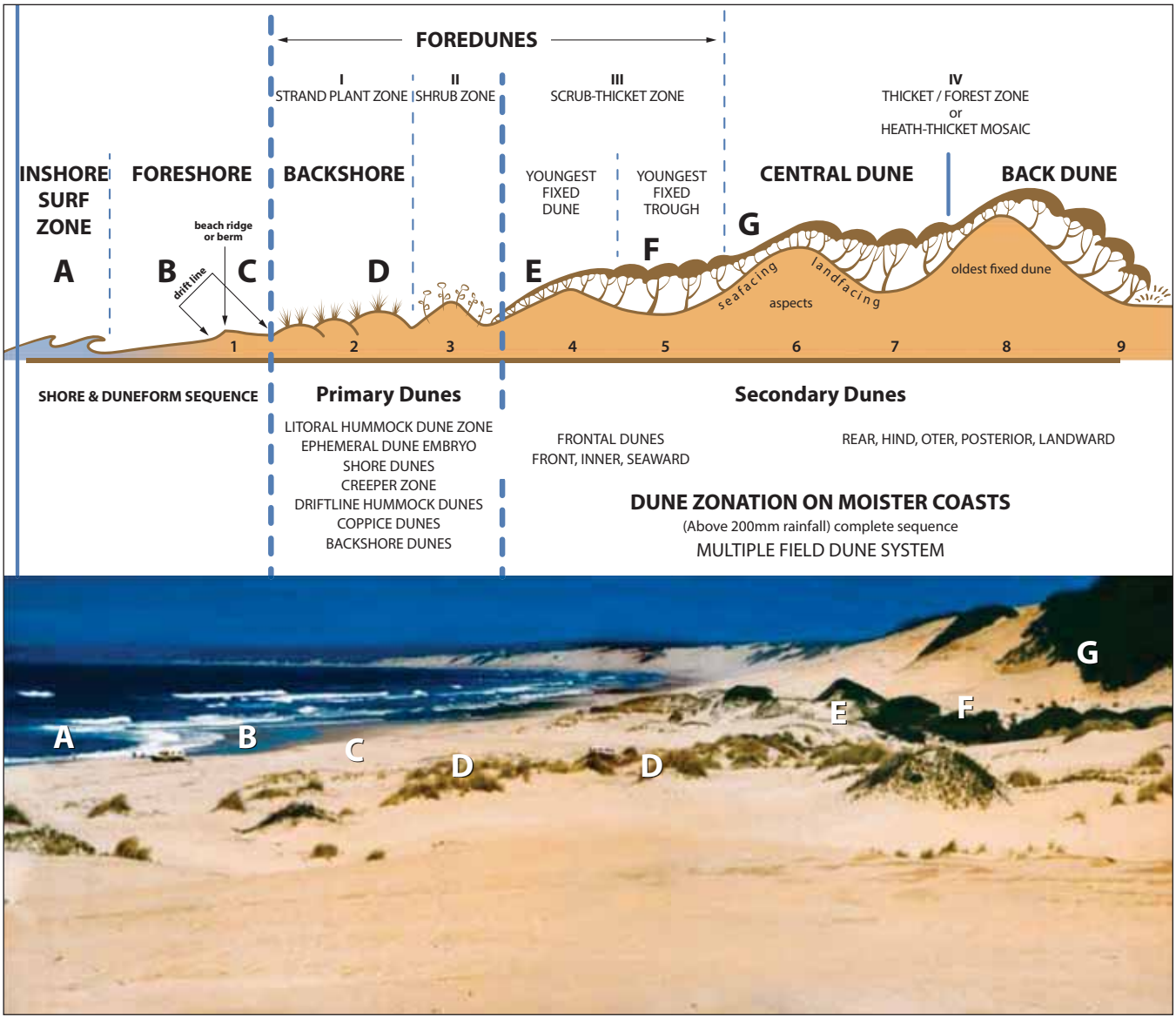


Figure 27.1. Typical transversal profile of a developing sandy coast showing geomorphological units and the different terminology used to characterize the coastal zone. (adapted from Tinley 1985 in Barwell 2011). Photo © A. Theron.

Table 27.1. Criteria for assessing the impact of drivers and pressures on the coastal social-ecological system.

#	Element	Criteria for assessing residual impact (qualitative assessment based on interpretation of available literature)					
		Rating:	**VL**	**L**	**M**	**H**	**VH**
		Score[1]:	**1**	**2**	**3**	**4**	**5**
1	Scale of mining activities in the context of the coastal sand system		Remotely if at all	Indirectly and controlled	Indirectly and uncontrolled	Directly and controlled	Directly and uncontrolled
2	Sustainable growth potential of the mining activity		Insignificant	Low	Medium	High	Very high
3	Societal benefit potential (jobs) of the mining activity		Significant / far reaching job gains	Direct job gains	Neutral	Direct job losses	Indirect job losses / far reaching
4	Economic benefits of the mining activity		Significant / far reaching	Direct benefit	Neutral	Direct cost to economy	Indirect cost to economy
5	Mining activity on the coastal sand system		Insignificant	Indirectly and controlled	Indirectly and uncontrolled	Directly and controlled	Directly and uncontrolled
6	Policy governing the mining activity		Explicit	Adequate	General	Non explicit	Not clear / lacking
7	Level of capability to control the mining activity		Mature	Competent	Growing	Embryonic	Lacking

Note 1: The score of 1 is associated with a residual impact rating of VL (Very Low) scaling up to a score of 5 for a residual impact rating of VH (Very High).

ASSESSMENT RESULTS

The assessment results for the identified types of coastal mining activities in each country (as reflected in available literature) are depicted in Tables 27.2 to 27.6. Table 27.7 shows the overall residual state and impact of the collective coastal mining activities on the coastal social-ecological system of each of the countries as well as the overall score (normalised).

Referring to the assessment criteria in Table 27.1, Table 27.2 depicts the residual impact of the current scale of coral rock and limestone quarrying. It can be seen that the scale of impact of such mining by the formal sector is considered to be *remotely if at all* (score 1 – Table 27.1). No information is available on informal quarrying although mention is made of some community based activities in Somalia resulting in an impact rating of *directly and uncontrolled* (score 5). Note that the scale of impact on the biotic system (for example important habitats and/or specific species) may be significant but this is not considered in this assessment as the focus is on the abiotic components of the coastal sand system.

From the literature it is determined that there is a *high growth potential* (score 4) for formal mining in the countries assessed. This is mainly due to the under-utilization of known resources. The sustainable growth potential for informal quarrying is considered to be *insignificant* (score 1) in Kenya, Mozambique and Tanzania (mainly due to the associated expense as well as the existence of good policies.

Since natural resources are underexploited in Somalia there is a *very high growth potential* (score 4) in the formal sector. Due to the unstable situation in Somalia, the potential for uncontrolled growth in the informal activities is *very high* (score 5) if market demand exists. This results in a *direct benefit* (score 2) rating for the economy at a local level but *neutral* (score 3) on a national and regional scale.

In Table 27.3 it can be seen that the residual impact of the current scale of terrestrial and river sand quarrying in the formal sectors is considered to be *indirectly and controlled* (score 2). The artisanal component (informal sector) is rated as *indirectly and uncontrolled* (score 3).

The literature review suggests that there is a *high* potential (score 4) for sustainable growth in both the formal and informal sectors in the countries where information is available. In Somalia the potential is *low* (score 2) due to the current limited demand and lack of infrastructure. Since natural resources are under-exploited in Somalia there is a *very high* (score 5) growth potential in the formal sector and due to the unstable situation the potential for uncontrolled growth in the informal activities is *very high* (score 5) if local market demand exists. This results in a *direct benefit* (score 2) at a local level but *neutral* (score 3) at the national and regional scales.

The residual impact of the current scale of beach sand mining is shown in Table 27.4 as being *remotely if at all*

Table 27.2. Coral and limestone quarrying for cement manufacturing and aggregates.

WIO Country	Current scale of coastal mining activities		Sustainable growth potential		Societal benefit (Job creation)		Economic benefit			Significance of impact on the coastal sand system		Policy on coastal mining	Level of capability to control
	Formal	Informal	Formal	Informal	Local	National	Local	National	Region	Local	Region		
Comoros												1	3
Kenya	1		4	1	2	1	2	1	3	1	1	1	3
Madagascar	1		4		2	1	2	1	3	1	1	1	3
Mauritius												1	3
Mozambique	1		4	1	2	1	2	1	3	1	1	1	3
Reunion (France)													
Seychelles												1	1
Somalia	1	5	4	5	2	3	2	3	3	5	3	5	5
South Africa	1		4		2	3	2	3	3	2	1	1	3
Tanzania	1	5	4	3	1	1	1	1	1	3	3	1	3
Normalised score	1	5	4	3	2	2	2	2	3	2	2	1	3

Table 27.3. Terrestrial and river sand quarrying (including from hills, river banks, estuaries and floodplains).

WIO Country	Current scale of coastal mining activities		Sustainable growth potential		Societal benefit (Job creation)		Economic benefit			Significance of impact on the coastal sand system		Policy on coastal mining	Level of capability to control
	Formal	Informal	Formal	Informal	Local	National	Local	National	Region	Local	Region		
Comoros												1	3
Kenya	2	3	4	4	2	3	2	3	3	3	1	1	3
Madagascar	2	3	4	4	2	3	2	3	3	3	1	1	3
Mauritius												1	3
Mozambique	2	3	4	4	2	3	2	3	3	3	1	1	3
Reunion (France)													
Seychelles												1	1
Somalia		1	2	2	4	4	2	3	3	3	1	5	5
South Africa	4	5	4	4	2	3	2	3	3	5	1	1	3
Tanzania	2	3	4	4	2	3	2	3	3	3	1	1	3
Normalised score	2	3	4	4	2	3	2	3	3	3	1	1	3

Table 27.4. Beach sand (including sand from foredunes).

WIO Country	Current scale of coastal mining activities		Sustainable growth potential		Societal benefit (Job creation)		Economic benefit			Significance of impact on the coastal sand system		Policy on coastal mining	Level of capability to control
	Formal	Informal	Formal	Informal	Local	National	Local	National	Region	Local	Region		
Comoros		5	1	1	5	5	4	5	3	5	1	1	5
Kenya	1	3	1	1	5	5	4	5	3	5	3	1	3
Madagascar	1	3	1	1	5	5	4	5	3	5	3	1	3
Mauritius												1	3
Mozambique	2	3	4	4	5	5	4	5	3	5	3	1	3
Reunion (France)													
Seychelles		5			4		4			5		1	1
Somalia	1	5	4	5	4	4	2	3	3	3	1	5	5
South Africa	1	1	1	1	4	4	4	5	3	5	3	1	3
Tanzania	1	3	1	1	5	5	4	5	3	5	3	1	3
Normalised score	1	4	2	2	5	5	4	5	3	5	2	1	3

(score 1) for the formal sector. The scale of current beach sand mining by the informal sector is considered to be *direct and uncontrolled* (score 4) in the countries where information is available.

From the literature reviewed, there is an *insignificant* growth potential (score 1) for formal and informal beach and foredune sand mining in the countries where information is available. This is thought to be due to a resource constraint prevalent at coastal cities where there may be a market demand. In places, it is difficult for artisanal miners to gain access to the beach and foredunes because of the existing development on the beachfront. In many countries, restricting this activity is seen as a priority and available policies are implemented and policed.

The exception appears to be Somalia where there appears to be a *high to very high* growth potential due to the current underutilization of known resources and uncertainty about the existence of suitable policy and a lack of controlling capability. Although there is a lack of beach and foredune sand in many of the coastal cities in Mozambique where the effects of coastal erosion are noticeable, the potential to utilize the extensive sand deltas at major river mouths does exist thus attracting a score of 4 (*high*).

Many of the sandy parts of the shoreline within the WIO region are utilized for tourism with many resorts located adjacent to sandy beaches. These resorts offer

many direct and indirect job opportunities. Often the resort infrastructure is located directly on the foredune and thereby reduces the storm buffering potential of the foredunes. The depletion of beach sand due to mining has a large potential impact on the local economy through direct job losses (score 4) and far reaching job losses (score 5) at a national scale. Regionally the impact is neutral (score 3).

The assessment of the specific residual impact of beach and foredune sand mining activities on the various components of the coastal sand system (Figure 27.1) shows a rating of direct and uncontrolled (score 5) due to the scarcity of beach sand resource in most of the WIO countries. The only exception is Somalia where the impact is assessed to be indirect and uncontrolled (score 3) due to a lack of market demand. Removal of beach and foredune sand has an insignificant impact on the regional coastal sand system.

Table 27.5 summarizes the residual impact of the mining activities related to extracting minerals from titaniferous sand dunes. Being a formalized activity under strict control, the scale is scored at 2 (indirect impact and controlled). No information could be found on informal activities. Available geological information indicates a *high* growth potential (score 4) for the formal sector with an *insignificant* (score 1) potential for the informal sector due to the highly specialized nature of mineral extraction and post-mining management. Job creation potential is rated as being *significant* and far reaching at a local level thus scoring a 1 and *neutral* (score 3) at a national level. A strong positive residual impact on the local economy is indicated through a *direct benefit* (score 2) rating. With mining activities typically located a distance inland from the shoreline and well controlled through monitored environmental management plans, the impact on the coastal sand system is considered to be *indirect and controlled* (score 2).

Table 27.6 shows the residual impact of salt works development typically on estuary floodplains where natural mangrove stands are typically removed to create large expanses of saltwater pans where salt is formed during the evaporation of seawater in the pans under controlled conditions. Being a formalized activity under strict control, the scale is scored at 2 (indirect impact and controlled). No information could be found on informal activities but the impact from informal solar salt works are rated as being *indirect and uncontrolled* (score 3). In many of the WIO countries a large number of estuary floodplains exist where the sustainable growth potential for both formal and informal salt extraction activities is rated as *medium* (score 3). Note that the scale of impact on the biotic system (for example important habitats and/or specific species) may be a lot more and this is not considered in this chapter.

In Table 27.7 it can be seen that the overall residual impact of the current scale of coastal mining within the context of the coastal sand system from both the formal as well as the informal sectors is considered to be *remotely if at all* (Table 27.1). The literature suggests that there is a medium to high growth potential for formal mining in various countries. This is mainly due to the under-utilization of known resources. High scores reflect the opportunity for economic growth due to the controlled formalization of mineral extraction from titanerifous dune sands, formal quarrying of limestone and coral rock (for cement and coarse aggregate) as well as sand from identifiable areas within the coastal belt.

The societal benefit is reflected in terms of the potential for job creation since the lack of formal economic opportunities was identified as one of the root causes of resource over-exploitation and environmental degradation. The results show that at a local level, coastal mining offers direct job gains as well as having significant / far reaching job gains due to the demands generated by the coastal industries and tourism. The impact at a national level is mainly deemed neutral since, even though formal coastal mining activities may be an important activity in a specific country, the impact is not more or less than the other sectors where jobs are concerned. A similar situation exists for the residual impact on the local, national and regional economy where the rating falls into a band between of *direct benefit* (score 2) to *neutral* (score 3).

When examining the assessment of the specific residual impact of coastal mining activities on the various components of the coastal sand system (see Box 27.1), it can be seen that the overall rating for the WIO region is deemed to be *indirect and controlled* (score 2) at a local scale and *insignificant* (score 1) at a regional scale. It is important to read this specific assessment score in conjunction with the assessment of the scale of the mining activities as well as considering the existence of coastal management and mining policies and the capability to implement the said policies. These are rated as being *adequate* (score 2) in most countries for the former and *growing* (score 3) for the latter.

Table 27.5. Mineral-rich (titaniferous) sand dunes (for example Ilmentite, zircon, rutile).

WIO Country	Current scale of coastal mining activities		Sustainable growth potential		Societal benefit (Job creation)		Economic benefit			Significance of impact on the coastal sand system		Policy on coastal mining	Level of capability to control
	Formal	Informal	Formal	Informal	Local	National	Local	National	Region	Local	Region		
Comoros													
Kenya	2		4	1	1	3	2	1	1	2	1	1	3
Madagascar	2		4		1	3	2	1	1	2	1	1	3
Mauritius												1	3
Mozambique	2		4	1	1	3	2	1	1	2	1	1	3
Reunion (France)													
Seychelles												1	1
Somalia			4	1	1	3	2	3	1	3	1	5	5
South Africa	2		4	1	1	3	2	1	1	2	2	1	3
Tanzania	1		3	1	1	3	2	1	1	2	1	1	3
Normalised score	2		4	1	1	3	2	1	1	2	1	2	3

Table 27.6. Solar salt works located on estuary / river floodplains (includes Mangrove removal).

WIO Country	Current scale of coastal mining activities		Sustainable growth potential		Societal benefit (Job creation)		Economic benefit			Significance of impact on the coastal sand system		Policy on coastal mining	Level of capability to control
	Formal	Informal	Formal	Informal	Local	National	Local	National	Region	Local	Region		
Comoros													
Kenya	2	3	3	3	2	3	2	3	3	2	1	1	3
Madagascar													
Mauritius												1	3
Mozambique	2		3		2	3	2	3	3	2	1	1	3
Reunion (France)													
Seychelles												1	1
Somalia	1	3	4	4	2	2	2	2	3	3	1	5	5
South Africa	2		3		2	3	2	3	3	2	1	1	3
Tanzania	2	3	3	3	2	3	2	3	3	2	1	1	3
Normalised score	2	3	3	3	2	3	2	3	3	2	1	2	3

Table 27.7. Overall residual state and impact for all coastal mining in the WIO countries

WIO Country	Current scale of coastal mining activities		Sustainable growth potential		Societal benefit (Job creation)		Economic benefit			Significance of impact on the coastal sand system		Policy on coastal mining	Level of capability to control
	Formal	Informal	Formal	Informal	Local	National	Local	National	Region	Local	Region		
Comoros		1			1	1	1	1	1	1		1	2
Kenya	2	2	3	2	3	3	3	3	3	3	1	2	3
Madagascar	1	1	2	1	2	2	2	2	2	2	1	2	3
Mauritius												2	3
Mozambique	2	1	4	2	3	3	3	3	3	3	1	2	3
Reunion (France)	0	0	0	0	0	0	0	0	0	0	0	0	0
Seychelles		1			1		1			1		1	1
Somalia	1	2	4	3	3	3	2	3	3	4	1	5	5
South Africa	2	1	3	1	2	3	3	3	3	3	2	2	3
Tanzania	1	2	3	2	2	3	2	3	2	3	2	2	3
Normalised score	1	1	1	1	2	2	2	2	2	2	1	2	3

CONCLUSION ON THE ASSESSMENT

Understanding the activities (the drivers of change) and their underlying social and economic pressures (the root causes), result in an assessment of the current state of the coastal sand system. Estimating the net effect of coastal mining activities on the coastal sand system can then lead to a qualitative conclusion on the contribution of coastal mining and the associated impact on the coastal abiotic system.

Reflected as a residual impact, the overall state of the current scale of coastal mining on the abiotic coastal system from both the formal as well as the informal sectors is rated as VERY LOW for the WIO countries where information is available. Note that the scale of impact on the biotic (for example important habitats and/or specific species) and social/cultural/historic perspective may be a lot more as this is considered beyond the scope of this chapter.

In some of the WIO countries, the under-utilisation of known resources leads the growth potential for formal mining to be assessed at a medium to high level. The high scores reflect the opportunity for economic growth due to the controlled formalization of mineral extraction from titanerifous dune sands, formal quarrying of limestone and coral rock (for cement and coarse aggregate) as well as sand from identifiable areas within the coastal belt. The oppor-

tunity exists for current infrastructure to be used to export high quality building sand to the island countries from areas where sustainable sources exist.

RESPONSE AND POLICY CONSIDERATIONS

The following pointers can be considered for incorporating into existing policies that relate to managing of coastal mining activities in WIO countries:

- The available literature (for example ASCLME 2012a–i) shows that explicit policies that relate to coastal mining activities do exist in most of the WIO countries under consideration. A policy of explicitly sharing good practice within the WIO region could be strengthened.
- The information indicates that the level of capabilities to control the mining activities fall in the *mature* to *competent* categories. A policy of active succession planning and multi-national skills development will secure a sustainable research and management capability within the WIO countries.
- It appears that (some) authorities are finding it challenging to implement policies especially in areas where informal mining activities prevail. A policy that guides the utilisation of a valuable natural resource should be formulated when more detailed quantifiable research is undertaken. The opportunity exists to implement actions that inform and educate the public and managers on the functioning of the coastal sand system and its importance as a natural protection against existing and future, climate change enhanced, forces from the sea.
- The importance and value of the coastal sand system as a regulating ecosystem service within the coastal social-ecological system should be acknowledged and recognised in coastal zone management policies. For example, a coastal hazard level should be defined and coastal development (including mining activities) restricted to beyond the littoral system to ensure that the buffering services can be sustained within the projected climate change scenarios.
- The opportunity exists to use the sand that is left over from commercial heavy mineral mining activities in Kenya and Mozambique as a commercially exploitable natural resource for export to WIO countries where this resource is limited. A policy of ensuring the direct participation of current artisanal (informal) sand miners in the whole value chain of this venture would enhance the socio-economic benefit across the whole WIO region at a local as well as national level whilst ensuring the integrity of the coastal sand system.

References

ASCLME (2012a). *National Marine Ecosystem Diagnostic Analysis. Comoros*. Contribution to the Agulhas and Somali Current Large Marine Ecosystems Project (supported by UNDP with GEF grant financing)

ASCLME (2012b). *National Marine Ecosystem Diagnostic Analysis. Kenya*. Contribution to the Agulhas and Somali Current Large Marine Ecosystems Project (supported by UNDP with GEF grant financing)

ASCLME (2012c). *National Marine Ecosystem Diagnostic Analysis. Madagascar*. Contribution to the Agulhas and Somali Current Large Marine Ecosystems Project (supported by UNDP with GEF grant financing)

ASCLME (2012d). *National Marine Ecosystem Diagnostic Analysis. Mauritius*. Contribution to the Agulhas and Somali Current Large Marine Ecosystems Project (supported by UNDP with GEF grant financing)

ASCLME (2012e). *National Marine Ecosystem Diagnostic Analysis. Mozambique*. Contribution to the Agulhas and Somali Current Large Marine Ecosystems Project (supported by UNDP with GEF grant financing)

ASCLME (2012f). *National Marine Ecosystem Diagnostic Analysis. Seychelles*. Contribution to the Agulhas and Somali Current Large Marine Ecosystems Project (supported by UNDP with GEF grant financing)

ASCLME (2012g). *National Marine Ecosystem Diagnostic Analysis. Somalia*. Contribution to the Agulhas and Somali Current Large Marine Ecosystems Project (supported by UNDP with GEF grant financing)

ASCLME (2012h). *National Marine Ecosystem Diagnostic Analysis. South Africa*. Contribution to the Agulhas and Somali Current Large Marine Ecosystems Project (supported by UNDP with GEF grant financing)

ASCLME (2012i). *National Marine Ecosystem Diagnostic Analysis. Tanzania*. Contribution to the Agulhas and Somali Current Large Marine Ecosystems Project (supported by UNDP with GEF grant financing)

Barwell, L. (2011). *Integrity assessment procedure for buffer dune systems on the Cape South Coast, South Africa*. MSc. Thesis Civil Engineering. University of Stellenbosch, South Africa.

DHI and Samaki (2014). *Coastal Profile for Mainland Tanzania 2014 Thematic Volume – Draft 0*. Investment Prioritization for Resilient Livelihoods and Ecosystems in Coastal Zones of Tanzania DHI and Samaki Consultants

Government of Kenya (2009). *State of the Coast Report: Towards Integrated Management of Coastal and Marine Resources in Kenya*. National Environment Management Authority (NEMA), Nairobi

Kristensen, P. (2004). *The DPSIR Framework*. Workshop on a comprehensive/detailed assessment of the vulnerability of water resources to environmental change in Africa using river basin approach. 27-29 September. UNEP Headquarters. Nairobi, Kenya

Masalu, D.C.P. (2002). Coastal Erosion and Its Social and Environmental Aspects in Tanzania: A Case Study in Illegal Sand Mining. *Coast. Manage.* 30 (4), 347-359

Roger, H.C. (2002). Impact on the Coastal Environment of Marine Aggregates Mining. *Int. J. Environ. Stud.* 59(3), 297-322

Theron, A.K. and Barwell, L.B. (2012). *Responding to Climate Change in Mozambique: Theme 2: Coastal Planning and Adaptation to Mitigate Climate Change Impacts*. Report prepared for National Institute for Disaster Management (INGC) by CSIR. Stellenbosch, South Africa

Tinley, K.L. (1985). *Coastal dunes of South Africa*. South African National Science Programme report 109. Pretoria: FRD-CSIR. South Africa

USACE (1984). *Shore protection manual (SPM)*. Department of the Army, U S Army Corps of Engineers, CERC. vol. 1. U.S. Army Coastal Engineering. Vicksburg, Mississippi.

USACE (2004). *Coastal Engineering Manual (CEM)*. U.S. Army Coastal Engineering Very-Tech, USA

UNEP/Nairobi Convention Secretariat (2009). *Transboundary Diagnostic Analysis of Land-based Sources and Activities Affecting the Western Indian Ocean Coastal and Marine Environment*. UNEP Nairobi, Kenya

UNESCO (2000). *Pan-African Conference on Sustainable Integrated Coastal Management; Proceedings of the Workshops: An integrated approach*. (PACSICOM). 18-25 July. IOC Workshop Reports series No. 165. Maputo, Mozambique



28
Tourism and Recreation

Sachooda Ragoonaden

Opposite page: Touristic activities at Grand Baie, northwestern Mauritius. © José Paula.

INTRODUCTION

Tourism is a vital tool for economic development and poverty reduction (UNWTO 2002). It provides a multitude of recreation facilities. Tourism is defined as "*the activities of persons travelling to and staying in places outside their usual environment for not more than one consecutive year for leisure, business and other purposes*"(UNWTO 2013) and recreation as "*Activity done for enjoyment when one is not working*" (Oxford Dictionary). Annually, it is estimated to be worth US$ 30 000 million and contributes to 9 per cent of global GDP and represents 1 of 11 jobs in the world (UNWTO 2013). It is one of the largest and fastes growing sectors in the world (UNWTO 2013). Coastal destinations feature as one of the most common types of tourism (UNEP/Nairobi Convention Secretariat and WIOMSA 2009). The coastal area, a prolific source of biodiversity and ecosystem services, provides numerous opportunities for tourism and recreation (Beatley and others, 1994) such as swimming, sun bathing, pleasure boating, snorkelling, reef walking and SCUBA diving. The open ocean also offers many opportunities for tourism and recreational activities that include sport fishing, whale and dolphin watching and cruise tourism.

Coastal tourism can also contribute to degradation of the marine environment, as the natural environment, tourism and recreational activities are inextricably linked. Nevertheless, the economic benefits of tourism and recreation in generating employment, local income and foreign exchange is sufficiently important that the relationship between tourism, biodiversity and ecosystems services warrants aggressive conservation measures to ensure sustainability of the tourism sector. Tourism is however also subject to external influences. The recent international financial crisis has had adverse impacts on the WIO tourism industry (Mazilu and others, 2011).

TOURIST ATTRACTIONS IN THE WESTERN INDIAN OCEAN

The WIO region provides a range of unique attractions and recreational activities for local and international tourism. Coastal tourism is very popular among local populations, particularly in the Small Island Developing States (SIDS) and coastal region of the mainland states of the WIO region. Coastal tourism in the WIO is both a direct and indirect driver of the state of the coast. The region has all the physical, environmental and cultural attractions to make the tourism industry a viable option for their socio-economic development. The marine environment offers many opportunities for employment to local communities and in places provides economic incentives to protect the marine ecosystems. The range of employment opportunities include hotels, restaurants, housing and residential activities, vending, beach hawking, agriculture and fishing activities. The SIDS and East Africa mainland countries, particularly islands, are associated with sea, sand and sun - all features of the coastal and marine environment that

attract tourists.

The main tourism features of the Western Indian Ocean (WIO) include sandy beaches, clean water, abundant sunshine, mangrove forest (Box 28.1), and lagoons and seas (UNEP 2003). The region has a high diversity of coral reefs with significant economic value (Barton 1994), particularly for dive tourists. The economic benefits of dive tourism was estimated to be an additional US$ 75 000 – 174 000 annually in Kenya (Crabble and McClanahan 2007). The tourism sector in Madagascar is still relatively undeveloped taking into account the size and unique biodiversity of the country (Picard 2010). The clear turquoise water of the small islands of Nosy Be and Ifaty, with a 90-km long coral reef and Ile Sainte Marie off the east coast are ideal for diving, snorkelling and fishing. In addition, the rich and distinctive feature of the cultures of the WIO countries also offers many potential opportunities for the development of the tourism sector in the region (Honey and Gilpin 2009).

Mauritius and Seychelles are identified as exclusive beach and sun destinations. Marine-related tourism activities in Kenya, Madagascar, France (Reunion), South Africa and Tanzania, which are primarily famous for wildlife parks and mountain destinations, currently make a smaller contribution to the national economy. However, the potential for growth is considerable. The natural beauty, wildlife and historic heritage of the Mozambican coastline has excellent opportunities for beach, cultural, and eco-tourism. The Bazaruto Archipelago is first on the "Top 10 Tourist Attractions" in the country as measured by the Global Tourism Places (2013). In Kenya, the Lamu archipelago and Malindi township with beautiful beaches are the 5th and 9th among the 10 top tourist attractions in the country (Global Tourism Places 2013). Zanzibar, Mafia and Pemba islands (Wagner 2004) all have well-developed coastal tourism sectors and are rated the 4th, 6th and 8th top tourist attractions in Tanzania (Touropia 2013, www.touropia.com).

In the WIO region, whale and dolphin watching is a popular tourism attraction. It contributes significantly to the local economies in Zanzibar and Mozambique (Berggren and others, 2007). Whale watching (humpback whales) activities are increasing in many areas, such as in the Sainte Marie Channel (northeast Madagascar), Reunion and Mayotte (Kiszka and others, 2009). Dolphin watching activities are also important in Mauritius (Box 28.2).

Recreational fishing refers to fishing for food or to release, as a leisure activity or hobby. Sport fishing clubs and services attracting tourists exist in all WIO countries, most notably in Kenya, Mauritius, South Africa and the

BOX 28.1. MANGROVE FOREST FOR ECOTOURISM IN KENYA



Mangrove boardwalk entrance at Gazi Bay, Kenya. © José Paula.

The development of mangroves as ecotourism sites is growing worldwide. At Gazi, a coastal village in Kenya, the women have established a community- based ecotourism project which profits from the value of the mangrove's scenic beauty and biodiversity. The Gazi Women Mangrove 300 m Boardwalk is a community-based conservation effort. The building of the mangrove boardwalk was funded by the City Council of Overijse (Belgium) and the International Ocean Institute (IOI), through the Kenya Marine and Fisheries Research Institute, employing local villagers for construction. Almost 100 per cent of the profit generated through the boardwalk goes into the Gazi community to improve health care and the physical facilities of Gazi Primary school as well as provide scholarships to poor children from the village. About 100 school children have been supported by the ecotourism project and two main water systems under the "clean water for all" initiative have been supported through the project, providing water to more than 1 500 persons in the village (James Kairo pers comm).

The potential of mangrove forests for tourism is still to be exploited as it is the case in other countries (Ayob and others, 2009, Salam and others, 2000, Mangrove Action Project 2013).

Seychelles (IUCN 2004). In South Africa, recreational fishing attracts many dedicated to the growing sport, increasingly an activity focused on sustainability. All recreational fishing requires a license, and "catch size and bag limit" must be adhered to, in order to protect local marine life.

The Indian Ocean is an emerging cruise destination (Dowling 2006). South Africa and East African ports have established some cruise trade. The expansion of cruise tourism is on many national growth and development agendas (Kohler 2003, Mwakio 2013, Government of Mauritius 2013). Some 10 000 tourists in cruise vessels visited the island of Seychelles in 2000 (Seychelles Vision 21) and the number increased to 200 000 in 2010. In Mauritius, the cruise segment registered an improvement during the period 2010/2011 with 27 calls and 26 751 passengers. For the same period, US$ 234 000 were derived directly from cruise tourism and some US$ 18 million from indirect activities.

CONTRIBUTIONS AND IMPACTS

Benefits and opportunities

Africa and the WIO countries are increasingly attracting international tourists. In Africa, an estimated increase of 6 per cent of international arrivals in 2012 was reported (UNWTO 2013) with 52.4 million international tourist arrivals, exceeding the 50 million mark for the first time. This is the second fastest growth by region after Asia and the Pacific.

Within the WIO region (Fig. 28.1), South Africa was by far the biggest tourism attraction where tourist arrival grew by 10 per cent in 2012 to over 9 million (Table 28.1). Other regional destinations that experienced growth in tourist arrivals were Tanzania (24 per cent), Madagascar (13 per cent) and the Seychelles (7 per cent).

Socio-economy of tourism

The tourism and recreation sector is a global force for socio-economic development, promotion of economic growth and alleviating poverty (Steiner 2006, Richardson 2010, Dwyer and Spurr 2011) with direct economic as well as significant indirect and induced impacts. It promotes infrastructure development and maintenance such as road networks, airport facilities and amenities in the coastal and beach zones, which have the potential to benefit the whole country and its local population (Phillips and Jones 2006, Seetanah and others, 2011).

In the WIO region, the growth rate, measured as tourism income for all the countries, was quite encouraging as shown in Table 28.1. South Africa has the greatest share in tourist receipts (29.8 per cent) followed by Tanzania (4.7

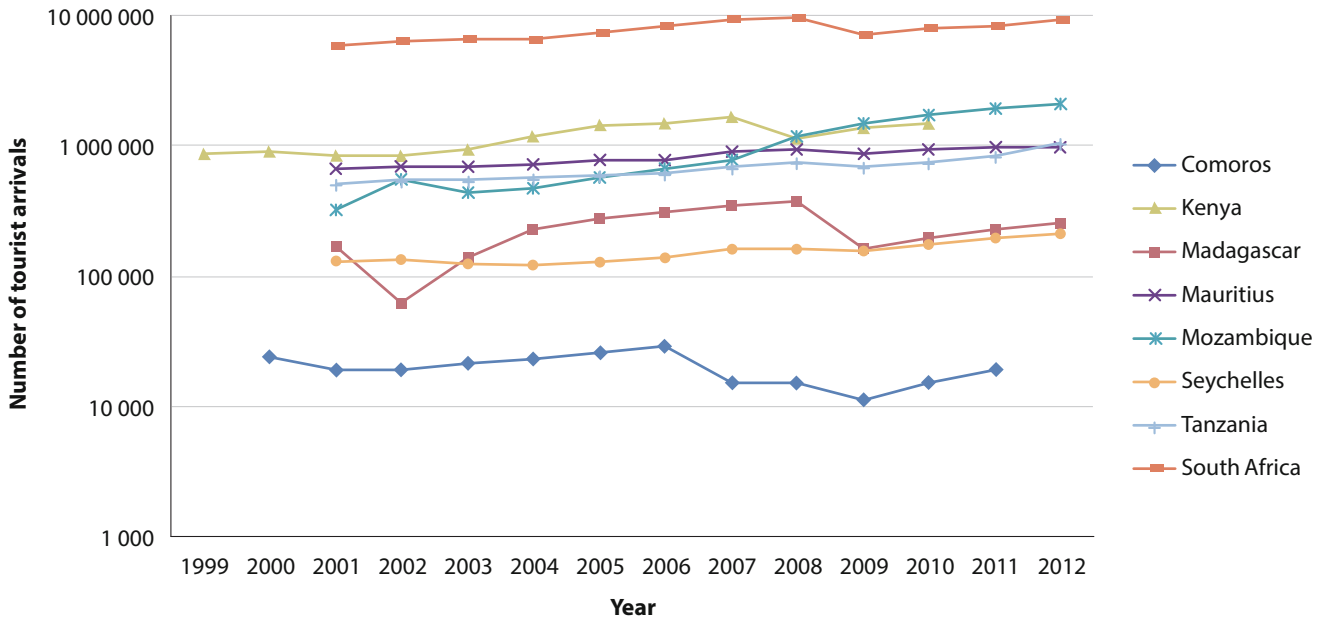


Figure 28.1. Number of tourist arrivals in Western Indian Ocean countries. Source: World Travel and Tourism Council Data.

Table 28.1. Trend in International Tourist Arrivals and Receipts in the WIO countries for the period 2011 to 2013.

Destinations	International Tourist Arrivals							International Tourism Receipts			
	(1 000s)			Change (%)			Share (%)	US (US$ million)			Share (%)
	2011	2012	2013*	2011/10	2012/11	2013/12*	2013	2011	2012	2013*	2013*
Comoros	19	...	...	22.9	...	...	...	44	39	...	...
Kenya	1 750	1 619	...	19.1	(-)7.5	...	...	926	935	...	...
Madagascar	225	256	196	14.8	13.7	(-) 23.3	0.4	...	...	...	...
Mauritius	965	965	993	3.2	0.1	2.9	1.8	1 488	1 477	1 321	3.9
Mozambique	1 902	2 113	...	10.7	11.1	...	...	231	250	...	...
Seychelles	194	208	230	11.4	7.0	10.7	0.4	291	310	344	1.0
Somalia	...	...	...	...	...	...	...	...	...	...	...
South Africa	8 339	9 188	9 510	3.3	10.2	3.5	17.0	9 547	9 994	9 238	27.0
Tanzania	843	1 043	...	11.8	23.7	...	...	1 353	1 713	1 880	5.5

Source: UNWTO (2014) | * = provisional figure | ... = figure or data not (yet) available.

per cent) and Mauritius (4.4 per cent). Based on international tourist receipts for 2012, South Africa has the greatest share (67.9 per cent) followed by Tanzania (11.6 per cent) and Mauritius (10.0 per cent). In Seychelles and Mauritius, destinations where the marine environment is the main attraction, tourism plays a major role in the economy, representing 63 per cent and 28 per cent of the GDP, respectively (Table 28.2).

Environment

Tourism, often associated environmental costs, supports conservation through private reserves, communal conservancies, and contributions to public protected areas (Buckley 2008). One main source of revenue contributing to marine ecosystem preservation is derived from visitor fees. In some cases, more than 50 per cent of parks funding is derived from tourism, although the average is typically around 10 per cent (Buckley 2012). For marine protected areas, Needham (2010) has shown that tourist SCUBA divers have a strong inclination to protect coral reefs.

Ecotourism is becoming popular among environmentally conscious tourists. It links areas of high ecological value to low-impact tourism and present opportunities for sustainable environmental tourism development. A deliberate shift towards ecotourism is resulting in benefits to ecosystems, tourist and the local communities alike. Ecotourism in coral reef areas, combined with the ecosystem restoration, has been on-going in the Dar es Salaam Marine Reserve System and is considered an alternative source of income for the local community (Wagner 2004).

Employment opportunities

The tourism industry is an important source of direct and indirect employment. It creates opportunities for the development of small and medium scale artisanal industries. For example, in Seychelles and Mauritius, it contributes 26.3 per cent and 12.1 per cent to national employment respectively (Table 28.2). Its contribution to GDP, particularly in Seychelles (63.0 per cent) is quite substantial, whilst proving to be also significant in Mauritius (28.0 per cent). At the other extreme, Comoros records the lowest portion of employment in the tourism industry, and an industry contribution of only 6.8 per cent to its GDP.

Impacts of tourism

Although tourism has immense potential to enhance socio-economic development and contribute to environmental rehabilitation, it also has a wide range of negative social and environmental impacts (Gössling 2006, Gössling and Schumacher 2010, Gössling and others, 2011) as shown in Table 28.3. The health status of the marine environment in the WIO is increasingly under threat and the additional pressure of tourism and recreation is a growing environmental concern.

Poverty in many countries of the region has led to sex trade in coastal regions which have the right ingredients to draw tourists from all over the world (Kibicho 2005, BBC 2014, IRIN 2015). Sexually transmitted diseases including the HIV/AIDS, are spreading within these coastal communities mostly due to the booming opportunities for diverse sexual persuasions (IRIN 2015). Beira's municipal government and local non-governmental organisations plan to

Table 28.2. Contributions of the Tourism industry to the WIO countries to GDP and employment. Source: World Travel and Tourism Council Data.

Countries	Gross Domestic Products (GDP)				Employment		
	Contribution to GDP (%)	Leisure travel spending (% of GDP)	Business travel spending (% of GDP)	Forecast for 2023 (%/a)	Number of jobs	% of total employment	By 2023
Comoros	6.8	84,3	15.7	3.3	5 000	2.4	7 000
France (Reunion)	7.4	81.2	18.8	3.8	7 500	3.1	11 000
Kenya	12.5	66.4	33.6	4.5	232 500	4.3	286 000
Madagascar	15.5	93.0	7.0	3.9	212 000	4.5	279 000
Mauritius	28.0	60.4	39.6	4.8	69 500	12.1	95 000
Mozambique	7.5	59.8	40.2	5.6	255 000	2.7	349 000
Seychelles	63.0	92.7	7.3	2.8	11 000	26.3	11 000
Somalia	-	-	-	-	-	-	-
Tanzania	13.2	83.0	17.0	6.4	422 000	4.0	502 000
South Africa	9.8	67.2	32.8	4.4	619 500	4.6	786 000

Table 28.3. Threat and challenges related to tourism development in the Western Indian Ocean. Adapted from Gössling (2006).

Economic	Social	Environment	Political
• Lack of foreign investors	• Insufficient code of conduct	• Inadequate monitoring of ecosystems	• Lack of socio-political stability
• Foreign investment leads to back flow of money	• Insufficient consultation and participation of local communities in decision making	• Pressure for property development, tourism operations and visitor management rights inside protected areas (Buckley 2012)	• Too many actors involved in decision making
• Lack of adequate infrastructure (access roads and transports)	• High levels of crime in tourist areas, including beaches (Ryan and Kinder 1996, Ratclife 2004)	• Inadequate Environmental and Social Impacts Assessment	•Conflicting local versus national legislation
• Inadequate accommodation	• Possible harassment of tourists, often on beaches (Chepkwony and Kangogo 2013)	• Area management plans missing	• Corruption
• Privatisation of beaches – loss of public access	• Prostitution and sex tourism on the increase (Kibicho 2005, Picard 2007)	• Protected areas often become inhabited	• Land conversion for hotel and infrastructure development resulting in social conflict between the local population and the authorities (Sunlu 2003, Gössling 2006)
• Use of beaches and intertidal zone hinder fishing activities and mariculture	• Incidents of sexual assault and sexual victimization on cruise ships (Klein and Poulston 2011)	• Pollution eg sewage from hotels	• Shift of user-rights from local communities to the government
• Lack of adequate qualified staff	• Commercialisation of religious rituals, traditional ethnic rights and festivities	• Habitat degradation eg on corals due to trampling	
• Loss of fishing grounds due to creation of marine parks	• Lack of educational facilities for tourists	• Beach vegetation removal for hotel construction	
	• Friction, conflict and dishonesty between tourists from overseas and local population (Cohen 1984)	• Endangered species such as turtles often tourist's attractions	
	• Conflict due to cultural, historical and socio-economic differences between residents and international tourists, and internal divisions within communities	• Freshwater scarcity	
	• Conflict with traditional and commercial coastal resource uses (Picard 2007)	• Overfishing of certain species as a result of tourists demand eg lobsters	
	• Discontent caused by a sense of social marginalisation of local inhabitants (Ryan 2001)	• Digging coral sand for construction	
	• Increased population in coastal towns	• Anchor damage	
		• Clearing of mangroves for construction	
		• SCUBA divers and snorkelers cause substantial damage to coral reefs (Davis and Tisdel 1996, Meyer and Holland 2009, Rouphael and Hanafy 2007)	
		• Oil-spills from dive-boats.	
		• Leasing tourism operating rights often detrimental to community wellbeing and biodiversity conservation (Buckley 2008)	

launch HIV/AIDS awareness-raising campaigns in areas like Miramar, to reach tourists, most of whom are European, as well as locals, including sex workers and fishermen (IRIN 2015). Whilst any social problems have their origin in the sex trade, other root-causes of the problems should also be addressed. For example, the creation and funding of alternative small-scale tourism projects has been suggested as a starting point to finding a long-term solution to the social problems in the coastal tourism areas of Kenya (Kibicho 2005).

POLICY RESPONSES

Sustainable coastal development needs to adopt a long-term planning and management timeframe (Marafa 2013) to promote sustainable tourism (Nash and Butler 1990, May 1991, Butler 1993) in order to maintain environmental and cultural integrity (Puppim de Oliveira 2005). This will help generate income, employment and conserve the local ecosystems and cultural heritage (UNEP 2003). A multi-faceted approach and action are needed, that includes enhanced sensitization of the assets and importance of the marine environment, instilling a feeling of ownership of the environment to promote stewardship of the coastal and marine environment amongst the various marine users and the development of interactive and participatory planning (Buckley 2012). The WIO countries have to rethink their position to strive for a bigger global market share. They should deploy more effort to diversify their coastal and marine tourism products and continue to innovate and improve coastal-based destinations in order to sustain the tourism industry.

Promote mutually beneficial tourism and conservation

Of particular interest is the ability of tourism to motivate large-scale positive change in land use by generating financial and political support for conservation (Buckley 2012). While this is increasingly urgent in the WIO region in view of the on-going environmental challenges, the growing popularity of coastal tourism has prompted governments such as Kenya to approve seemingly unlimited and *ad hoc* development in favour of the tourism sector (Su 2010). Hotels and other tourism infrastructure are being constructed without due consideration of adequate set-back distances which result in increase in coastal erosion (Phillips and Jones 2006). This will be compounded by the impacts of climate change, particularly sea level rise and the increased frequency and intensity of coastal storms. Research priorities are the need to develop quantitative sustainability indicators (Butler 1999) and establish environmental accounting measures for coastal and marine tourism (Buckley 2012).

Promote whale and dolphin watching

Whales and dolphins play a very important role in the health of the ocean environment and provide a source of income through whale watching tourism (see eg www.whalefacts.org/why-are-whales-important/). If responsibly developed and managed, it could bring much needed income to the region. To make it sustainable, proper adaptive management should be developed. This could include:

- Limiting the number of licenses issued and the maximum number of tourists and vessel trips per day;
- Including the presence of marine mammal experts on board to assess if the type of performed behaviour is compatible with the boat approach; and,
- Instigating periodic monitoring and reporting of potential impacts of the activity on the cetacean population.

Encourage cruise tourism and manage impacts

Though cruise vessels can cause much damage to the environment, some cruise vessels have made some significant investments (The Ocean Conservancy 2002) in advanced solid waste and wastewater processing equipment. They have adhered to the *Cruise Industry Waste Management Practices and Procedures*, to promote waste minimization, reuse, and recycling throughout the industry (The Ocean Conservancy 2002). Nevertheless, pollution due to cruise vessel effluents into the marine environment continues. The Ocean Conservancy (2002) has made the following recommendations, to address the problem:

- Reduce and regulate cruise ship discharges
- Improve monitoring and inspections
- Strengthen enforcement mechanisms
- Improve air quality control
- Develop education and training programmes
- Improve research and development

It has also been noted that various payments, including the high cost of visas and the time taken to process passports, have discouraged cruise ships operators from including some destinations, such as Bazaruto in Mozambique and Anakoa (Nosy Be) in Madagascar (UNEP/Nairobi Convention Secretariat and WIOMSA (2009). Efficient and effective port services for cruise vessels that visit the

BOX 28.2. WHALE AND DOLPHIN WATCHING by Imogen Webster



Humpback whales, a major ecotourism target. © Glenn Edney (www.grida.no)

Whale and dolphin watching is becoming an increasingly popular recreational and eco-tourism activity (Higham and Lück 2008, Hoyt and others, 2009, Mustika 2013). O'Connor and others (2009), estimated that 13 million people participated in whale watching in 119 countries with direct revenue estimated at US$872.7 million and indirect revenue of US$2 113.1 million. The level of interest in this activity has led to popular support for the protection of marine mammals from commercial whaling and other threats such as bycatch and ship strikes (Draheim and others, 2010, Christensen and others, 2009, Cunningham and others, 2012).

There is growing concern over the effects of the tourism industry on whale and dolphin behaviour and conservation (Williams and Ashe 2007, Jensen and others, 2009, Williams and others, 2011). A case study off the island of Zanzibar has shown that dolphin watching alter the behaviour, both individual and population level of Indo-Pacific bottlenose dolphins (Stensland and Berggren, 2007, Berggren and others, 2007).

Whale and dolphin watching in Mauritius has grown by an average of 56 per cent annually since 1998 (O'Connor and others, 2009). The daily average number of whale watching boats ranges between 30-40, and up to 80 boats in peak season. In 2009, the Mauritius Marine Conservation Society recorded 64 operators offering daily trips to view and swim with spinner and Indo-Pacific bottlenose dolphins, with most companies employing more than one boat. In addition, there are large catamarans, normally in association with hotels that offer day cruises that include diving and snorkelling and a variety of water sports, but that also may have cetacean encounters while at sea. The high concentration of boat and swimmer interaction can potentially have impacts (both long and short-term) on the resident cetacean populations.

South African coastline are required, to continue to attract cruises and sustain the industry.

Promote research and monitoring

Monitoring and research related to tourism activities remains negligible in WIO countries except for Kenya and South Africa (Gössling 2006). Global tourism-related research topics have long been identified (May 1991) and have not changed much except for the confounding element of climate change (Buckley 2012). Such research priorities are equally applicable to sustain coastal tourism development in the WIO region, and a starting point would be preparation of an updated tourism research agenda.

There are a growing number of students from overseas countries involved in research on the tourism industry in the WIO region, though it remains mostly uncoordinated (Gössling 2006). Local researchers should be provided with facilities and encouragement to undertake research and publish findings, and research should be catalogued and made widely-available, electronically. As an incentive, some international journals are already providing generous access and lower publication rate to researchers from developing countries (Gössling 2006).

Establishment of Marine Protected Areas

The effectiveness of Marine Protected Areas (MPA) in increasing fish stocks and diversity has been recognised (eg Gell and Roberts 2003). Coral reefs which protected within MPAs are increasingly being considered as attractive sites for recreational SCUBA diving (Davis and Tidshell 1996, Green and Donnelly 2003) and other tourist activities, generating significant revenue. In the Caribbean and Central America, the revenue generated from the associated fees is estimated at US$ 1–2 million (Green and Donnelly 2003). The protection of existing MPAs and establishment of more MPAs should be promoted with increases in fees and licenses where they exist, for increased revenue for the benefit of the tourism industry and local population.

Curbing Piracy

Piracy in the Western Indian Ocean has emerged and escalated as a major security concern for countries in the WIO region. Initially confined to the region off Somalia, it rapidly spread further south, beyond the equator. In Seychelles, it particularly affected the tourism and fishing industries. Tuna fishing activities alone are reported to have declined by 54 per cent from January to August 2009 due to the risk of piracy. Some tourism activities such as boat charters to outlying islands were also severely affected. However, it has been noted that attacks carried out by Somalia-based pirates have continued to decline since the peak in 2011 when there were 175 incidents (NATO 2014), down to only 23 incidences in 2013 (Madsen and others, 2014). Pirate attacks on cruise liners are also a serious threat to the cruise ship industry in the region and this risk has increased significantly (Idarat Maritime 2013).

Improving coastal and shoreline management

New approaches in shoreline management are needed to address environmental factors, as are policy frameworks to manage beaches in a sustainable way for coastal tourism development. Four issues are responsible for the changing relationship between coastal tourism and shoreline management: an increase in, and the changing nature of tourist-related pressure at the coast; advances in shoreline management approaches including the adoption of Integrated Coastal Zone Management (ICZM) principles; the geomorphologic behaviour of coastal systems; and, climate change and sea level rise (Jennings 2004).

In the WIO, the nature and magnitude of coastal tourism has fundamentally changed over time. Coastal urbanisation and the presence of the tourism industry and its activities within potentially fragile environments such as sandy beaches, coral reefs, mangroves and seagrasses have led to pollution and serious threats from erosion and flooding (Mwakumanya and Bdo 2007, Breetzke and others, 2008, Government of Mauritius 2010).

Introducing beach awards systems

The Blue Flag Programme (www.blueflag.org), which has been claimed provide an excellent opportunity to promote sustainable coastal development (Thomsen 2001), improve coastal infrastructure and attract international tourists (Seetanah and others, 2011) has been adopted by many countries around the world (McKenna and others, 2011). It is centred on 33 well-defined criteria, including standards for water quality, safety, environmental education and information, the provision of services and general environmental management. These criteria need to be sustained for one year for a beach or marina to be eligible for status renewable the subsequent year.

Currently, only South Africa and Reunion are implementing the Blue Flag Programme, though other WIO countries should consider participating. They should also

establish and place emphasis on their own criteria and conduct basic research into the preferences and priorities of beach users and assess the cost-effectiveness of improvements in terms of increase in visitor numbers and improved environmental quality.

Promoting domestic tourism

While domestic tourism stimulates local economies and should be encouraged, it is often neglected in favour of international tourism with coastal infrastructure often developed to favour overseas tourists. WIO countries should rethink their tourism development approach. Coastal tourism within the region represents a considerable opportunity for growth and development that needs to be exploited. Studies should be conducted to identify strengths and weaknesses to develop sustainable domestic tourism in the coastal zone, and strategies developed to encourage a strong domestic tourism market that attracts locals towards coastal recreational and tourist activities.

CONCLUSIONS

According to *Tourism Towards 2030* (UNWTO 2014), the number of international tourist arrivals worldwide is expected to increase by an average of 3.3 per cent a year over the period 2010 to 2030. In absolute numbers, international tourist arrivals will increase by some 43 million a year, compared to an average increase of 28 million a year during the period 1995 to 2010, reaching 1 400 million by 2020 and 1 800 million by the year 2030 (UNWTO 2014). International tourist arrivals in Africa will grow at double the rate (+4.4 per cent a year) of that in advanced economy destinations (+2.2 per cent a year). Africa is expected to more than double its arrivals in this period, from 50 million to 134 million. Countries he WIO region should get prepared to improve their infrastructure and facilities to cope with the substantial increase.

For decades, the source for international tourism in the region has traditionally been from Europe. For instance, in Mauritius in 2013, 47.9 per cent of international tourists were from Europe and 14.4 per cent from Reunion (Digest of Statistics 2014). Emerging economies, particularly Asian countries should be the focus of of future marketing efforts, as these countries have shown an increase in the number of tourists travelling abroad. China is becoming a large potential market which should be explored. Boosted by rising disposable incomes, fewer restrictions on foreign travel and an appreciating currency, Chinese tourism spending abroad has increased almost tenfold in the 13 years since 2000 (UNWTO 2014). The Russian Federation climbed one place in 2013 to become the fourth largest outbound market, following a 25 per cent increase to US$ 54 000 million (UNWTO 2014). Mauritius and Reunion are already planning joint ventures to attract more Chinese tourists. Countries in the region should develop regional strategies to attract more tourists in addition to those from the traditional sources (mainly Europe). Many countries such as Mozambique, Tanzania and Kenya are expected to benefit from new offshore oil and gas discoveries in particular, from which earnings can be invested into improving infrastructure with hopes of also attracting more tourists from non-traditional economies.

References

Ayob, M.Z., Saman, F.M. and Hussin Z.H. (2009). Tourists' Satisfaction on Kilim River Mangrove Forest Ecotourism Services. *International J. Business Manag.* 4(7), 76-83

Barton, D.N. (1994). *Economic Factors and Valuation of Tropical Coastal Resources*. SMR-Report 14/94. Center for Studies of Environment and Resources, University of Bergen, Norway

BBC (2014). *Kenya's hidden sex tourism in Malindi*. Available at http://www.bbc.com/news/world-africa-27427630

Beatley, T., Brower, D.J. and Schwab, A.K. (1994).An introduction to coastal zone management. Island Press, Washington, D.C.

Berggren, P., Amir, O.A., Guissamulo, A., Jiddawi, N.S., Ngazy, Z., Stensland, E., Sarnblad, A. and Cockroft, V.G. (2007). *Sustainable Dolphin Tourism in East Africa*. MASMA Technical Report. WIOMSA Book Series No 7

Blue Flag. http://www.blueflag.org/

Breetzke, T., Parak, O., Celliers, L., Mather, A. and Colenbrander, D.R. (2008). *Living with coastal erosion in Kwazulu-Natal: Short-term, Best Practice Guide.*

KwaZulu-Natal Department of Agriculture and Environmental Affairs. Cedara, Pietermaritzburg. Available at http://www.kzndae.gov.za/Portals/0/Environment/Erosion%20strategy%20edoc.pdf

Buckley, R.C. (2008). Testing take-up of academic concepts in an influential commercial tourism publication. *Tour. Manag.* 29(4), 721–729

Buckley, R.C. (2012). Sustainable tourism: Research and reality. *Ann. Tour. Res.* 39(2), 528-546

Butler, R.W. (1993). Tourism - an evolutionary perspective. In *Tourism and sustainable development: monitoring, planning, managing.* (eds. J.G. Nelson, R. Butler and G. Wall) Department of Geography Publication Series No 37, pp. 27-43. University of Waterloo. Waterloo, Ontario

Butler, R.W. (1999). Sustainable tourism: A state-of-the-art review. *Tourism Geogr.* 1(1), 7-25

Chepkwony, R. and Kangogo, M. (2013). Nature and Factors Influencing Tourist Harassment at Coastal Beach of Mombasa, Kenya. *Int. Res. J. Social Sci.* 2(11), 17-22

Christensen, A., Needlam, M.D. and Rowe S. (2009). Whale Watchers' Past Experience, Value Orientations, and Awareness of Consequences of Actions on the Marine Environment. *Tourism in Marine Environments* 5(4), 271-285

Cohen, R. (1984). The sociology of tourism: approaches, issues and findings. *Annu. Rev. Sociol.* 10(1), 373-392

Crabble, M. and McClanahan, T.M. (2007). Biosocioeconomic evaluation of shipwrecks used for fisheries and Dive tourism enhancement in Kenya. *Western Indian Ocean J. Mar. Sci.* 5(1), 35-54

Cunningham, P.A., Huijbens, E.H. and Wearing, I. (2012). From whaling to whale watching: examining sustainability and cultural rhetoric. *J. Sustainable Tour.* 20(1), 143-161

Davis, D. and Tidshell, C. (1996). Economic management of recreation scuba diving and the environment. *J. Environ. Manag.* 48(3), 229-248

Digest of Statistics (2014). *Digest Of International Travel And Tourism Statistics*. International Travel And Tourism Statistics. Vol. 40. Ministry of Finance and Economic Development. Port Louis, Mauritius. Available at http://statsmauritius.govmu.org/English/Documents/TravelandTourism/tourism13.pdf

Dowling, R.K. (2006). Looking ahead: The future of cruising. In *Cruise Ship Tourism* (ed. R.K. Dowling) pp. 414-436. CABI publication

Draheim, M., Bonnelly, I., Bloom, T., Rose, N. and Parsons, E.C.M. (2010). Tourist Attitudes Towards Marine Mammal Tourism: An Example From the Dominican Republic. *Tourism in Marine Environments* 6(4), 175-183

Dwyer, L. and Spurr, R. (2011). *Tourism Economics Summary.* STCRC Centre for Economics and Policy. Gold Coast Campus Griffith University. Australia. Available at http://www.crctourism.com.au/wms/upload/resources/Tourism%20Economics%20Summary%20WEB.pdf

Gell F.R. and Roberts C.M. (2003). Benefits beyond boundaries: the fishery effects of marine reserves. *Trends Ecol. Evol.* 18: 448-455.

Global Tourism Places (2013). *Top 10 Tourist Attractions in Mozambique.* Available at http://globaltourismplaces.com/top-10-tourist-attractions-in-mozambique/

Gössling, S. (2006). Towards sustainable Tourism in the Western Indian Ocean. *Western Indian Ocean J. Mar. Sci.* 5(1), 55-70

Gössling, S. and Schumacher, K.P. (2010). Implementing carbon neutral destina- tion policies: Issues from the Seychelles. *J. Sustainable Tour.* 18(3), 377–391

Gössling, S., Peeters, P., Hall, C. M., Ceron, J.P., Dubois, G., Lehman, L.V. and Scott, D. (2011). Tourism and water use: Supply, demand and security, and international review. *Tour. Manag.* 33(1), 16–28

Government of Mauritius (2010). *Second National Communication*. United Nations Framework Convention on Climate Change (UNFCCC). Mauritius Available at http://unfccc.int/resource/docs/natc/snc_mauritius.pdf

Government of Mauritius (2013). *The Ocean Economy. A Roadmap for Mauritius*. Prime Minister's Office

Green, E. and Donnelly, R. (2003). Recreational Scuba Diving In Caribbean Marine Protected Areas: Do The Users Pay? *AMBIO* 32(2), 140-144

Higham, J. and Lück, M. (eds.) (2008). Marine wildlife and tourism management: Insights from the natural and social sciences. CABI. Wallingford, UK

Honey, M. and Gilpin, R. (2009). *Tourism in the Developing World: Promoting Peace and Reducing Poverty.* United States Institute for Peace. Special Report. Washington, D.C.

Hoyt, E. (2009). Whale watching. In *Encyclopedia of Marine Mammals*. (eds. W.F. Perrin, B. Würsig and J.G.M. Thewissen) 2nd edition, pp. 1219-1223. Academic Press, San Diego

Idarat Maritime (2013). *Pirate cruises?* http://www.idaratmaritime.com/wordpress/?p=211 Accessed at 11

December 2014

IRIN (2015). *Mozambique: Tourism, beaches and sex - a recipe for HIV*. Humanitarian news and analysis. Available at http://www.irinnews.org/report/79376/mozambique-tourism-beaches-and-sex-a-recipe-for-hiv

Jennings, S. (2004). Coastal tourism and shoreline management. *Ann. Tour.Res*. 31(4), 899-922

Jensen, F.H., Bejder, L., Wahlberg, M., Aguilar, S.N., Johnson M. and Madsen P.T. (2009) .Vessel Noise Effects On Delphinid Communication. *Mar. Ecol. Prog. Ser.* 395, 161–175

Kibicho, W. (2005). Tourism and the Sex Trade in Kenya's Coastal Region. *J. Sustainable Tour.* 13(3), 256-280

Kiszka, J., Berggren, P., Rosenbaum, H.C., Cerchio, S., Rowat, D., Drouot-Dulau, V., Razafindrakoto, Y., Vely, M. and Guissamulo, A. (2009). *Cetaceans in the southwest Indian Ocean: a review of diversity, distribution and conservation issues*. Report SC/61/ O18 to the Scientific Committee of the International Whaling Commission

Klein, R.A. and Poulston, J. (2011). Sex at Sea: Sexual Crimes Aboard Cruise Ships. *Tourism in Marine Environments* 7(2), 67-80

Kohler, K. (2003). *KwaZulu-Natal's Cruise Tourism Industry*. Tourism KwaZulu-Natal Occasional Paper No 8. KwaZulu-Natal Provincial Government. Pietermaritzburg. Available at http://www.zulu.org.za/userfiles/1/file/ForIvestorandResearcher/Research/Occ%20Papers%20PDFs/Occ%20paper%208%20KZN%20Cruise%20Tourism%20Industry.pdf

Madsen, J.V., Seyle, C., Brandt, K., Purser, B., Randall, H. and Roy, K. (2013). *The state of maritime piracy*. Oceans Beyond Piracy Project One Earth Future Foundation. Available at http://oceansbeyondpiracy.org/sites/default/files/attachments/SoP2013-Digital.pdf

Mangrove Action Project (2013). *Gazi Women Ecotourism Project*. http://mangroveactionproject.org/gazi-women-ecotourism-project/ Accessed at 21 November 2014

Marafa, L.M. (2013). Integrating Sustainable Tourism Development in Coastal and Marine Zone Environment, Études caribéennes 9-10. http://etudescaribeennes.revues.org/1373Accessed at 26 Novembre

May, V. (1991). Tourism, environment and development. Values, sustainability and stewardship. *Tour. Manag.* 12(2), 112-118

Mazilu, M., Avram, M. and Ispas, R. (2011). The Effects of the World Economic Crisis on the Tourist Market from Romania. *Int. J. Energy Environ*. 5(1), 113-122

McKenna, J., Williams, A.T. and Cooper, J.A.G. (2011). Blue Flag or Red Herring: Do beach awards encourage the public to visit beaches? *Tour. Manag.* 32(3), 576-588.

Meyer, C.G. and Holland, K.N. (2009). Spatial dynamics and substrate impacts of recreational snorkelers and SCUBA divers in Hawaiian Marine Protected Areas. *J. Coast. Conservat.* 12(6), 209-217

Mustika, P.L.K, Birtles, A., Everingham, Y. and Marsh H. (2013). The human dimensions of wildlife tourism in a developing country: watching spinner dolphins at Lovina, Bali, Indonesia. *J. Sustainable Tour.* 21(2), 229-251

Mwakio, P. (2013). *Cruise ship docks at Mombasa port with 650 tourists*. The Counties. 27 December http://www.standardmedia.co.ke/thecounties/article/2000100893/cruise-ship-docks-at-mombasa-port-with-650-tourists

Mwakumanya, M.A. and Bdo, O. (2007). Beach Morphological Dynamics: A Case Study of Nyali and Bamburi Beaches in Mombasa, Kenya. *J. Coastal Res.* 23(2), 374-379

Nash, D. and Butler, R. (1990). Towards sustainable tourism. *Tour. Manag.* 11(3), 263–264

NATO (2014). NATO Shipping Centre Piracy statistics. Available at http://www.shipping.nato.int/Pages/Piracystatistics.aspx

Needham, M.D. (2010). Value orientations toward coral reefs in recreation and tourism settings: a conceptual and measurement approach. *J. Sustainable Tour.* 18(6), 757–772

O'Connor, S., Campbell, R., Cortez, H. and Knowles, T. (2009). *Whale Watching Worldwide: tourism numbers, expenditures and expanding economic benefits*. A special report from the International Fund for Animal Welfare. Yarmouth M.A., USA

Phillips M.R. and Jones A.L. (2006). Erosion and tourism infrastructure in the coastal zone: Problems, consequences and management. *Tour. Manag.* 27(3), 517–524

Picard, D. (2007). *ReCoMaP - Sustainable Development of Coastal Tourism in the South West Indian Ocean I: Potential And Feasibilities Of National And Local Development Of Coastal Ecotourism*. Regional Programme for the Sustainable Management of the Coastal Zones of the Indian Ocean Countries. Indian Ocean Commission. European Union

Picard, D. (2010). *Tourism chapter of the coastal livelihood country report for Madagascar*. UNDP GEF Agulhas and Somali Currents Large Marine Ecosystems Project

(ASCLME). Available at http://www.academia.edu/3747794/Tourism_Chapter_of_the_Coastal_Livelihood_Country_Report_for_Madagascar_2010_

Puppim de Oliveira, J.A. (2005). Tourism as a Force for Establishing Protected Areas: The Case of Bahia, Brazil. *J. Sustainable Tour.* 13(1), 24-49

Ratclife, H. (2004). The hotspot matrix: A framework for the spatio-temporal targeting of crime reduction. *Police Pract. Res.* 5(1), 5-23

Richardson, B. (2010). *The Contribution of Tourism to Economic Growth and Food Security*. USAID Mali, Office of Economic Growth. Michigan State University, USA

Rouphael, A.B. and Hanafy, M. (2007). An alternative management framework to limit the impact of SCUBA divers on coral assemblages. *J. Sustainable Tour. 15*(1), 91-103

Ryan, C. (2001). *Sex Tourism: Trends in Liminality*. Routledge, London

Ryan, C. and Kinder, R. (1996). The deviant tourist and i: the case of the tourist and the New Zealand prostitute. In *Tourism, crime and international security issues* (eds. A. Pizam and Y. Manfielfd). pp. 23-36. New York

Salam, M.A., Ross, L.G. and Beveridge M.C.M. (2000). Eco-tourism to protect the reserve mangrove forest the Sundarbans and its flora and fauna. *Anatolia* 11(1), 56-66.

Seetanah, B., Juwaheer, T.D., Lamport, M,J., Rojid, S., Sannassee, R.V. and Subadar Agathee, U. (2011). Does Infrastructure Matter In Tourism Development? *University of Mauritius Research Journal* 17, 89-108

Steiner, C. (2006). Tourism, poverty reduction and the political economy: Egyptian perspectives on tourism's economic benefits in a semi-rentier state. *Tourism Hospitality Planning and Development* 3(3), 161-177

Stensland, E. and Berggren, P. (2007). Behavioural changes in female Indo-Pacific bottlenose dolphins in response to boat-based tourism. *Mar. Ecol. Prog. Ser.* 332, 225-234

Su, Y.P. (2010). *A Review of "Coastal tourism development". J. Sustainable Tour.* 18(8), 1034-1036

Sunlu, U. (2003). Environmental impacts of tourism. In *Local resources and global trades: Environments and agriculture in the Mediterranean region* (eds. D. Camarda and L. Grassini) pp. 263-270. Bari : CIHEAM (Options Méditerranéennes : Série A. Séminaires Méditerranéens. No 57). Conference on the Relationships between Global Trades and Local Resources in the Mediterranean Region, 2002/04. Rabat, Morocco. Available at http://om.ciheam.org/om/pdf/a57/04001977.pdf

The Ocean Conservancy (2002). *Cruise Control.* A Report on How Cruise Ships Affect the Marine Environment. The ocean Conservancy. Washington, D.C. Available at http://act.oceanconservancy.org/site/DocServer/cruise-control.pdf?docID=141

Thomsen, F.B. (2001). Blue flag campaign: A practical tool for integrated coastal management. In *Inter Coast: International Newsletter of coastal management*. University of Rhode Island. Coastal Resources Center, USA

UNEP (2003). *Tourism and Local Agenda 21: The Role of Local Authorities in Sustainable Tourism*. United Nations Environment Programme. The International Council for Local Environmental Initiatives

UNEP/Nairobi Convention Secretariat and WIOMSA (2009). *Transboundary Diagnostic Analysis of Land-based Sources and Activities Affecting the Western Indian Ocean Coastal and Marine Environment.* UNEP Nairobi, Kenya

UNWTO (2002). *Tourism and Poverty Reduction*. World Tourism Organisation, Madrid

UNWTO (2013). *Tourism Highlights, 2013 edition*. World Tourism Organisation

UNWTO (2014). *Tourism Highlights, 2014 edition*. World Tourism Organisation

Wagner, G.M. (2004). Coral Reefs and Their Management in Tanzania. *Western Indian Ocean J. Mar .Sci.* 3(2), 227–243

Williams, R. and Ashe, E. (2007). Killer whale evasive tactics vary with boat number. *J Zool* 272(4), 390-397.

Williams, R., Ashe, E., Sandilands, D. and Lusseau, D. (2011). *Stimulus-dependent response to disturbance affecting the activity of killer whales*. Scientific Committee of the International Whaling Commission

WIOMSA IUCN (2004). *Managing Marine Protected Areas: A TOOLKIT for the Western Indian Ocean*. IUCN Eastern African Regional Programme. Nairobi, Kenya



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Urbanisation, Coastal Development and Vulnerability, and Catchments

Louis Celliers and Cebile Ntombela

Opposite page: Coastal development at Catembe with Maputo in the background, Mozambique. © José Paula.

URBANISATION, COASTAL DEVELOPMENT AND VULNERABILITY

The growth of urban areas that form coastal cities, especially in the WIO, places an increasing demand on natural coastal extractive and non-extractive resources. The use and conversion of coastal land and catchments is considered a permanent effect of growth and development. Urbanisation has direct effects on biodiversity and the state of the coastal environment. The location of coastal urbanisation inherently translates to socio-economic vulnerability. Coastal cities of the WIO region are desirable places to live and work which results in ongoing and increasing urbanisation. The populations of the urban areas of the region are also vulnerable to natural disasters associated with this location in the coastal zone.

Urbanisation and globalisation are symbols of the 21st century (Barau and Ludin 2012). Urban areas are a confluence of people, economic activity, and the built environment. Urbanisation is simultaneously a demographic, economic, and land-use change phenomenon (Zhang and Seto, 2011). Urbanisation is a multifaceted, heterogeneous and complex phenomenon that is highly contextual. Urbanisation can refer simply to the growth of population in towns but a more complex definition would be to describe the social and political changes that may occur when people live in large, nucleated settlements. Urbanisation can also refer to two important structural changes, namely, the rate of change or growth of urbanisation levels (the share of the national population in towns) and the extent to which this change is accompanied by shifts in the economy and employment (UN-Habitat 2014).

Generally speaking, economic factors, especially spatial inequalities in economic development, employment opportunities and wages, are underlying drivers of urban migration (Seto 2011). The size and characteristics of rural and urban human settlements in Africa are also partially driven by climate change. The majority of migration flows observed in response to environmental change are within country boundaries (Tacoli 2009). The abundance of resources in the coastal zone and the general desirability of living near the ocean add complexity to the cause and effect of urbanisation.

Cities have become a focal point for production, exchange and consumption, and urbanisation is trademarked by mass consumption (Bogardi 2008, Beaverstock and others, 2011, Barau and Ludin 2012). African economies are demonstrating gradual improvement with an increasing number of nations progressing towards high rankings among the world's emerging economies. However, eastern Africa is the world's least urbanized but fastest urbanising sub-region on the continent and Africa as a whole still experiences massive urban poverty and other social problems (UN-Habitat 2014).

Three African cities - Dar es Salaam, Khartoum and Abidjan - are projected to reach megacity status within a generation from now (UN-Habitat 2014). The prevailing worldwide view is that cities are engines of growth and

human development, but this perspective is challenged by the unfolding realities in Africa. Most coastal cities in the WIO region are experiencing higher than average growth and development rates. The "high road" to urban economic and general developmental progress requires more broadly shared benefits to all socio-economic strata (UN-Habitat 2014). According to Seto (2011), the physical growth of cities (in mega-deltas) is limited by four interacting factors:

- Local biophysical constraints due to human activities;
- Large-scale environmental change;
- Uncertainties around future economic growth; and
- Effectiveness of urban planning institutions.

CATCHMENTS

The flow of coastal river catchments, which connect terrestrial and freshwater ecosystems to oceans, enables essential ecological processes in coastal and marine environments. As river networks drain watersheds, they transport freshwater, sediment, nutrients, biota and chemicals, which, along with oceanic forces, influence the availability of natural resources in estuaries and coastal environments (UNEP/Nairobi Convention Secretariat and WIOMSA 2009a). However, this interaction between catchments and the coastal and marine environments has been identified as one of the processes subject to environmental pressures in coastal zones of the WIO region (UNEP/Nairobi Convention Secretariat and WIOMSA 2009b).

Three major issues linked to river-coast interaction in the WIO region are the modification of river flows (water quantity), water quality and sediment loads, primarily as a result of abstraction; damming; inappropriate land-use practices; and increased floods and seasonal flow patterns, as described below:

- **Water quality** has been most affected by nutrient loads and contaminants originating from domestic sewage and industrial and agricultural chemicals (UNEP/Nairobi Convention Secretariat and WIOMSA 2009b).
- **Water quantity** or the modification of river flows in the region has been attributed to: consumptive uses of water leading to reduced flow; impoundment or damming which increases the surface area of rivers; change in seasonal flow patterns; and increased floods as a result of wetland losses or the loss of water retention capacity. These are further exacerbated by the realities and uncertainties of climate change with some catchments predicted to receive more rainfall than normal while others receive less (UNEP/Nairobi Convention Secretariat and WIOMSA 2009b).
- The alteration of **sediment loads**, which has been attributed to climate change, land-use practices and the construction of dams, is widely evident in most of the rivers in the region. Increased sediment loads have impacted the region's coastal and marine environment through smothering of mangroves, coral reefs and seagrass beds. Decreased sediment loads have affected the coastal and marine environment in the region through the erosion of the delta mouth and through increased salt-water intrusion leading to the destruction of mangrove habitats (UNEP/Nairobi Convention Secretariat and WIOMSA 2009b).

An assessment of hydrological and land-use characteristics affecting river-coast interactions conducted for the WIO region, identified a number of socio-economic and environmental pressures linked to river-coast interaction throughout the region. These include:

- Economic growth, which continues to drive increasing demand on limited water resources in river catchments for industry, mining, urban development, agriculture and energy generation thereby affecting the flow and quality of rivers across the region;
- Poverty and inequality, which often lead to such unsustainable land-use practices as over-stocking of cattle resulting in over-grazing and ultimately increased runoff of nutrients and soil erosion;
- Climate and natural processes, which influence the flow of rivers, turbidity and sediment transport. Climatic changes have largely been linked to extreme events such as floods and droughts. Floods are linked to such impacts as soil erosion and sedimentation while droughts lead to increased pollution concentration and reduce water volumes to the coast which then affects the essential river-coast interaction;
- Population growth, which has been experienced throughout the region at medium to high rates and been linked to irreversible changes to river systems and to greater demand on limited supplies;
- Lack of financial resources and human capital for effective implementation of regulatory measures and water management strategies;
- Lack of effective governance, characterised by a lack of inter-sectorial coordination and the misuse of available resources. Some of the areas in the region lack adequate enforcement of legislation and there is a general lack of

legal and institutional frameworks for the management of trans-boundary catchments; and,

- Lack of knowledge and awareness of the nature, causes and impacts of certain environmental problems. Different stakeholders also still lack awareness of the impact of their activities on the ecosystems (UNEP/Nairobi Convention Secretariat and WIOMSA 2009a).

COASTS AND CATCHMENTS OF THE WESTERN INDIAN OCEAN REGION

According to UN-Habitat (2014), more than a quarter of Africa's population lives within 100 km of the coast and more than half of Africa's total population living in low-elevation coastal zones is urban, accounting for 11.5 per cent of the total urban population of the continent (see Figure 29.1).

The decade 2000-2010 saw 20.8 million new urban dwellers in the Eastern African sub-region (Kenya, Tanzania and the Island States) and the forecast for the current decade (2010-2020) is that the total number of Eastern African urban dwellers will increase by more than 50 per cent (UN-Habitat 2014). The Southern African sub-region (South Africa and Mozambique) is, after Northern Africa, the continent's most urbanised and projected to reach a region-wide urban majority around the end of the current decade (2010-2020). South Africa reached an urban majority of 62 per cent in 2011 with Mozambique projected to reach an urban majority by 2050 (UN-Habitat 2014). The urban population of some WIO countries are given in Figure 29.2.

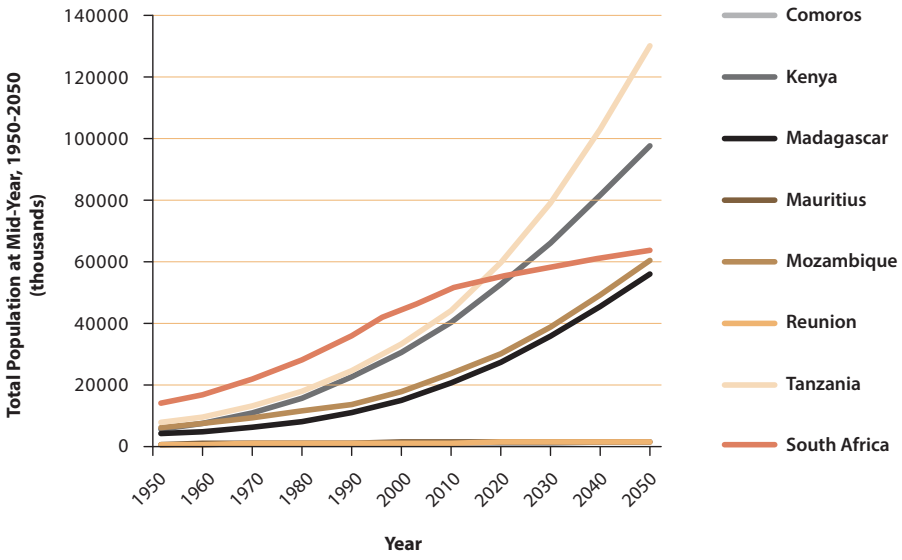


Figure 29.1. Total mid-year population of countries in the Western Indian Ocean. Source: DESA (2014).

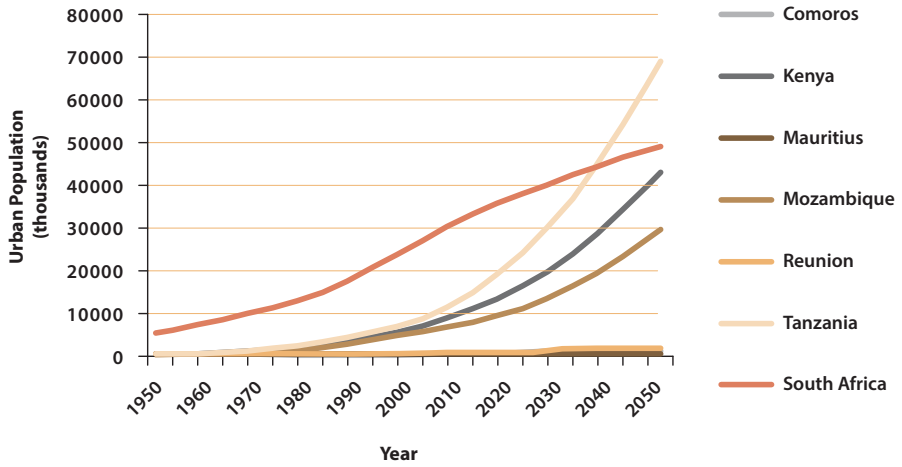


Figure 29.2. Urban Population at Mid-Year by Major Area, Region and Country, 1950-2050. Source: DESA (2014).

For the Eastern Africa sub-region, the 2030-2040 decade is projected to add numbers of urban dwellers equivalent to 110 per cent of the entire 2010 urban population. The total number of urban dwellers in 2040 is projected to reach a massive five times the 2010 figure.

These high projections are cause for concern given existing unemployment of the urban population and the extent and condition of slums in Eastern Africa. While there is a definite deceleration of urban growth (declining urbanisation rates), the absolute urban population is projected to increase and will remain a challenge. Small island states like Seychelles, Mauritius and, to some extent, French Reunion are exceptions to this generalisation since urban population growth is small, in absolute terms, or even declining (UN-Habitat 2014)

Tanzania has a particularly high absolute population growth with 41.9 million projected to increase to 61.5 million (2010-2050). Over that same period, Kenya will have to accommodate 38.1 million new urban dwellers, Madagascar 27.7 million, and Somalia 14.4 million. According to UN-Habitat (2014), four WIO countries are heading for urban majorities: Madagascar and Somalia (by 2050) and Mauritius and Tanzania (by 2040). Comoros and Kenya had a delayed entry in the global urban transition and are projected to remain rural despite their current strong to moderate absolute urban growth (UN-Habitat 2014).

Environmental impact of urbanisation

The expansion of the built environment is among the most irreversible human impacts on the global biosphere and urban land-use change remains one of the primary drivers of habitat loss and species extinction (Hahs and others, 2009). Figure 29.3 provides an indication of the development footprint of some of the major cities in the region. The data provided shows electric light emitted at night (2012) as a proxy for economic development and urbanisation (Doll and others 2006, Elvidge and others, 2009, Ghosh and others, 2010).

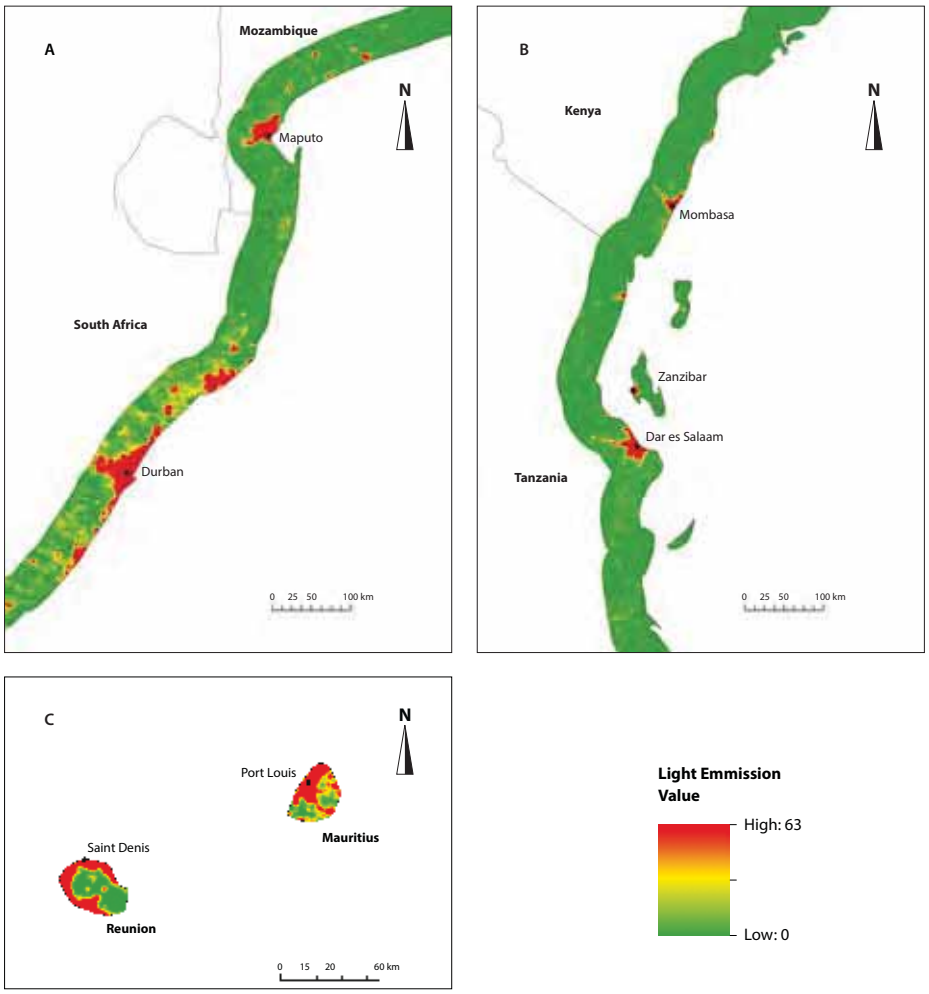


Figure 29.3. Night light emission from cities; **a)** Durban and Maputo; **b)** Dar es Salaam and Mombasa; and **c)** Port Louis and Saint Denis in the Western Indian Ocean region as a proxy for economic development and urbanisation. Source: ngdc.noaa.gov/eog/dmsp.html.

The use and conversion of coastal land, urbanisation, population growth, demographics shifts, poverty and a lack of alternative livelihoods, increased wealth, urbanisation and consumption rates (eg building materials, fish; ASCLME/SWIOFP 2012a, ASCLME/SWIOFP 2012b) intensifies the demand on coastal and marine resources at the national level. The transboundary diagnostic analysis (UNEP/Nairobi Convention Secretariat and WIOMSA 2009b) identified several direct causal links between urbanisation and water quality degradation, habitat a community modification and a decline in living marine resources. Some of the specific links between urbanisation and coastal environmental quality included:

• Water quality degradation:

- Alteration of natural river flow and changes in freshwater input and sediment load;

- Degradation of ground and surface water quality;

- Microbiological contamination from land-based (domestic, industrial, agriculture and livestock) and marine (mariculture, shipping) sources; and

- Solid wastes / marine debris (plastics etc.) from shipping and land-based-sources.

• Habitat and community modification:

- Shoreline change due to modification, land reclamation and coastal erosion;

- Disturbance, damage and loss of upland / watershed habitats (>10 m elevation);

- Disturbance, damage and loss of coastal vegetation and floodplain habitats (to 10 m elevation);

- Disturbance, damage and loss of mangrove habitats, coral reef habitats and seagrass habitats; and the

- Introduction of exotic non-native, invasive and nuisance species.

• Declines in living marine resources;

- Decline in populations of reef and demersal fish; and

- Decline in populations of prawns and shrimp.

Coastal urbanisation, environmental impacts and vulnerability

Coastal urban areas on the mainland countries of the WIO are mostly located in the vicinity of estuaries, mangrove swamps and coral lagoons. The island states have quite different patterns of urbanisation due to their small land-areas. For all the islands, except Madagascar, the entire land area can be considered to be part of the coastal zone. The environmental impacts of urbanisation depend on the national environmental, social and political context (Table 29.1).

Table 29.1. Urban features of and associated issues in the Western Indian Ocean countries.

Country	Features	Major issues relating to urbanisation	Coastal alteration, infrastructure and populations
Kenya	The relatively short coastal region has about 2.5 million people (population density of 77/ km^2) which is 8 per cent of the total national population (ASCLME 2012). Major urban areas include Mombasa, Malindi and Kilifi and Mombasa County accounts for 27 per cent of the total coastal population. Features include: Important infrastructure in the coastal region: roads, airports, railways, ports and harbours, energy, water supply and sanitation. Urban centres include: Kilifi, Lamu and Malindi. Mombasa has one of the largest sea ports in Eastern Africa. Presently, there are plans to construct a second large port at Lamu. A number of smaller ports exist in Lamu, Malindi, Kilifi and Shimoni.	Over-exploitation of nearshore fisheries, degradation of mangrove areas, shoreline changes and conflicts in the use of natural resources. Increased generation of waste and disposal of domestic sewage and industrial waste. Increased incidents of contamination of ground and surface water resources and associated public health risks. Most of the pollution hotspots are located near urban centres (Republic of Kenya 2009).	Low levels of alteration of the coastline. Port assets exposed at Mombasa and potentially more so in future eg planned Lamu port. Coastal infrastructure at risk in limited number of coastal urban areas.
Tanzania	Five coastal regions cover 15 per cent of total land area hosting 25 per cent of the population. Dar es Salaam is the largest city and seaport followed by Tanga and Zanzibar. The port handles cargo destined for land locked countries such as Burundi, Rwanda, Uganda, Malawi and Zambia. Dar es Salaam is projected to reach mega-city scale within the current decade 2010-2020 (UN-Habitat 2014).	Pollution; accessibility (hospitals, markets); lack of infrastructure; population pressure, resource degradation; increased unplanned settlement; crime, lack of good quality data on the coastal infrastructure; and inadequate research on the coastal regions infrastructure status.	Low levels of alteration of the coastline. US$ 130 million ports assets exposed to climate change impacts (Nicholls and others, 2008).

Country	Features	Major issues relating to urbanisation	Coastal alteration, infrastructure and populations
Mozambique	Forty five coastal districts and a total population of 20.5 million. Seventy per cent of the population lives in coastal districts. The districts with larger populations are Maputo City, Massinga, Nampula, Nacala-a-Velha, Alto Molocue, Milange Morrumbala, Mocuba, Maganja da Costa, Ile and Angonia. High degree of natural coastal and marine living resources use by coastal communities. Main sea ports are located in Maputo, Beira, Nacala and Pemba. An extensive coastline, along with ten ports, highlights the strength and promise of coastal transport in Mozambique. The scale of the coastline magnifies the importance of ports, particularly as a means of developing trade.	Extensive natural resource base, along with opportunities for mining development, could potentially facilitate national growth. Highly vulnerable to natural disasters, in particular events such as floods, drought, wave and tide hazards and cyclones (UN-Habitat, 2014, Theron and Barwell 2012).	Exposed soft sand coasts with high coastal and marine living resource dependency. Low levels of alteration except in port-urban areas. Rural and urban population susceptible to climate events such as cyclones. US$ 400 million ports assets exposed to climate change impacts (Nicholls and others, 2008)
South Africa	Total population estimated at 49.32 million of which 21.2 per cent is concentrated in KwaZulu-Natal and 13.5 per cent in the Eastern Cape of the WIO region. Forty per cent of total population lives within 100 km of the coast. Coastal population is concentrated in the cities (and ports) of Durban, Richards Bay, East London and Port Elizabeth. There is also a large rural population along the Wild Coast and ribbon development along the coast of KwaZulu-Natal, excluding the MPA in the north of the province	Intense development pressure on the coastline threatens natural biodiversity and ecosystem service delivery such as protection from storm damage. Many linefish species targeted by increasing numbers of recreational fishers. Coastal development ruining the aesthetic appeal of scenic areas. Lack of effective land use management and spatial development planning by local municipalities, particularly in the underdeveloped former homeland areas such as Kwa-Zulu, Transkei and Ciskei, has also facilitated strip development of coastal areas. Most local municipalities are understaffed and have problems securing and keeping suitably qualified staff.	Highly altered, significant investment in coastal infrastructure including ports. US$ 570 million ports assets exposed to climate change impacts (Nicholls and others, 2008)
Comoros	The Comoros, consisting of three islands, has Ngazidja (Grande Comore) as the most populated island with 296 177 inhabitants, followed by Ndzuwani (Anjouan) 243 732 and Mwali (Moheli) 35 751. The population is mainly concentrated along the coasts and spread over a small insular territory. The Comorian population is predominantly rural with 72.1 per cent in rural areas against 27.9 per cent in urban areas and remains amongst the world's most sparsely urbanised countries. Comorian urbanisation is strongly concentrated in three cities: the two insular capitals (Matsamudu and Fomboni) and the federal capital Moroni. Harbours play a vital role in the country's insular economy where the demand for manufactured goods, food and energy products such as hydrocarbons are met almost entirely from imports. Ports also provide transportation of goods and passengers between the islands. Mutsamudu harbour on Anjouan is the only deep water port.	Unbalanced spatial distribution of the population; irregular occupation and construction; problems of housing; sanitation; urban security; environmental degradation and urban unemployment.	Medium levels of alteration and high dependency on natural goods and services. Island populations both urban and rural highly susceptible to climate events. Ports play a critical role in national economy.
Seychelles	More than 80 per cent of the population reside on Mahé which is 60 per cent urbanised. The capital, Victoria and the main fishing port are located on its central east coast. Approximately 40 per cent of the population lives on the East Coast of Mahé, a coastal belt about 7 km long and 1 km wide (Shah 1998). Ninety to 100 per cent of the population is concentrated on the coastal zone (Shah 1998). The coastal population of Seychelles (found within 100 m of the coastline) is expected to increase from 161 to 203 persons/km^2 between 1995 and 2015 (Payet 2002). Port Victoria is a major hub for the Western Indian Ocean tuna fishery. In 2003, it handled 88 per cent of the total amount of tuna caught by purse seiners in the Western Indian Ocean (SFA 2003).	Coastal development, without consideration for sealevel rise and increase in the frequency and intensity of extreme natural events such as flooding and storm surges. Properties lack the necessary setback distance to the beach or are directly on the shoreline and on the sand dunes. Severe projected climate change issues including but not limited to: damage to properties and infrastructure located on the coastal plains and reclaimed land; eroding shorelines and beaches; threat to groundwater aquifers and coral island fresh water lens (Government of Seychelles 2011)	High levels of alteration and high dependency on natural goods and services. High proportion of island populations living near the shoreline where both urban and rural residents are susceptible to climate events.

Country	Features	Major issues relating to urbanisation	Coastal alteration, infrastructure and populations
Madagascar	The 2009 total population of Madagascar was estimated at 19 600 000 inhabitants (INSTAT 2011) of which 34 per cent live within 100 km of the coast. They are distributed in 13 coastal regions, subdivided into 43 coastal districts occupying an area of 404 519 km^2. Average density in coastal areas is 22.44 inhabitants/km^2. Madagascar is served by 6 international ports: Toamasina, Mahajanga, Antsiranana, Nosy-be, Toliara, and Ehoala, and 12 coastal navigation ports: Vohemar, Maroantsetra, Mananjary, Manakara, Taolagnaro, Morombe, Morondava, Maintirano, Port Louis, Antsohihy, Sambava and Antalaha.	Accessibility (hospitals, markets), lack of infrastructure, population pressure, poverty and lack of sanitation. Near coastal cities, unregulated coastal activities are increasing considerably especially overfishing, exploitation of mangroves, and tourism. Pollution is particularly noticeable in all coastal areas of Madagascar. This can be due to watershed soil erosion and deforestation, chemical pollution caused by industrial activities, and municipal and domestic wastes.	Low levels of alteration and high dependency on natural goods and services. Island populations both urban and rural highly susceptible to extreme climate events.
Mauritius	The 2010 population was 1 283 415. Mauritius is one of the most densely populated countries in the world with 629 inhabitants/km^2. Approximately 27 per cent of its total population and 50 per cent of its rural population live within the coastal zone. Infrastructure is well-developed and contributes to supporting the economic development of the country. Port Louis is the main navigational gateway for trade. However, there are no regular maritime connections with the other islands of the South West Indian Ocean.	Critical habitats such as coral reefs and seagrass beds impacted by climate change and over-exploitation with reduction of associated benefits. Major challenge is human capacity. Requirement to mainstream environmental protection in development planning processes. Need for an integrated approach for management of the coastal zone. I addition, an effective regulatory framework and mechanism is required to replace the presently scattered responsibilities among various agencies. Other issues: pollution control including wastewater; industrial effluents; soil erosion; agriculture and livestock runoff control; solid waste and marine litter.	High levels of alteration and high dependency on natural goods and services. Island populations both urban and rural highly susceptible to extreme climate events. High degree of reliance on contribution of port to GDP.

Coastal cities

Cities are often the most vulnerable to disasters, due to dense populations (Figure 29.4), extensive infrastructure and variety of activities within comparatively small geographical areas. Even though the extent and scale of disasters at city-level are often localised, the impacts often extend to the national scale, given the critical political, social and economic roles of cities (UN-Habitat 2014).

Coastal cities are more than a collection of people and buildings and form complex systems of habitation, infrastructure, public services – and their wastes. The inherent vulnerability of WIO cities to natural disasters is exacerbated by being located in low-lying coastal and estuarine delta areas. Contributing factors to specific vulnerability in the WIO coastal zone include being located in very low-lying coastal plains, in close proximity to the shoreline, a high incidence of poverty, a low capacity to build and maintain infrastructural defences, susceptibility to cyclone activity, and soft erodible coasts.

In most cases, coastal cities are associated with ports, which contribute to their regional importance. Nicholls and others (2008) contend that the concentration of future exposure to sea level rise and storm surge in rapidly growing cities in developing countries in Africa, amongst others, emphasises a need to integrate the consideration of climate change into both national coastal flood risk management and urban development strategies. The contribution of port cities to global trade also means that failure to develop effective adaptation strategies would inevitably have local, national and wider economic and security consequences; therefore local strategies will need to be incorporated within a wider spatial and time frame to address broader issues (Hanson and others, 2011).

Coastal vulnerability

Vulnerability is defined by UNEP as the extent to which a population or an ecosystem is liable to be affected by a hazard event, and mitigated by the capacity of a population or ecosystem to cope with these effects (UNEP 2005). Several regional assessments have identified East Africa as one of the most threatened coastal regions in Africa and globally (Dasgupta and others, 2011, Boko and others, 2007, Brown and others, 2009, Brown and others, 2011, Hinkel and others, 2012). Coastal and ocean systems are important

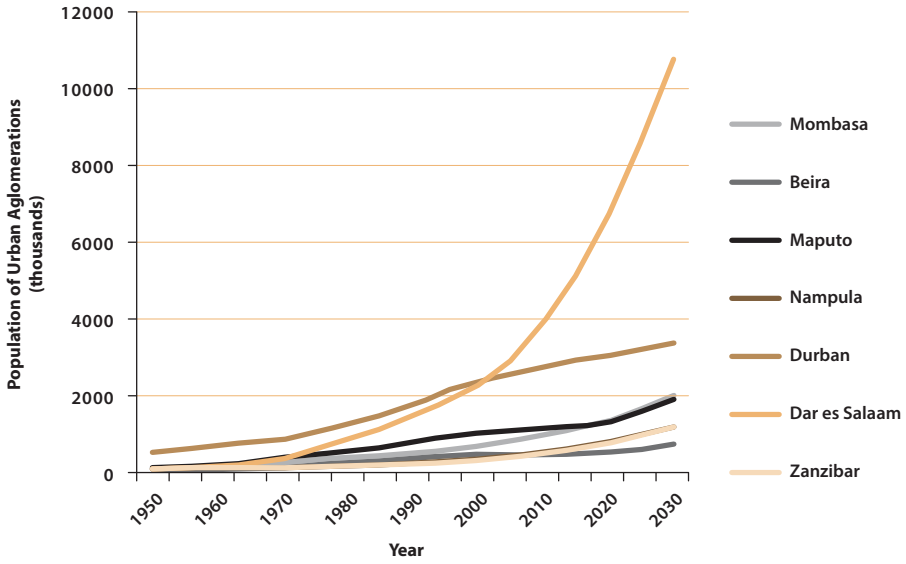


Figure 29.4. Population of coastal urban agglomerations with 300 000 inhabitants or more in 2014, 1950-2030 (DESA 2014)

BOX 29.1. CITIES AT RISK: DAR ES SALAAM, TANZANIA



View of Dar es Salaam from Kurasini Creek mouth. © José Paula.

Eight per cent of the city surface area lies within the low-elevation coastal zone defined as the land area below the 10 m contour lines; hosting approximately 5 per cent of the population (143 000) and an estimated US$ 168 million worth of economic assets, excluding the value of ports and harbours and tourism infrastructure. The population and economic assets at risk of 1-in-100-year return period extreme water levels by 2030 will range between 30 300 and 110 000 inhabitants and US$ 35.6 million to US$ 404.1 million (Kebede and Nicholls 2012). Some of the key findings proposed by Kebede and Nicholls (2012) included the development and implementation of appropriate land-use planning policy responses and investment priorities in order to steer land development away from low-lying areas. The authors conceded that enforcement of such policies could undoubtedly be an issue, especially where informal settlements dominate urbanisation (as in many developing countries).

for the economies and livelihoods of WIO countries, and are subject to existing stressors, such as overexploitation of resources, habitat degradation, loss of biodiversity, salinisation, pollution, urbanisation, overburdened infrastructure, coastal erosion, and rapid and unplanned growth (Alusa and Ogallo 1992, UNEP/Nairobi Convention Secretariat and WIOMSA 2009b, ASCLME/SWIOFP 2012a, ASCLME/SWIOFP 2012b, Kithiia 2011, Kebede and Nicholls 2012).

Coastal systems are expected to be exposed to hazards relating to sea level rise and to also experience impacts through high sea levels combined with storm swells

BOX 29.2. CITIES AT RISK: MOMBASA, KENYA.



View of Mombasa from KMFRI. © José Paula.

A popular tourism destination due to its favourable climate, Mombasa has many sandy beaches, and a considerable historical and cultural heritage. Tourism was shown to contribute more than 12 per cent of the Gross Domestic Product in 2004 and continues to grow. Mombasa is located at low altitude, and experiences high temperature and humidity levels, all of which contribute to its vulnerability to climate change. Parts of the city and its surroundings are likely to be submerged with a rise in sealevel resulting in a disruption of ecosystem functions and balance, agricultural and industrial activities, water supply, and the destruction of human settlements. As one of the biggest seaports in East Africa, this will impact negatively on the city's economy and, by extension, on the national economy. Awuor and others (2008) suggested that one of the key interventions to anticipate and manage the projected impacts would be to develop strategic options to guide future development of the city. They also suggested the development of a code of conduct to guide future development and that existing coastal management legislation must be reviewed. Encouraging settlement away from the most vulnerable areas remains one of the least expensive and pro-active ways through which future vulnerabilities may be reduced; see also Kithiia and Dowling (2010).

(Kithiia 2011, Hinkel and others, 2012). Key long-term impacts of climate change in the WIO region will be sea level rise, together with increasingly severe and possibly more frequent storms and storm surges. Most coastal cities in the region are situated at low elevation (below 10 metres above mean sea level), often next to lagoons and estuaries and more often than not associated with important harbours and industrial facilities (UN-Habitat 2014). Few, if any coastal cities are prepared for the predicted impacts of extreme climate events and cities such as Dar es Salaam (Box 29.1), Mombasa (Box 29.2), Maputo and Beira (Box 29.3), and Port Louis (Box 29.4), are particularly vulnerable to sea level rise.

Nicholls (2006) estimated that for the African Indian Ocean Coast in 1990, 7 million people were living in the hazard zone (potentially exposed population) and of those in the hazard zone 562 000 people were at risk to coastal flooding. The 2020 projection was that 14 million people would be living in the hazard zone and 1.2 million people would be at risk to flooding. In a similar continental scale (Africa) study by Hinkel and others (2012), 16–27 million people are expected to be flooded per year, and damage costs will reach between US$ 5 000 million and US$ 9 000 million per year in 2100, if no adaptation takes place. The same authors postulated that if adaptation measures (in terms of beach nourishment and dike construction) were employed, the number of people flooded can be reduced by two orders of magnitude and the economic damages cut by half in 2100.

Other climate change impacts, such as flooding of rivers, estuaries and deltas or an increased migration toward coastal towns due to increased drought inland, induced by climate change, will also affect coastal zones (IPCC 2014). Socio-economic vulnerability is expected to increase over the next two decades. The extent to which this vulnerability will increase with increased exposure to hazards depends on the adaptive capacity of countries in the WIO (Kebede and others, 2010, Theron and Barwell 2012).

Vulnerability to environmental change is increased where ecosystem goods and services are declining eg integrity of coral reef systems because of changing ocean pH, which in turn may reduce natural protection levels pro-

BOX 29.3. CITIES AT RISK: MAPUTO AND BEIRA, MOZAMBIQUE



View of Maputo from Catembe. © José Paula.

The city is vulnerable to the effects of climate change by virtue of its proximity to the shoreline. It is the most densely populated urban area in the country. Maputo's low-elevation zones with flat topography are host to large slum concentrations. During severe flooding in 2000, 2 million Mozambicans were affected, with 650 000 forced from their homes – a possible portent of future environmental change impacts (UN-Habitat 2014). Existing impacts of a rising sealevel include salinization, causing damage to agriculture ventures and contributing to urban poverty. In Beira, saline intrusion could extend tens of kilometres inland; and sealevel rise might exacerbate this pre-existing vulnerability (UN-Habitat 2014). Flooding of the most populated low elevation coastal zone may result in serious consequences for the urban poor whose capacity to adapt to climate change is limited. Shrinkage of sand strips on the beaches results in serious coastal erosion with negative consequences for economic activity. Some of the key actions towards better adaptation to the vulnerabilities include the development of adequate policy, strategic and planning tools based on the outcomes of stakeholder engagement/awareness and detailed assessments (eg Theron and Barwell 2012), in order to provide policy- and decision-makers with a range of adaptive options for cities.

vided by coral reefs from storm surges and tsunamis. Some countries such as Seychelles have embarked on a land reclamation adaptation project to boost climate resilience, but adaptation programmes are few and poorly carried out in the rural areas of the African sub-region, with adaptation essentially being "forced" upon the rural poor. They are not active participants in adaptation but are subject to it, forced to migrate to wherever the possibility of better survival exists. Many of the displaced walk hundreds of kilometres to reach places of safety, only to be further disenfranchised and exploited in their new countries or cities of residence" (UN-Habitat 2014)

Catchments of the WIO Region

The WIO region has twelve major river catchments (Table 29.2). Three of these catchments, namely the, Juba-Shabelle, Limpopo River and Zambezi River Catchments, are among Africa's major trans-boundary river catchments (UNEP 2010). The region's major rivers, namely, the Maputo, Incomati, Limpopo, Save, Tana, Athi-Sabaki, Rufiji, Zambezi and Ruvuma arise from central highlands and transport and discharge large volumes of siliciclastic sediment into the coastal zone (UNEP/Nairobi Convention Secretariat and WIOMSA 2009a).

The status of some of the major WIO region catchments are summarised below.

Tana River Catchment

Water use in the Tana Catchment is dominated by hydropower electricity generation, which supplies an average of 40 to 64 per cent of Kenya's electricity demand (Knoop and others, 2012). The construction of hydropower dams in the upper Tana catchment has been largely linked to significant changes in the flow of the river in the lower Tana catchment (IUCN 2003, UNEP/Nairobi Convention Secretariat and WIOMSA 2009b, Knoop and others, 2012). While these dams have altered the river's downstream flow and its physical characteristics, it is noteworthy that they have played a significant role in decreasing the frequency

BOX 29.4. CITIES AT RISK: PORT LOUIS, MAURITIUS



View of Port Louis and harbour looking west from the Citadel. © Thierry.

A large proportion of the Mauritius urban population is concentrated in Port Louis, a major coastal city with most of the urban population of the island found within two neighbouring districts: Port Louis and Plaines Wilhems. The city is only located five metres above mean sea level and also hosts the only port on the island for import and export trade. Port Louis is exposed to risks and impacts associated with storms, storm-surges, flooding, coastal erosion and direct damage to infrastructure, services and property (Tadross and Johnston 2012). Climate change threats such as sea-level rise, storm surge and flooding include impacts to water and sanitation, transport, health, energy, and agriculture sectors. Some of the emerging priority vulnerabilities that need to addressed include the successful mainstreaming of climate change issues, which is presently scanty and fragmented into national development plans and strategies; development of a national adaptation and a mitigation strategy; and the setting up of the necessary regulatory and administrative framework to ensure that both mitigation and adaptation measures are being adopted and implemented in all sectors (Government of Mauritius 2010).

and magnitude of floods. Furthermore, dam construction on the Tana River has caused an estimated 56 per cent decline in sediment load, which has led to beach erosion and the loss of mangroves and wetlands along the Tana Delta (UNEP/Nairobi Convention Secretariat and WIOMSA 2009b). Municipal water use and medium-sized irrigation schemes constitute other major forms of water use in the Tana catchment (Knoop and others, 2012). Overall, Tana catchment has been described as 'water scarce' given the decline in *per capita* water availability over the years, a trend mainly attributed to rapid population growth within the catchment area (Knoop and others, 2012).

The high population density and intense agriculture, especially in the Upper Tana catchment, have led to over-abstraction of surface water. Furthermore, water quality in this region is largely affected by pollution from tea factories and poor sanitation facilities used by tea zone dwellers.

The Middle Tana catchment is largely used for livestock, agriculture and tree harvesting, and is characterised by a lack of adequate natural resources management. This region faces water quality issues resulting from a lack of functional sewage systems, quarrying, sand harvesting and chemical wastes from farms (Knoop and others, 2012). The Lower Tana is characterized by water scarcity with high levels of evapotranspiration due to high temperature. Even so, this region is earmarked for agricultural growth, particularly for sugar cane farming, bio-fuel plantations, horticulture and rice (Knoop and others, 2012).

Athi-Sabaki River Catchment

Land and water use within this catchment area mainly includes intensive agriculture with both small-scale and large-scale farming, particularly livestock and wildlife overgrazing, resulting in soil erosion. The catchment largely features industrial and domestic uses as well. Overall, the major environmental threats in the Athi-Sabaki catchment include sedimentation, agricultural pollution and deforestation (UNEP/Nairobi Convention Secretariat and WIOMSA 2009a).

Unlike the Tana River, which is also located in Kenya, the Athi-Sabaki River is not heavily dammed and has high levels of sediment loads ranging from 5 to 13 million tonnes

Table 29.2. Main characteristics of the twelve major catchments of the Western Indian Ocean Region.

Name of Catchment	Country/Countries Sharing Catchment Area	Catchment Area (km^2)	Characteristics
Juba-Shabelle	Somalia, Ethiopia and Kenya	783 000	The Juba and Shabelle Rivers stretch over a distance of 1 808 km and 2 526 km respectively. The two rivers originate in Ethiopia and merge in Somalia before reaching the Indian Ocean. These two rivers constitute the only perennial surface flow in southern Somalia. However, two thirds of the river catchments are situated outside of Somalia mainly in Ethiopia with part of the Juba catchment in Kenya.
Tana	Kenya	126 898	The Tana River Catchment covers about 23 per cent of the total area of the Republic of Kenya. The Tana River, the longest river in Kenya (850 km), originates from mountain ranges in central Kenya, meanders through the arid and semi-arid eastern landscape of Kenya and reaches the Indian Ocean through a Delta covering approximately 1 300 km^2. This river has an estimated discharge of 9 000 million m^3 (representing 32 per cent of the country's total annual river discharge) with an estimated 6.8 million tonnes of sediment load which varies seasonally. The Tana River Delta, which is colonised by mangroves (4 100 ha) features four main estuaries. These are Kipini, Mto Kilifi, Mto Tana, and Mto Moni. These estuaries extend up to 10 km inland and provide habitat and nursery ground for juvenile fish and shrimps.
Athi-Sabaki	Kenya	69 930	The Athi-Sabaki Catchment is the fourth largest in Kenya. It has two main tributaries, namely, Tsavo and Athi rivers, which converge at the lover region of the basin to form Sabaki River. The Athi-Sabaki River, the second longest in Kenya, flows into the Indian Ocean via the Sabaki estuary in Malindi Bay. The Sabaki estuary is 2.5 km long with a surface area of 0.58 km^2 and characterized by the high deposition of sediment load. The estuary is ecologically significant as a habitat and nursery ground for shrimps and feeding ground for birds.
Pangani	Tanzania, Kenya	43 650	The Pangani River basin in Tanzania has a total area of 43 650 km^2, located in northeastern Tanzania and drains into the Indian Ocean south of Tanga City. The main rivers in this basin are the Pangani River (which accounts for 27 300 km^2 and the coastal rivers of Umba, Sigi and Msangazi, located in the south of the basin. The headwaters of Pangani River are in the mountains of Kilimanjaro and Meru. The major tributaries of Pangani River are Ruvu, Weruweru, Kikuletwa, Rau and Kikafu rivers.
Rufiji	Tanzania	177 000	Rufuji catchment is the largest in Tanzania incorporating four major rivers, namely, Great Ruaha River, Kolombero River, Luwegu River and Rufiji. The Rufiji River contributes 50 per cent of the national total freshwater discharges to the sea. This catchment features a number of wetlands with major ones being the Utengule in the Great Rauha and the Kibasila in the Kilombero. The lower Rufuji floodplain features a permanent lake system made up of 13 lakes. About 50 km^2 of the Rufiji Delta is covered in mangrove forests, which greatly support the productivity of fisheries.
Ruvuma/Rovuma	Malawi, Mozambique, Tanzania	155 400	The biggest share of the total area of the Ruvuma catchment lies within Mozambique, which accounts for 65.5 per cent of the area, with Tanzania accounting for 34 per cent and Malawi for less than 1 per cent. The Ruvuma catchment features the Nyassa Nature Reserve and the Quirimbas National Park both of which are ecologically important landscapes. The Ruvuma estuary, which is shared by Tanzania and Mozambique, is rich in tropical coastal marine resources and is fringed by beaches and mangroves.
Zambezi	Angola, Botswana, Malawi, Mozambique, Namibia, Tanzania, Zambia and Zimbabwe	1 300 000	The Zambezi River Catchment is the fourth largest in Africa and carries an estimated runoff of about 103 000 million m^3 per year. The Zambezi River plays a critical role in sustaining and maintaining the productivity of aquatic flora and fauna in the Indian Ocean. The Zambezi Delta is about 100 km long 120 km wide at the coast covering a total area of 15 000 km^2. The Delta sustains the rich offshore Sofala Bank with its fisheries and is a key nursery ground for fish and offshore shrimp resources.
Pungwe	Mozambique, Zimbabwe	31 000	The Pungwe River is about 400 km long with 340 km of this river located in Mozambique. Zimbabwe shares only 5 per cent of the catchment. The estuary, through which the river enters the Indian Ocean, is utilised for aquaculture, mainly for prawn.
Limpopo	Botswana, South Africa, Mozambique, Zimbabwe	408 000	The Limpopo River is about 1 777 km long. It flows from the Limpopo Province in South Africa to form part of the South Africa-Botswana boarder in the north and then towards the east to form the South Africa Zimbabwe boarder and lastly southeast via Mozambique into the Western Indian Ocean. The Limpopo River estuary is relatively small and functions as a nursery for fish and shrimp. From its limited mangroves, the estuary is also a source of building material for local communities.

Name of Catchment	Country/Countries Sharing Catchment Area	Catchment Area (km^2)	Characteristics
Incomati	Mozambique, South Africa, Swaziland	46 800	South Africa shares 63 per cent of the total Incomati Tiver catchment area while Mozambique and Swaziland share 32 per cent and 5 per cent respectively. The river flows from South Africa through Swaziland and then back to South Africa before it reaches the Indian Ocean through Mozambique. The Incomati estuary is relatively small spatially and features a number of inter-linked habitats including a long narrow peninsula and a series of islands within the river. This estuarine ecosystem supports aquatic birds and provides food provisioning services.
Maputo	South Africa, Swaziland, Mozambique	28 500	South Africa and Swaziland share 93.9 per cent (28 230 km^2) of the total Maputo River catchment area, with the remaining 6.1 per cent (1 570 km^2) shared by Mozambique. Maputo Bay covers an area of 70 000 ha which comprise estuarine, mangrove and marine components. The large mangrove forest supports fisheries.
Thukela	South Africa	30 000	The Thukela River flows from the Drakensberg Mountains in KwaZulu-Natal province (KZN) in South Africa through central KZN and into the Indian Ocean. The river has an estimated runoff of 3 799 million m^3 per annum.
Betsiboka	Madagascar	49 000	The Betsiboka River has one of the largest catchments in Madagascar. The river's estuary is large but shallow and experiences significant tidal incursions during spring tides as well as accretion linked to high levels of sediment deposition. Mangroves (which cover 420 km^2) serve as feeding grounds for shrimp, crab and finfish. They also serve as a source of building material for local communities.

per year. The increase in sediment loads, particularly in the 1990s, has been attributed to extensive deforestation and expansion of agriculture within the catchment (Arthurton and others, 2008). This has resulted in a range of coastal issues such as choking of the estuary at Malindi and ultimately affecting tourism development. Heavy siltation is also causing accretion and pro-gradation of beaches between Ngomeni and Malindi. Siltation has also reduced the depth of water in Malindi Bay affecting its use as a port. Deposition of silt has also degraded sensitive coral reefs and seagrass habitats. A positive impact of the sediment accretion has been the increase in mangrove area in the Sabaki estuary (UNEP/Nairobi Convention Secretariat and WIOMSA 2009a). This catchment is also affected by increased rainfall and extreme climate events.

Pangani River Catchment

Land and water use in the Pangani River catchment area include tourism, mining, industry, small scale fishing, agriculture, hydropower generation and domestic use. The catchment features a number of National Parks, Game Reserves and Controlled Areas. The catchment is exploited for its mineral and gemstone deposits, and particularly for tanzanite, a distinctive blue diamond unique to Tanzania. There are numerous environmental pressures in the catchment. These include deforestation, demands for land, destructive farming practices, uncontrolled development, uncontrolled mining activities, over-fishing, deteriorating water quality, introduction of alien species and a lack of environmental awareness. The changing flow regime has also altered the river channel and bed (UNEP/Nairobi Convention Secretariat and WIOMSA 2009b).

Rufiji River Catchment

Land and water use in the Rufiji catchment include agriculture, mining, forestry, livestock farming, fishing, wildlife, navigation and human settlements (RBWO 2007). Most of these exert negative environmental pressure on the river and estuary (UNEP/Nairobi Convention Secretariat and WIOMSA 2009a).

Maputo River Catchment

Water from the Maputo River is primarily used for irrigation and the generation of hydro-energy. In the catchment, agriculture is an important contributor to employment, poverty alleviation and input into the manufacturing sector. Farming accounts for 86 per cent of water use in the catchment. More than half of the 40 960 ha sugarcane crops in the catchment are irrigated. Forestry, another major water user, accounts for 367 700 ha of the catchment (SADC 2010). Agricultural, industrial and urban discharges into the river have been linked to deterioration of water quality in Maputo Bay (UNEP/Nairobi Convention Secretariat and WIOMSA 2009b).

Thukela River Catchment

The Thukela River catchment is located in a predominantly rural region of the province of KwaZulu-Natal in

South Africa. The impoverished communities are mainly dependent on subsistence farming in degraded agricultural areas (Chikozozho 2005). The catchment is characterised by commercial agriculture, manufacturing industry, trade, transport and a growing tourism industry around the Drakensburg Mountains. The upper Thukela catchment features three major dams and inter-basin transfer infrastructure used for water supply and stream flow regulation. These have impacted flow and sediment conditions of the Thukela River and estuary which has become one of the key environmental concerns in the catchment. The catchment is also affected by deteriorating water quality due to acid mine drainage and industrial and municipal discharges into the system. Stream flow reduction during dry winter seasons affects water quality at the estuary (UNEP/Nairobi Convention Secretariat and WIOMSA 2009b).

Betsiboka River Catchment

This catchment area incorporates some major cities in Madagascar including the capital city-Antananarivo, Maevatanana and Marovoay. Two large dams located in the Ikopa tributary, constitute the main source of drinking water for an estimated population of the 1.9 million inhabitants of Antananarivo. The environmental issues in the catchment result from poor land-use practices and the effects of climate change. The southwestern region of the catchment has been affected by increasing periods of droughts interspersed by highly variable rainfall patterns downstream. Land-use practices such as "slash and burn" farming is associated with land degradation which results in increased sediment loads entering Mahajanga Bay. The Betsiboka River is important for shipping and local transport. The estuary noticeably features red-coloured water as a result of sediments from the eroded catchment. Turbidity resulting from high sediment loads has also impacted local coral reefs in the Antrena coastal area.

EMERGING ISSUES AND POLICY RESPONSES

Urbanisation, Development and Vulnerability

The existing and emerging issues identified and described above require a number of policy responses in order to mitigate negative environmental, social and economic consequences. These are:

- Disaster risk reduction and climate change adaptation must be prioritised in order to better manage extreme events as well as distinctive slow-onset, semi-permanent changes such as sea level rise or rising temperatures. Vulnerability and resilience assessments, as well as explicitly human security considerations, are core concerns of disaster risk reduction and climate change adaptation, facing similar challenges. Some specific challenges that must be dealt with by policy includes; inadequate political will; lack of financial support for mainstreaming; and lack of investment in preventative and proactive measures to reduce vulnerability to probable future threats and vulnerability drivers;
- Promote and undertake research devoted to exploring innovative and cost effective ways of addressing the climate problem (Kithiia and Dowling 2010);
- Encourage and promote robust urban planning processes that seek to reduce the dichotomy between formal governing institutions and networks of actors that provide local capacities. National urbanisation policy frameworks must complement local strategies for changes to be quicker and deeper, and this includes identifying various levers by which action can be triggered and sustained. These actions are likely to be enhanced if good science (including the use of new data, methodologies and models), is used to inform policy (Kithiia and Dowling 2010)
- Reduce the high levels of vulnerability and low adaptive capacity in local governments with poor capacities and resources (Kithiia 2011). Weak local government creates and exacerbates problems including the lack of appropriate regulatory structures and mandates; poor or no planning; lack of or poor data; lack of disaster risk reduction strategies; poor servicing and infrastructure (particularly waste management and drainage); uncontrolled settlement of high-risk areas such as floodplains, wetlands, and coastlines; ecosystem degradation; competing development priorities and timelines; and a lack of coordination among government agencies (Kithiia and Dowling 2010, Kithiia 2011, IPCC 2014).
- Existing land-use plans in most WIO countries are inadequate or lacking, and in order to update such plans authorities need to identify and establish the environmental baselines to inform appropriate zoning and take into account the onset of climate change. Mechanisms such as coastal development setbacks and development limits must be incorporated into urban planning and building controls. Some specific measures, as described by Theron and Barwell (2012), include:
  - Introducing policy and planning processes to ensure

that coastal construction is a safe distance away from the high-water mark, and reinstate natural defence mechanisms with the necessary environmental authorisations;

- Undertaking holistic planning and implementation through the development and implementation of coastal management programmes that incorporate shoreline management plans;

- Establishing a coastal development setback line which is designed to protect both the natural environment from encroachment of buildings as well as protecting beachfront developments from the effects of storms and accelerated coastal erosion;

- Working with nature by protecting the integrity of buffer dune systems, which should be vegetated with appropriate dune species, as per the original natural zones, and maintained;

- Maintaining, or even better, increasing the sand reservoir (volume) stored in the dune system; and,

- Protecting, restorating and maintaining natural systems like mangroves and coral reefs.

• Mainstream adaptation options into integrated coastal management and sustainable development plans. There is growing recognition that scientists, policymakers, residents, managers and other key stakeholders must work together to establish a framework for adaptation that is mainstreamed into the current coastal management processes and practices;

• Planning regimes of WIO coastal cities should consider the requirement for socio-political reforms and changes. Current planning remains largely piecemeal, responding only to a minority of, often wealthier, recipients. The negotiation of existing patterns of segregation, as well as how formal and informal systems combine are overdue and remain critical elements to unlocking the "dualistic" nature of urban development.

• Improve the capacity of municipal and central governments to govern urban land markets by collecting revenue from land and property transfers, sales, rates and taxes, upon which municipalities generally depend. The dual system of land management in Eastern African cities is unsuitable for the long-term development of these cities, since municipal revenues and the capacity to act are inadequate.

• Initiate a debate on coastal urban equity, since current coastal development is primarily intended for the wealthy, which threatens eviction of poor and low-income residents in some cases. Seek to address the general interest, rights and needs of all stakeholders. The needs of the poor should be incorporated through equality and human rights-based urban interventions. All WIO coastal cities need services provided by cleaners, waste collectors, gardeners, "askaris" (security guards) and other low-income service providers.

• Develop effective adaptation strategies for port cities of the WIO region. Integrate the consideration of climate change into long-term coastal flood risk management and disaster planning (Hanson and others, 2011).

Catchments

The catchment and estuarine degradation resulting from modified river flows, water quality and sediment loads are linked to a lack of appropriate governance and management interventions at regional, national and sub-national scales. Some suggestions for regional policy interventions include:

• Development of coordinated, non-conflicting and relevant legal frameworks for the management of transboundary catchments. This is a necessity since the majority of the catchments are shared between states;

• Effective implementation of inter-governmental management instruments for river catchment management;

• Development of protocols for inter-sectorial water governance and the involvement of the stakeholders from the sectors (agriculture, industry, water authorities, local government etc.) involved in water resource management;

• Improvement in the collection of data and information relevant for water resource management. Monitoring and assessment of rivers, catchments and estuaries are needed to understand and predict the changes in catchments and the effect on the coastal and marine environment;

• Improved financial investment in the development of human capital in order to facilitate and promote the effective implementation of agreements and water management programmes; and,

• The development of integrated regional policies for water resource management in order to address the growing demand on water resources.

References

Alusa, A.L. and Ogallo, L.J. (1992). *Implications of Expected Climate Change in the Eastern African Coastal Region: an Overview*. UNEP Regional Seas Reports and Studies No 149. UNEP 1992. Nairobi

Arthurton, R., Le Tissier, M., Snoussi, M., Kitheka, J., Shaghude, Y., Kane, A., Flöser, G. and Kremer, H. (2008*). AfriCat LOICZ - Global Change Assessment and Synthesis of River Catchment - Coastal Sea Interactions and Human Dimensions in Africa*. LOICZ Reports and Studies No 30. LOICZ IPO. Geesthacht, Germany

ASCLME (2012). *National Marine Ecosystem Diagnostic Analysis (MEDA)*. Agulhas and Somali Current Large Marine Ecosystems Project (ASCLME). UNDP. GEF. Unpublished report. Kenya

ASCLME/SWIOFP (2012a). *Transboundary Diagnostic Analysis for the western Indian Ocean*. vol 1: Baseline. South Africa

ASCLME/SWIOFP (2012b). *Transboundary Diagnostic Analysis for the western Indian Ocean*. vol 2: Diagnostic Analysis. South Africa

Awuor, C.B., Orindi, V.A. and Adwera, A.O. (2008). Climate Change and Coastal Cities: The Case of Mombasa, Kenya. *Environ. Urban*. 20(1), 231–42

Barau, A.S. and Ludin, A.N.M. (2012). Intersection of Landscape, Anthropocene and Fourth Paradigm. *Living Reviews in Landscape Research* vol 6(1)

Basnyat, D.B. and Gadain, H.M. (2009). *Hydraulic Behaviour of the Juba and Shabelle Rivers: Basic Analysis for Irrigation and Flood Management Purposes*. Technical Report No W-13. FAO-SWALIM. Nairobi, Kenya

Beaverstock, J.V., Faulconbridge, J.R. and Hoyle, M. (2011). Globalisation and the City. In *The SAGE Handbook of Economic Geography* (eds. A. Leyshon, R. Lee, L. McDowell, and P. Sunley) pp. 189–201. SAGE, London

Bogardi, J.J. (2008). Foreword. In *Megacities: Resilience and Social Vulnerability.* (eds. Bohle, H.-G. and Warner, K.) source 10, pp. 7. Bonn (UNU-EHS)

Boko, M, Niang, I., Nyong, A., Vogel, C., Githeko, A., Medany, M., Osman-Elasha, B., Tabo, R. and Yanda, P. (2007). Africa. In *Climate Change Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (eds. Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J. and Hanson, C.E.) pp. 433–467. Cambridge University Press. Cambridge,UK

Brown, S., Kebede, A.S. and Nicholls, R.J. (2009). *Sea-Level Rise and Impacts in Africa, 2000 to 2100*. University of Southampton, UK

Brown, S., Kebede, A.S. and Nicholls, R.J. (2011). *Sea-level rise and impacts in Africa, 2000 to 2100*. University of Southampton, UK

Chikozozho, C. (2005). Policy and institutional dimensions of small-holder farmer innovations in the Thukela River Basin of South Africa and the Pangani River Basin of Tanzania: A comparative perspective. *Phys. Chem. Earth, Pts A/B/C* 30(11), 913-924

Dasgupta, S., Laplante, B., Murray, S. and Wheeler, D. (2011). Exposure of Developing Countries to Sea-Level Rise and Storm Surges. *Clima. Chang.* 106(4), 567–79

Defense Meteorological Satellite Program (DMSP). Data Archive, Research, and Products. Available at http://ngdc.noaa.gov/eog/dmsp.html

DESA (2014). *World Urbanization Prospects: The 2014 Revision*. United Nations, Department of Economic and Social Affairs, Population Division. CD-ROM Edition. NY

Doll, C.N.H., Muller, J.P. and Morley J.G. (2006). Mapping regional economic activity from night-time light satellite imagery. *Ecol. Econ*. 57(1), 75-92

Elvidge, C.D., Sutton, P.C., Tuttle, B.T., Ghosh, T. and Baugh, K.E. (2009). Global Urban Mapping Based on Nighttime Lights. In *Global Mapping of Human Settlement* (eds. Gamba, P. and Herold, M.) pp. 129 – 144. CRC Press, Taylor and Francis Group. Boca Raton, Florida, USA

Ghosh, T., Powell, R., Elvidge, C.D., Baugh, K.E., Sutton, P.C. and Anderson, S. (2010). Shedding light on the global distribution of economic activity. *The Open Geography Journal* 3(1), 148-161

Government of Mauritius (2010). *Second National Communication of the Republic of Mauritius under the United Nations Framework Convention on Climate Change (UNFCCC*). Mauritius Meteorological Services, Government of Mauritius

Government of Seychelles (2011*). Seychelles' Second National Communication under the United Nations Framework Convention on Climate Change (UNFCCC).* Government of Seychelles. Ministry of Home Affairs, Environment, Transport and Energy Government of

Seychelles

Hahs, A., McDonnell, M., McCarthy, M., Vesk, P., Corlett, R., Norton, B., Clemants, S.E., Duncan, R.P., Thompson, K., Schwartz, M.W. and Williams, N.S.G. (2009). A global synthesis of plant extinction rates in urban areas. *Ecol. Lett.* 12(11), 1165–1173

Hanson, S., Nicholls, R., Ranger, N., Hallegatte, S., Corfee-Morlot, J., Herweijer, C. and Chateau, J. (2011) A global ranking of port cities with high exposure to climate extremes. *Clim. Chang.* 104(1), 89–111

Hinkel, J., Brown, S., Exner, L., Nicholls, R.J., Vafeidis, A.T. and Kebede, A.S. (2012). Sea-Level Rise Impacts on Africa and the Effects of Mitigation and Adaptation: An Application of DIVA. *Reg. Environ. Change* 12(1), 207–24

INSTAT (2009). *Population Census for Madagascar*. National Institute of Statistics of Madagascar

IPCC (2014). *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects*. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (eds. V.R. Barros, C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White) Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

IUCN (2003). *Tana River, Kenya: Integrating Downstream Values into Hydropower Planning*. Case Studies in Wetland Valuation No 6. Integrating Wetland Economic Values Into river Basin Management

IUCN Eastern and Southern Africa Programme (2009). *The Pangani River Basin: A Situation Analysis*. 2nd edition. Nairobi, Kenya

Kebede, A.S. and Nicholls, R.J. (2012). Exposure and Vulnerability to Climate Extremes: Population and Asset Exposure to Coastal Flooding in Dar Es Salaam, Tanzania. *Reg. Environ. Change* 12(1), 81–94

Kebede, A.S., Brown, S. and Nicholls, R.J. (2010). *Synthesis Report: The Implications of Climate Change and Sea-Level Rise in Tanzania – The Coastal Zones*. Report submitted to the Global Climate Adaptation Partnership (GCAP). Oxford, UK

Kithiia, J. (2011). Climate Change Risk Responses in East African Cities: Need, Barriers and Opportunities. *Curr. Opin. Environ. Sustain.* 3(3), 176–80

Kithiia, J. and Dowling R. (2010). An integrated city-level planning process to address the impacts of climate change in Kenya: the case of Mombasa. *Cities* 27(6), 466-475

Knoop, L., Sambalino F. and Van Steenbergen, F. (2012). *Securing Water and Land in the Tana Basin: a resource book for water managers and practitioners*. 3R Water Secretariat. Wageningen, Netherlands

Nicholls, R.J. (2006). Storm surges in coastal areas. In *Natural disaster hotspots: Case Studies*. (eds. M. Arnold, R.S. Chen, U. Deichmann, M. Dilley, A.L. Lerner-Lam, R.E. Pullen, Z. Trohanis) No 6, pp. 79–108. The World Bank Hazard Management Unit. Disaster Risk Management Series. Washington, D.C.

Nicholls, R.J., Hanson, S., Herweijer, C., Patmore, N., Hallegatte, S., Corfee-Morlot, J., Chateau, J. and Muir-Wood, R. (2008*). Ranking Port Cities With High Exposure and Vulnerability to Climate Extremes: Exposure Estimates*. OECD Environment Working Papers No 1. OECD publishing

Payet, R.A. (2002). Integrated Coastal Zone Management in Seychelles. In *The Voyage from Seychelles to Maputo: Successes and Failures of Integrated Coastal Management in Eastern Africa and Island States 1996-2001* (eds. C. Voabil and S. Engdahl) Vol 2, pp. 121-148. SEACAM Publication, Mozambique

RBWO (2007). *Details of the Rufiji Basin*. Rufiji Basin Water Office. Available at http://www.rufijibasin.com/details.html Accessed at 11 May 2015

Republic of Kenya (2009) *State of the Coast Report: Towards Integrated Management of Coastal and Marine Resources in Kenya*. National Environment Management Authority (NEMA). Nairobi

SADC (2010). *Economic Accounting of Water Use: Maputo River Basin Pilot Report*. ACP-EU Water Facility Grant No 9 ACP RPR 39-90. Southern African Development Community Egis Bceom International. Final Report.

Sebhat, M.Y. (2014). Water balance of the Juba and Shabelle Rivers in Ethiopia-Somalia. *International Research Journal of Agricultural Science and Soil Science* 4(4), 65-75

Seto, K.C. (2011). Exploring the Dynamics of Migration to Mega-Delta Cities in Asia and Africa: Contemporary Drivers and Future Scenarios. *Glob. Environ. Chang.* 21(1), S94-S107

SFA (2003). *Annual report*. Seychelles Fishery Authority. Victoria, Seychelles

Shah, N.J. (1998) Marine Science Country Profiles: Seychelles. No 31. Intergovernmental Oceanographic

Commission and Western Indian Ocean Marine Science Association

Tacoli, T. (2009). Crisis or adaptation? Migration and climate change in a context of high mobility. *Environ. Urban*. 21(2), 513-525

Tadross, M. and Johnston, P. (2012). *Climate Change Projections for Port Louis: Adding value through downscaling*. Climate Systems Analysis Group, University of Cape Town. Commissioned by ICLEI – Local Governments for Sustainability – Africa. Unpublished Research Report. Cape Town, South Africa

Theron, A.K. and Barwell, L.B. (2012). *Responding to Climate Change in Mozambique: Theme 2: Coastal Planning and Adaptation to Mitigate Climate Change Impacts*. Report prepared for National Institute for Disaster Management (INGC) by CSIR. Stellenbosch, South Africa

Thiemig, V., Pappenberger, F. Thielen, J. Gadain, H., de Roo, A., Bodis, C., Del Medico, M. and Muthusi, F. (2010). Ensemble flood forecasting in Africa: a feasibility study in Juba-Shabelle river basin. *Atmos. Sci. Lett.* 11(2), 123-131

UNEP (2005). *Assessing Coastal Vulnerability: Developing a Global Index for Measuring Risk*. UNEP. Nairobi, Kenya.

UNEP (2010). *Africa Water Atlas*. Division of Early Warning and Assessment (DEWA). United Nations Environment Programme (UNEP). Nairobi, Kenya.

UNEP/Nairobi Convention Secretariat and WIOMSA (2009a). *An assessment of hydrological and land use characteristics affecting river-coast interactions in the Western Indian Ocean region*. UNEP/Nairobi Convention Secretariat and WIOMSA. Nairobi, Kenya

UNEP/Nairobi Convention Secretariat and WIOMSA (2009b). *Transboundary Diagnostic Analysis of Land-based Sources and Activities Affecting the Western Indian Ocean Coastal and Marine Environment*. UNEP Nairobi, Kenya

UN-Habitat (2014). *The State of African Cities 2014: Re-imagining sustainable urban transitions*. UN-Habitat. Nairobi, Kenya

Van der Zaag, P. (2000). *The Pungwe River Basin*. SADC Water Sector. ICP collaboration Portal. http://www.icp-confluence-sadc.org/riverbasin/102 Accessed at 1 April 2015

Zhang, Q. and Seto, K.C. (2011). Mapping urbanization dynamics at regional and global scales using multi-temporal DMSP/OLS nighttime light data. *Remote Sens. Environ*. 115(9), 2320–2329



30

Marine Genetic Resources and Bioprospecting in the Western Indian Ocean

Rachel Wynberg

Opposite page: Nudibranchs are of interest in bioprospecting programmes and have been the source of dolastatins, under investigation for their anti-tumour activity. © Hendrik Martens / Shutterstock.

INTRODUCTION

Over the last few decades, increasing attention has been given to the commercial potential of exploiting marine genetic and associated natural product resources for a range of industries including pharmaceuticals, food and beverage, cosmetics, agriculture and industrial biotechnology (eg de la Calle 2009, Arrieta and others, 2010, Arnaud-Haond and others, 2011, Global Ocean Commission 2013, Martins and others, 2014). Furthermore, scientific and technological developments in molecular biology, genomics, and bioinformatics, have led to exciting new possibilities; whilst technological advances in observing and sampling the deep ocean have opened up previously unexplored areas to scientific research (Global Ocean Commission 2013). Since initial reports in the 1950s, some 23 570 natural products have been reported from marine organisms, growing at a rate of 4 per cent per year (Arrieta and others, 2010, Leal and Calado 2015). Only a small number of these products have reached the commercialised phase, yet marine bioprospecting provides significant economic opportunities with the global market for marine biotechnology products alone projected to reach US$ 4 900 million by 2018 (Global Industry Analysts Inc. 2013).

At the same time, the legal framework for marine genetic resources has become increasingly complex, characterised by a multiplicity of legal regimes and national and international laws. Marine genetic resources found within the EEZ are subject to national laws, and to provisions of the recently adopted Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilisation, an agreement under the Convention on Biological Diversity (CBD). The concept of "access and benefit sharing" (ABS) originated as a legal expression in the 1992 CBD arising from the unequal distribution of biodiversity throughout the world, the desire of biodiversity-poor but technology-rich industrialised countries to have continued access to these resources, and the determination of biodiversity-rich but technology-poor developing countries to benefit from the exploitation of their resources (Reid and others, 1993, Wynberg and Laird 2007). An agreement was reached requiring user countries to share benefits with provider countries, which in turn were required to facilitate access to their genetic resources. The Nagoya Protocol, which came into force in 2014, aims to create greater legal certainty for both providers and users of genetic resources by establishing clear and transparent procedures for access to genetic resources; and by helping to ensure the sharing of benefits once genetic resources leave the provider country through its new obligations related to compliance. In the high seas, natural resources are considered to be the "common heritage of humankind" and are subject to special rules under the United Nations Convention on the Law of the Sea (UNCLOS). Specialised ABS rules for these resources have not yet been developed.

What do these developments mean for countries of the Western Indian Ocean (WIO), whose territorial waters con-

tain many marine genetic resources that are of growing interest to industries? With the exception of South Africa, most research, development and commercialisation of marine genetic resources is currently located outside of the WIO region, as is the ownership of associated intellectual property rights. A suite of challenging issues face policy-makers attempting to implement the Nagoya Protocol and ensure compliance with various other legal instruments. These include questions relating to ownership and benefit flows from the commercialisation of marine genetic resources; how research and development in WIO countries can be further stimulated; sustainable use of marine genetic resources, and minimising the threat of overexploitation; how the movement of marine genetic resources can be tracked and monitored; and guidance with regard to the exploitation of marine genetic resources in the high seas. This chapter provides an overview of these questions, beginning with a description of the potential value of marine genetic resources and the industries that utilise them; current research and development activities in the WIO region; and the central issues requiring attention by policy-makers and decision-makers.

THE NATURE AND SCOPE OF MARINE BIOPROSPECTING

Marine bioprospecting, the exploration of biological material in the marine environment for commercially valuable genetic and biochemical properties, is a rapidly expanding research and commercial activity. Whereas bioprospecting in the terrestrial environment can be traced back centuries, collecting and screening commercially valuable samples from the marine environment, dependent on the development of technological advances such as SCUBA diving, is as recent as the 1950s (Molinsky and others, 2009).

The marine environment presents important economic opportunities due to high levels of biodiversity and endemism, holding promise of biologically active chemical entities for the development of novel natural products (Davies-Coleman and Sunassee 2012, Leal and others, 2012, Martins and others, 2014). There is particular interest in marine species that live in extreme environments, such as hydrothermal vents, seamounts, cold seeps and submarine trenches ("extremophiles"), which trigger organisms to adopt new biosynthetic pathways that generate interesting compounds (Greiber 2011, Davies-Coleman and Sunassee 2012). In the 1970s and 1980s, marine macroalgae were a major focus of marine natural product research, but bioprospecting efforts have since focused on microorganisms and marine invertebrates (Leal and others, 2013). Increasing research is also focused on the potential of marine microalgae, especially in the food and cosmetics industries (Martins and others, 2014).

Natural products are produced by many marine organisms as a chemical defence against predation, or as a response to inter-species competition for limited resources (Davies-Coleman and Sunasee 2012). A taxonomic analysis of new marine natural products discovered between 1990 and 2009 for invertebrates, indicated that the Phylum Porifera was the most abundant at 48.8 per cent, followed by Cnidaria (28.6 per cent); Echinodermata (8.2 per cent), Chordata (6.9 per cent) and Mollusca (5.8 per cent). Research points increasingly to symbiotic microbes as the source of the secondary metabolites of these larger organisms, biosynthesizing the natural products associated with their hosts (especially those found in sponges) (Marris 2006, Molinsky and others, 2009). This has led to a significantly increased research focus on marine microbes (Arrieta and others, 2010). Indeed, prokaryotes contribute 42 per cent of marine genes included in a patent analysis (Arrieta and others, 2010) and with the majority of microbes unexplored there is high potential for the development of useful products.

RESEARCH, DEVELOPMENT AND COMMERCIAL APPLICATIONS

A wide range of products include marine genetic resources, from those domesticated for food through to high-value cosmetic markets and high-end pharmaceuticals engineered for human health. Not all of these can be characterised as being produced as a result of bioprospecting, and uses range from the direct incorporation of seaweed in food supplements, for example, through to the use of bioactive ingredients in creams, lotions and ointments as cosmeceuticals, and the isolation of active compounds for the pharmaceutical industry. Investments in marine bioprospecting are typically extremely costly and risky due in part to the high costs of sampling in cases where this occurs in the deep sea, the low chances of success, and the significant regulatory hurdles for product approval. For example, it took more than three decades for Prialt®, the first pharmaceutical based on a marine source – the poison released by a tropical marine cone snail to paralyse its prey

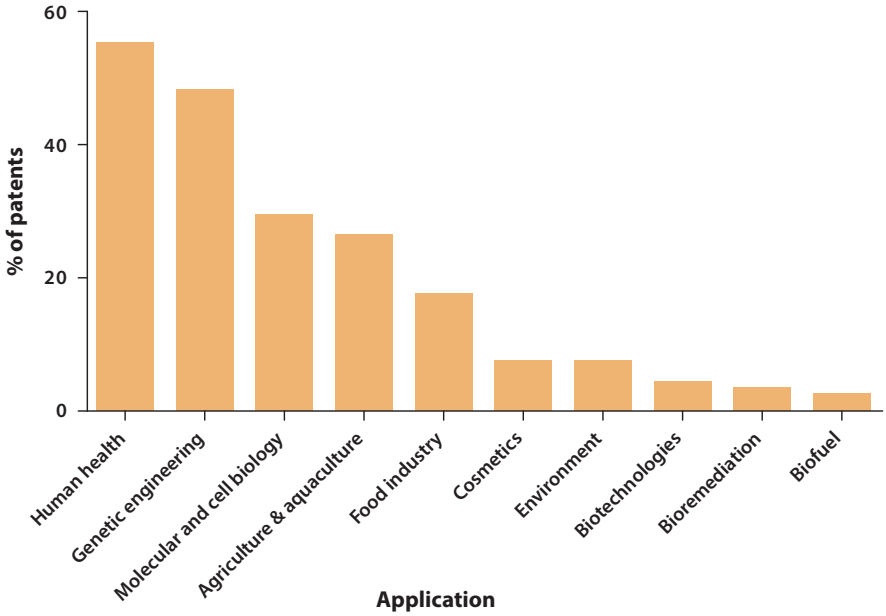


Figure 30.1. Synthesis of the uses proposed in the claims or description of 460 patents deposited at the International Patent Office and associated with genes isolated in marine organisms. Source: Arrieta and others, 2010.

– to be approved in the United States as a treatment for chronic pain (Marris 2006, Molinsky and others, 2009). Paradoxically, commercial supplies of Prialt®, a small polypeptide, were obtained through standard pharmaceutical manufacturing processes and exploitation of the natural source of this compound was never considered for supplying sufficient material for development. Regulatory hurdles are still significant but the time taken between the discovery of a molecule and product commercialisation have over the past decade significantly shortened due to technological advances in synthesising and scaling up production using biotechnology and aquaculture (Leal and others, 2014, Martins and others, 2014).

Figure 30.1 provides a synthesis of uses proposed in the claims of 460 patents (Arrieta and others, 2010), suggesting the predominance of the pharmaceutical and biotechnology industries for a range of applications from anti-cancer drugs through to applications in the fields of ecotoxicology, bioremediation, anti-fouling and biofuel production. A significant focus includes microalgae for large-scale production of polyunsaturated fatty acids for inclusion in dietary supplements; a range of biomedical applications such as fluorescent proteins, bone fillers and bioceramic coatings; polysaccharides derived from algae for use in the food and health sectors; and use of "extremozymes" in industrial applications (Arrieta and others, 2010, Silva and others, 2012, Laird 2013). Table 30.1 provides some examples of the types of marine natural products used in the pharmaceutical, food supplement, and personal care markets; the organisms they are extracted from; and the status of their development.

The considerable costs involved in marine bioprospecting research, alongside the advanced technologies and expertise required, have meant that most exploration has been undertaken by developed countries, notably, the United States of America, United Kingdom, Australia, Canada, Japan, Germany and Russia – but with the sampling often conducted in developing, tropical countries (Greiber 2011, Leal and others, 2012, Oldham and others, 2013). This is clearly illustrated in Figure 30.2 below. With the exception of South Africa and, to a lesser extent, Kenya, few WIO countries have engaged actively as research collaborators in international endeavours. In South Africa, Rhodes University has a long-standing bioprospecting collaboration with the National Cancer Institute, the Scripps Institution of Oceanography and pharmaceutical companies SmithKline Beecham (now GlaxoSmithKline) and Bristol-Myers Squibb, while the Oceanographic Research Institute in Kwazulu-Natal has had an active bioprospecting programme involving the University of Tel Aviv and the Spanish pharmaceutical company PharmaMar (Davies-Coleman and Sunassee 2012). A more recent player is the University of the Western Cape in Cape Town, South Africa, which, through its Institute for Microbial Biotechnology and Metagenomics, is engaged in marine microbial bioprospecting through PharmaSea, a large, EU funded

Table 30.1. Examples of marine natural products in the pharmaceutical, nutritional and personal care markets (Source: Global Ocean Commission 2013).

Category	Product	Organism	Status
Therapeutic	Yondelis® (cancer)	*Ecteinascidia turbinate* (ascidian)	US$ 78 million in 2012
Therapeutic	Prialt® (neuropathic Pain)	*Conus magus* (mollusc)	US$ 20 million in 2012
Therapeutic	Halaven® (cancer)	*Halichondria okadai* (sponge)	>US$ 200 million in 2011
Therapeutic	Salinisporamide (cancer)	*Salinispora tropica* (bacterium)	Phase 1
Therapeutic	Plinabulin (cancer)	*Aspergillus* sp. (fungus)	Phase 1
Biofilm inhibitor	Brominated furanones (quorum sensing inhibitor)	*Delisea pulchra* (red alga)	In trials
Sunscreen	Mycosporine like amino acids (UV absorbing)	*Coral zooxanthellae*	In trials
Cosmetic	Pseudopterosins (anti-inflammatory)	*Pseudopterogorgia elisabethae* (soft coral)	Commercialised
Cosmetic	Venuceane (anti-free radicals)	*Thermus thermophilus* (bacterium)	Commercialised
Nutrition	ω-3 fatty acids	*Crypthecodinium cohnii* (microalga)	Commercialised
Nutrition	Carotenoids (anti-oxidant)	*Dunaliella salina* (microalga)	Commercialised

project (www.pharma-sea.eu/partners/institutions/university-of-the-western-cape.html). The Kenya Marine and Fisheries Institute has been involved in bioprospecting initiatives as part of its collaboration with northern institutions. Although there has been research activity in other WIO countries such as Madagascar, these do not appear to be based on collaborative research programmes with the provider country.

Obtaining a sustainable supply of marine sources, often sparsely distributed, and located in inaccessible sites, presents a considerable challenge to product research and development. While bioprospecting typically requires the collection of only a limited amount of biomass in the discovery phase, recollection of interesting species, or scaling up for commercialisation may pose significant ecological threats. Key concerns include poor knowledge about the conservation status of many species, and the damage that may occur to the ecosystems in which they occur (Costello and others, 2010, Global Ocean Commission 2013).

Technological advances over the past decade have, however, begun to address this "supply" concern (Davies-Coleman and Sunassee 2012, Leal and others, 2014). For example, aquaculture is increasingly being used to produce assemblages of marine invertebrate-microorganisms that can be manipulated to produce higher yields of target metabolites (Leal and others, 2014). The accelerated development of classical analytical technologies, such as nuclear magnetic spectroscopy and mass spectrometry, also means that new compounds can now be identified from mere micrograms of source material. Advances in biotechnology and new approaches to metagenomic mining are presenting ample scope for the scaling-up of marine bioprospecting in future, in particular for microorganisms (Molinsky and others, 2009, Leal and others, 2012, Martins

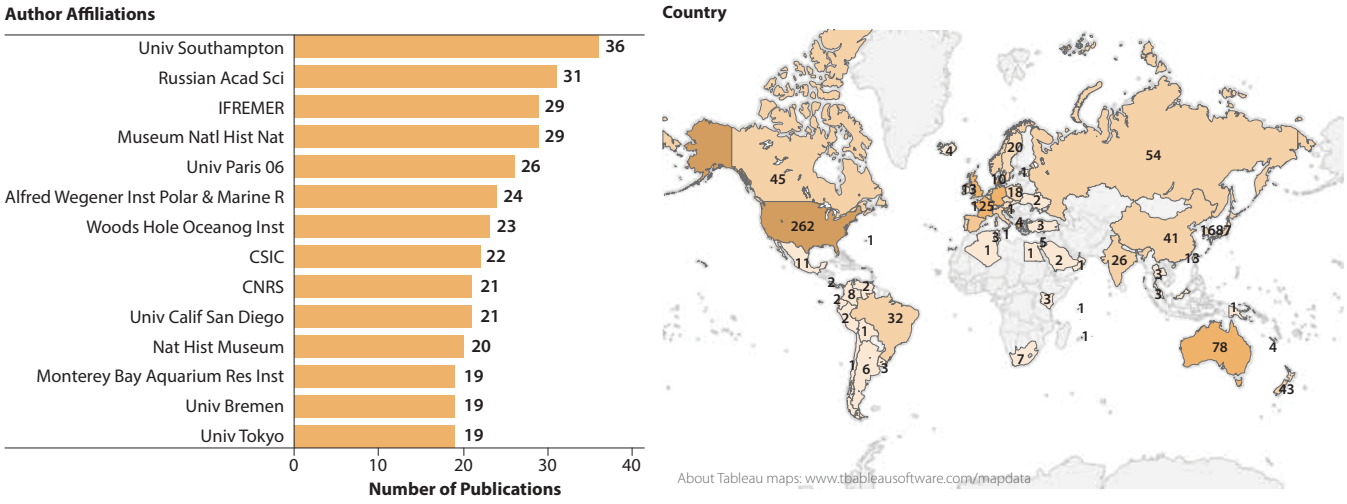


Figure 30.2. Author and country affiliations for scientific literature focused on marine genetic resources. Source: Oldham and others, 2013.

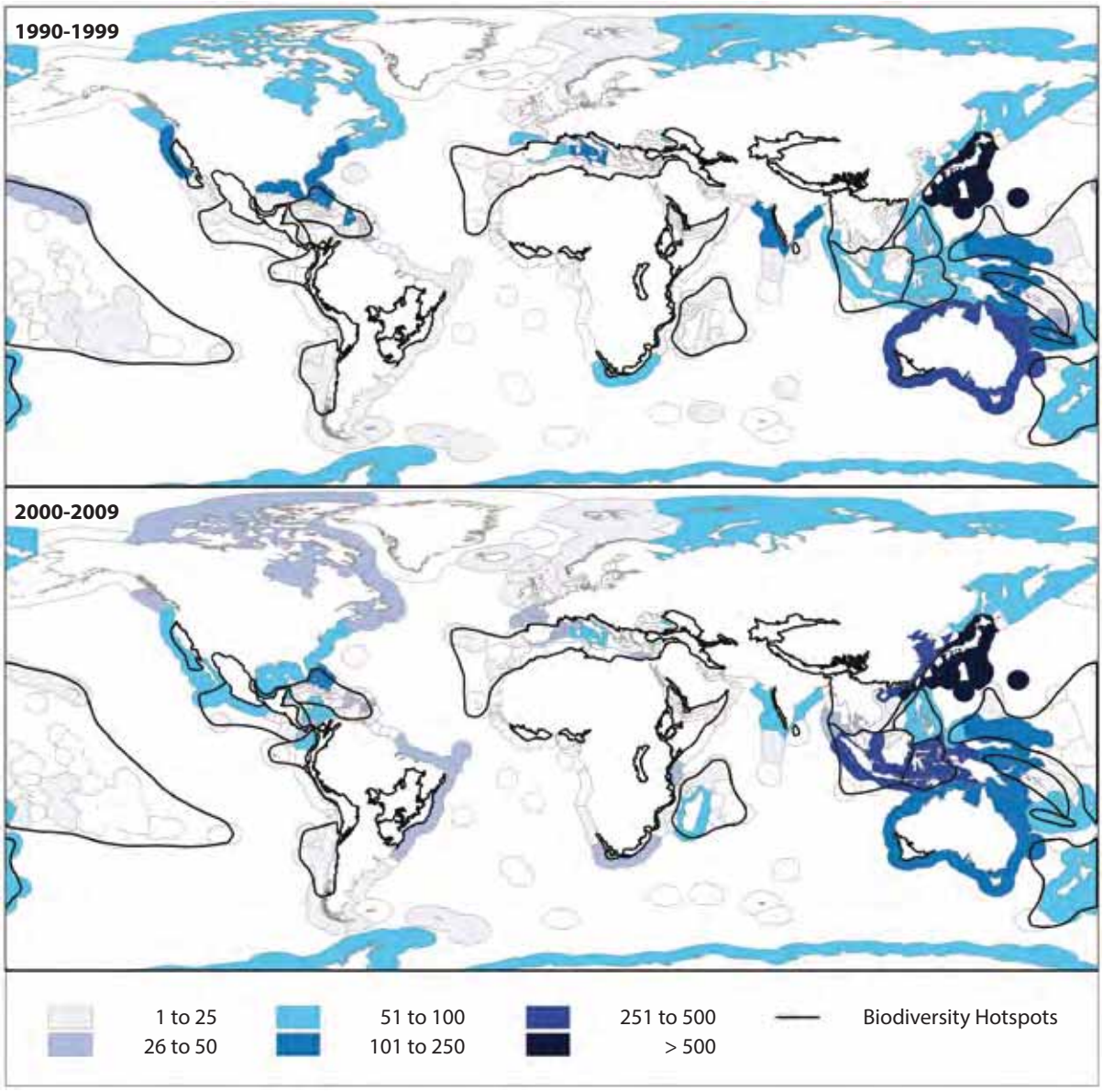


Figure 30.3. Number of new natural products from marine invertebrates for world Economic Exclusive Zones during the 1990s and 2000s. Boundaries of biodiversity hotspots are also presented. Source: Leal and others, 2012.

and others, 2014). 'Genome-mining', or metagenomic approaches, allow researchers to search directly within a sample for genes that produce enzymes with specific biocatalytic capabilities, rather than growing organisms in the laboratory as was previously necessary (Laird 2013).

NATURAL PRODUCT RESEARCH AND DEVELOPMENT IN THE WESTERN INDIAN OCEAN

Several areas in the WIO are of interest for natural products. Figure 30.3 illustrates trends in the discovery of new marine natural products from invertebrates over the last two decades. This demonstrates an increased interest in the WIO islands and east African coastline, although the most intense bioprospecting activity continues in Australasia. There is continued interest in the southern African coastline, linked to the occurrence of three biogeographical zones and high levels of endemism among marine organisms off the southern African coast (Costello and others, 2010, Davies-Coleman and Sunassee 2012). The presence of biodiversity hotspots in the WIO region also suggests that the area is likely to be of increasing interest for marine natural products. Only a small fraction of this biodiversity has been explored for its commercial potential (Davies-Coleman and Sunassee 2012).

Figure 30.4 presents a draft of occurrences in east and southern Africa of marine species in patent data, drawing from unpublished research conducted by Oldham and

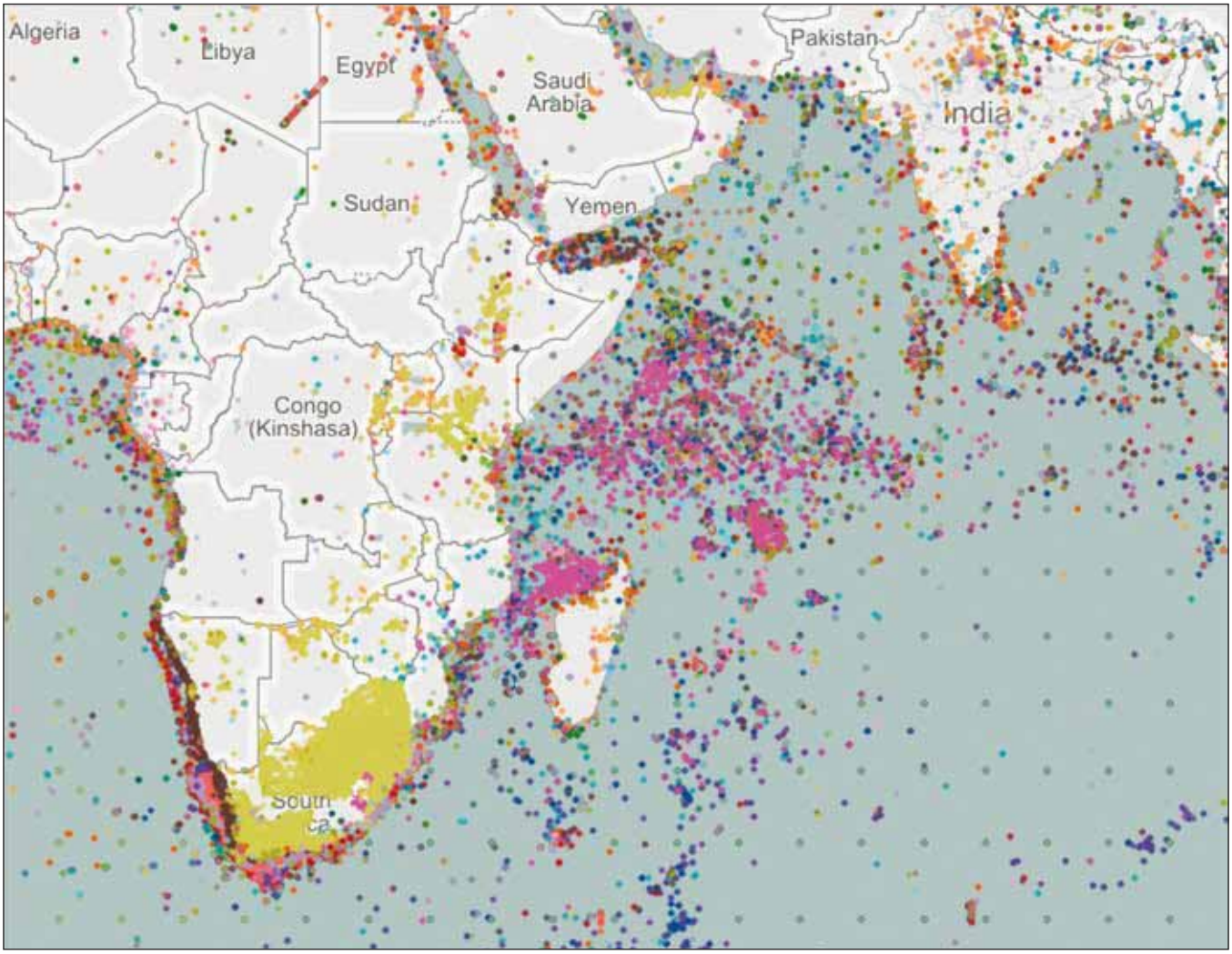


Figure 30.4. African occurrences of marine species in patent data. Source: Oldham and others (2013), Oldham and others (2014). Colours represent different species.

others (2013) and based on data from the Global Biodiversity Information Facility (GBIF). It is important to note that occurrence data does not necessarily mean the species was collected from the area. Although incomplete, it does give a picture of activity in the region. An especially noteworthy finding is the fact that natural product research mainly concentrates on marine invertebrates *inside* national jurisdictions (Oldham and others, 2013). Similarly, the majority of marketed products have been derived from organisms from inside national jurisdictions with limited exceptions for enzymes from extremophiles and Antarctic krill as a source of nutraceutical products (Oldham and others, 2013).

While there is increased global interest in marine microorganisms and microalgae for the pharmaceutical, cosmetic and food industries, there is a lack of knowledge about the distribution and occurrence of commercially interesting taxonomic groups in the WIO region. However, it is likely that there is significant potential in the WIO region to generate interesting new leads and that industry interest in the region will increase.

Major constraints that prevent this potential from being realised are the low levels of scientific and technical capacity that exist in most countries, with the possible exception of South Africa, and insufficient biodiversity knowledge. Without concerted efforts to strengthen this capacity and improve knowledge, benefits derived from the region's genetic resources are likely to continue to be reaped by developed countries. The Nagoya Protocol provides an important platform around which a new model of equitable research partnerships can evolve, not only between research institutions from WIO countries and those from the developed world, but also between research institutions and industry discovery and development programmes.

ACCESS AND BENEFIT SHARING

Marine biodiscovery, or bioprospecting, depends upon access to marine organisms, which in turn is governed by multiple legal regimes and national and international laws (Figure 30.5). Marine genetic resources found within the Exclusive Economic Zone (EEZ) are subject to national laws, and to the CBD and the Nagoya Protocol. This means that coastal states have the sovereign right to allow, prohibit and regulate marine bioprospecting in the EEZ; that users of genetic resources who wish to access this material must obtain prior informed consent from national competent authorities; and there must be mutually agreed terms on access and the sharing of benefits.

In practice, it has been extremely difficult to implement ABS principles for marine genetic resources, due in large part to their widespread occurrence and the challenges of determining ownership, but also to the evolving nature of ABS law and policy, and the absence of workable policy approaches in many countries (UNCTAD 2014). In all likelihood, therefore, most cases of marine bioprospecting in the EEZ have not been approved by national authorities, thus leaving the patent applicant and commercial entities as sole beneficiaries (UNCTAD 2014). Increased awareness is, however, leading to recognition of the importance of ABS in bioprospecting initiatives, articulated largely through research collaborations between developed and developing country institutions. The very low chances of commercial success and long-term nature of natural product research suggest that non-monetary benefits associated with scientific engagement and technology transfer are likely to be some of the more significant benefits to emerge from marine bioprospecting in the short-term.

In the high seas, or Areas Beyond National Jurisdiction (ABNJ), natural resources are considered to be the "common heritage of humankind" and are subject to the provisions of UNCLOS. Specialised ABS rules for these resources have not yet been developed and UN members are presently debating the desirability of a new international instrument arising from the conservation and sustainable use of marine biodiversity in these areas (Global Ocean Commission 2013). A central question is whether the benefits arising from the commercial use of these resources should be shared by the entire international community, or whether the States and corporations with the intellectual and technological know-how to exploit these resources should benefit. Unsurprisingly, the G77, which comprises countries that largely do not have suitable scientific and technological capacity, are supportive of an ABS regime that distributes benefits from this common resource more equitably. To date, the debate has focused largely on the *potential* economic value of marine genetic resources, as most research has been on resources from inside national jurisdictions (Oldham and others, 2013).

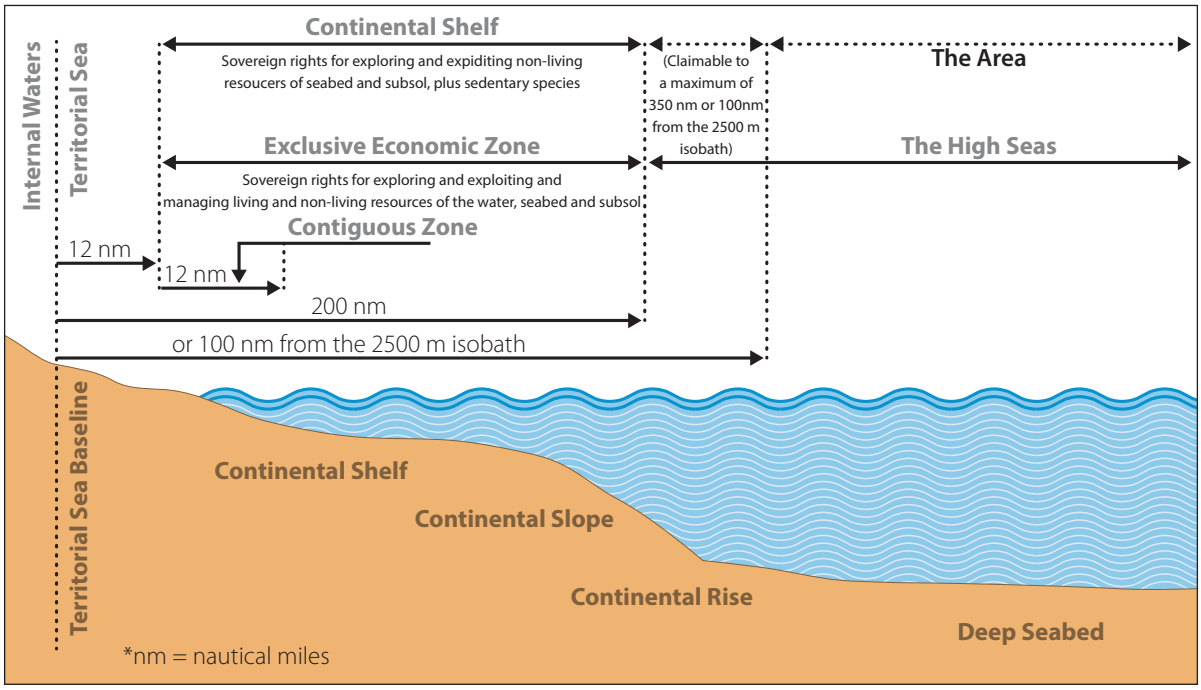


Figure 30.5. Cross-section of legal regimes governing marine resources in geographical zones. Source: Canadian Department of Fisheries and Oceans (www.charts.gc.ca/about-apropos/fs-fd/008-eng.asp)

Table 30.2. Overview of signatories and parties to the Convention on Biological Diversity (CBD) and the Nagoya Protocol

Western Indian Ocean State	Ratified CBD	Ratified or signed Nagoya Protocol	ABS Measures
Somalia	Y	Signed (09-01-12)	No ABS measures in place (Fifth National Report on the Implementation of the CBD, Mogadishu, February 2014, CBD website).
Kenya	Y	Ratified	Framework legislation and regulations were promulgated in 2006, setting out provisions for access to genetic resources and benefit sharing. The Regulations include specific provisions authorising the Minister to issue guidelines for access to and exploitation of living and non-living resources in the continental shelf, Territorial Seas and the Exclusive Economic Zone. The Science, Technology and Innovation Act sets the framework for scientific research.
Tanzania	Y	Neither signed nor ratified	ABS measures under development.
Mozambique	Y	Ratified	ABS measures under development.
South Africa	Y	Ratified	One of the first WIO countries to develop ABS laws, South Africa's Biodiversity Act was promulgated in 2004, followed by Regulations on Bioprospecting, Access and Benefit Sharing in 2008. Marine genetic resources are included within the ambit of these laws.
Comoros	Y	Ratified	No ABS measures in place
Madagascar	Y	Ratified	ABS measures under development.
Mauritius	Y	Ratified	ABS measures under development.
Réunion (France)	Y	Ratified (EU approval)	France does not yet have national ABS legislation covering the whole of its territory.
Seychelles	Y	Ratified	ABS measures under development.

Table 30.2 provides a summary of WIO signatories and parties to the CBD and Nagoya Protocol, and the ABS measures in place in each country. All ten WIO states are party to the CBD, and eight are party to the Nagoya Protocol. The exception is Tanzania which has neither signed nor ratified the Nagoya Protocol. All countries, with the exception of South Africa, and to a lesser extent Kenya and the Seychelles, are still in the process of developing ABS legislation. While ABS regulations have been in place in South Africa since 2008, implementation continues to be problematic, confounded by definitional issues of scope, low capacity levels, and a permitting system widely believed to be excessively onerous (Wynberg 2014).

CONCLUSIONS AND RECOMMENDATIONS

The marine genetic resources of WIO countries are likely to continue to be attractive for natural product research, especially with the accelerated development of genomics and increased interest in microorganisms. While marine bioprospecting presents a number of important opportunities for WIO countries, these are currently not being optimised. Appropriate laws are not yet in place; the costs of research and technologies remains prohibitively high; scientific capacity is low; and there are significant gaps in taxonomic and ecological knowledge.

The following recommendations are made to address some of these challenges:

- WIO countries should develop or strengthen national and regional ABS laws for marine biodiversity in the EEZ, with an emphasis on ensuring sufficient control over access and benefits, but without impeding research endeavours. Laws should be clear, simple and implementable. Countries that are not yet party to the Nagoya Protocol should be encouraged to ratify the agreement.
- In line with Article 8 of the Nagoya Protocol, particular attention should be given to promoting research that contributes to the conservation and sustainable use of biodiversity. Regulations should include a requirement for an assessment of the environmental impact of collecting activities.
- As noted in Articles 22 and 23 of the Nagoya Protocol, marine bioprospecting should be regarded as an opportunity to build scientific capacity in WIO countries and to transfer appropriate technology and access to technology from developed countries and institutions.
- Considerable effort should be given towards improving scientific knowledge about the marine biodiversity of

the WIO region, and in particular under-explored groups, including microorganisms and microalgae.

• In addition to capacity development and technology transfer, benefit sharing should include measures to strengthen the conservation of the area of collection and/or species collected. Countries should consider benefit-sharing measures to improve taxonomic knowledge and to improve access to raw and published data.

• Attention should be given to the possible development of a regional ABS approach for marine genetic resources in the WIO region, in line with the multilateral mechanism proposed by the Nagoya Protocol.

•Efforts should be undertaken to develop ABS rules for genetic resources in the high seas to ensure these potential benefits are gleaned by humanity as a whole.

• In international negotiations, WIO countries should support improved disclosure of the origin of material in patent applications to ensure greater transparency and improved tracking of the source of the material. Detailed information about the geographical and phylogenetic origins of marine genetic resources would help states to settle disputes over the ownership of material.

References

Arnaud-Haond, S., Arrieta, J.M. and Duarte, C.M. (2011). Marine biodiversity and gene patents. *Science* 331(6024), 1521 –1522

Arrieta, J.M., Arnaud-Haond, S. and Duarte, C.M. (2010). What lies underneath: conserving the oceans' genetic resources. *PNAS* 107(43), 18318-18324

Costello, M.J., Coll, M., Danovaro, R., Halpin, P., Ojaveer, H., and Miloslavich, P. (2010). A census of marine biodiversity knowledge, resources, and future challenges. *PLoS ONE* 5(8), e12110

Davies-Coleman, M.T and Sunassee, S.N. (2012). Marine bioprospecting in southern Africa. In *Drug discovery in Africa – impacts of geneomics, natural products, traditional medicines, insights into medicinal chemistry, and technology platforms in pursuit of new drugs*. (eds. K. Chibale, M. Davies-Coleman, and C. Masimirembwa) pp. 193-209. Springer-Verlag, Berlim

de la Calle, F. (2009). Marine genetic resources, a source of new drugs: the experience of the biotechnology sector. *International Journal of Marine and Coastal Law* 24(2), 209–220

Global Industry Analysts Inc. (2013). *Marine Biotechnology: A Global Strategic Business Report*. http://www.strategyr.com/marine_biotechnology_market_report.asp Accessed at 4 August 2014

Global Ocean Commission (2013). *Policy Options Paper No. 4: Bioprospecting and marine genetic resources in the high seas*. A series of papers on policy options, prepared for the third meeting of the Global Ocean Commission. November 2013. Available at http://www.globaloceancommission.org/wp-content/uploads/GOC-paper04-bioprospecting.pdf

Greiber, T. (2011). *Access and Benefit Sharing In Relation To Marine Genetic Resources From Areas Beyond National Jurisdiction - A Possible Way Forward*. No 301. Research Project of the Federal Agency for Nature Conservation. German Federal Agency for Nature Conservation. Bundesamt für Naturschutz (BfN). Germany

Laird, S. (2013). *Bioscience at a Crossroads: Access and Benefit Sharing in a Time of Scientific, Technological and Industry Change: The Pharmaceutical Industry*. Secretariat of the CBD, Toronto

Leal, M.C. and Calado, R.C. (2015). Marine natural products: biodiscovery, biodiversity and bioproduction. In *Bioactive natural products: chemistry and biology* (ed. G. Brahmachari) pp. 473-490. Wiley-VCH

Leal, M.C., Munro, M.H., Blunt, J.W., Puga, J., Jesus, B., Calado, R., Rosa, R. and Madeira, C. (2013). Biogeography and biodiscovery hotspots of macroalgal marine natural products. *Nat. Prod. Rep.* 30(11), 1380-1390

Leal, M.C., Puga, J., Serôdio, J., Gomes, N.C.M. and Calado, R. (2012). Trends in the discovery of new marine natural products from invertebrates over the last two decades – where and what are we bioprospecting? *PLoS ONE* 7(1), e30580

Leal, M.C., Sheridan, C., Osinga, R., Dionísio, G., Rocha, R.J.M., Silva, B., Rosa, R. and Calado, R. (2014). Marine microorganism-invertebrate assemblages: perspectives to solve the "supply problem" in the initial steps of drug discovery. *Mar. Drugs* 12(7), 3929-3952

Marris, E. (2006). Drugs from the deep. *Nature* 443(7114), 904-905

Martins, A., Vieria, H., Gaspar, H. and Santos, S. (2014). Marketed marine natural products in the pharmaceutical and cosmeceutical industries: tips for success. *Mar. Drugs* 12(2), 1066-1101

Molinsky, T.F., Dalisay, D.S., Lievens, S.L. and Saludes, J.P. (2009). Drug development from marine natural products. *Nat.Rev. Drug Discov.* 8(1), 69-85

Oldham, P., Hall, S. and Barnes, C. (2013). *Marine genetic resources in patent data*. United Nations University and One World Analytics, www.un.org/depts/los/biodiversityworkinggroup/workshop1_oldham.pdf Accessed at 4 August 2014

Oldham, P., Hall, S., Barnes, C., Oldham, C., Cutter, M., Burns, N. and Kindness, L. (2014). *Valuing the deep: marine genetic resources in areas beyond national jurisdiction*. Department for Environment Food and Rural Affairs (Defra). One World Analytics. Available at http://www.tinyurl.co/valuingthedeep

Reid, W.V., Laird, S.A., Meyer, C A., Gomez, R., Sittenfeld, A., Janzen, D.H., Gollin, M.A., and Juma, C. (1993). *Biodiversity prospecting: using genetic resources for sustainable development*. World Resources Institute, Instituto Nacional de Biodiversidad, Rainforest Alliance and African Centre for Technology Studies. Washington D.C, USA

Silva, T.H., Alves,A., Ferreira, B.M., Oliveira, J.M., Reys, L.L., Ferreira, R.J.F., Sousa, R.A., Silva, S.S., Mano, J.F. and Reis, R.L. (2012). Materials of marine origin: A review on polymers and ceramics of biomedical interest. *Int. Mater. Rev.* 57(5), 276-307

UNCTAD (2014). *The Oceans Economy: Opportunities and challenges for small island developing states*. UNCTAD/DITC/TED/2014/5. United Nations

Wynberg, R. (2014). *Implementing access and benefit-sharing legislation in South Africa. One step forward: two steps back?* PhytoTrade Africa

Wynberg, R., and S.L. Laird. (2007). Bioprospecting: tracking the policy debate. *Environment: Science and Policy for Sustainable Development* 49(10), 20-32


CAUTION

31

Summary of Other Human Activities in the Coastal and Marine Environment

Louis Celliers

Opposite page: Commuting in the Likoni ferry at the entrance of Kilindini Harbour, Mombasa, Kenya. © José Paula.

The Western Indian Ocean (WIO) offers a wealth of opportunity for the profitable and beneficial use of coastal and marine resources – a prospect for a true ocean economy. These benefits are derived from a range of human activities in the coastal and marine environment. Shipping moves, by a large margin, the bulk of the goods to the region, through many of the ecosystems described in this book. The region is also a source of, amongst others, fossil fuels for the generation of energy, and minerals for manufacturing and other uses. These extractive and non-renewable resources offer substantial economic benefit, if the negative environmental and social impacts can be mitigated. Coastal land as a resource allows for development, settlement and recreation opportunities, but is also a source of biodiversity and ecosystem services. These services contribute to the wellbeing of coastal communities. Urbanisation and coastal development result in permanent conversion of this resource and often the loss of most of the freely provided ecosystem goods and services. The exploitation of WIO genetic resources is a largely unexplored opportunity for the benefit of the regional and indeed the global population. Furthermore, the attractive and desirable coastal and marine habitats of the WIO, a non-extractive and renewable resource, are the basis for a growing tourism industry in the region.

Maritime activities, particularly shipping, are predicted to increase in the WIO. Seaborne trade volumes in Eastern Africa grew from 16.4 to 54 million tonnes between 1970 and 2012. Merchant shipping is the lifeblood of the region's economies and includes freight carried by general cargo ships, oil tankers, gas carriers, chemical tankers, bulk carriers, ferries and passenger ships, and containerships. This, together with factors such as climate change, heightens the environmental risks brought on by operational pollution from ships, shipping accidents, invasive alien species, and impacts from port operations. Piracy, illegal dumping and climate change are some of the current management issues that require policy interventions. Not only is it important for WIO countries to monitor environmental impacts of maritime activities, they also have to develop and maintain the capacity to regulate ships, provide them with appropriate maritime services (such as navigational aids) and respond to shipping accidents.

All countries in the region rely on the importation of oil to fuel power stations to generate electricity. **Energy supply** is needed in WIO countries for local industry, commerce and their citizens, and is a critical element for growth and development of their national economies. The WIO also has various energy sources located in, or accessed from the coastal and marine environment, eg natural gas has for over ten years been extracted from below the seabed and utilised for energy in countries such as Tanzania and Mozambique. The latter, with 100 trillion cubic feet (tcfg) of deep water gas, is ranked third overall of the African gas reserves, and Tanzania natural gas deposits are estimated at 50 tcfg. There are other less obvious alternatives to fossil fuels, notably energy derived from tides, currents and waves and the thermal differential in deep ocean water. In

the WIO these remain largely unexplored as a viable and sustainable source of energy. Structures in the ocean, marine geological exploration and fossil fuel production all potentially have a deleterious impact on the coastal and marine environment.

The coastal regions of mainland East Africa and Madagascar are endowed with a wealth of non-renewable mineral resources such as gypsum, manganese and titanium-rich dune fields and sandy shores. Even so, geological exploration of the region has been far from comprehensive and unknown deposits are likely to exist. **Mining** results in major environmental changes and degradation. The types of coastal mining activities in the WIO countries include the quarrying of coral rock and limestone for cement manufacture; aggregates for concrete and road-building; artisanal sand mining from catchments, floodplains, river banks, estuaries and lagoons; and industrial mining of titanium sand. The production of sea salt in salt pans, typically located on estuary flood plains, is also considered a mining activity. There remain significant opportunities for the exploitation of mineral resources to benefit national economies. These opportunities are offset by the potential for environmental degradation and loss of ecosystem services where mitigation and restoration is not a priority.

The WIO region provides a range of unique attractions and recreational activities for local and international **coastal and marine tourism**. Mainstays of the regional coastal tourism industry include sandy beaches, clean water, abundant sunshine, mangrove forests, lagoons and seas for sunbathing, snorkelling, dolphin and whale watching, ecotourism, fishing and other water sports. The contributions of tourism to the national economies of WIO countries range from 6.8 to 63 per cent for the island states (Comoros and Seychelles, respectively), and 7.5 to 13.5 per cent for mainland states (Mozambique and Tanzania, respectively). Tourism has immense potential to enhance socio-economic development, and contribute to environmental rehabilitation. This is a priority sector for development in all WIO countries. There are also a range of negative social and environmental impacts that require mitigation concomitant with the growth and development of the industry. Some of these include prostitution and sex tourism, a lack of integrated development planning, the need for community development and involvement, and habitat degradation. The lack of socio-political stability in countries in the region detracts from the potential benefits of a healthy coastal and marine tourism industry.

Urbanisation is a highly contextual, multifaceted, heterogeneous and complex phenomenon. The urbanisation of WIO countries, coupled with rapid development of the coastal margin translates into increased socio-economic vulnerability. Coastal cities of the region are desirable places to live and work in, and draw the population to the coast. For example, Dar es Salaam is projected to reach megacity status within the next generation. Populations in urban areas in the region are vulnerable to natural disasters within the coastal area. Urbanisation has direct effects on biodiversity and the state of the coastal environment. Expansion in the built environment results in some of the most irreversible human impacts on the global biosphere. Urban land-use change remains one of the primary drivers of habitat loss and species extinction. Some of the specific links between urbanisation and coastal environmental quality include water quality degradation, habitat and community modification and declines in living marine resources.

In addition, the interaction between **catchments** and the coastal and marine environments has been identified as one of the processes linked to environmental pressures in coastal areas of the region. The WIO region includes a total of twelve major river catchments and three of these – the Juba-Shabelle, Limpopo River and Zambezi River Catchments – count among Africa's major trans-boundary river catchments. Two major issues have been linked to river-coast interaction in the WIO: the alteration of river flows and water quality; and the alteration of sediment loads. Major challenges in maintaining the function of the ecosystem goods and services provided by catchments are directly linked to governance and management issues which need intervention at both regional and national scales.

Globally, **marine genetic resources** provide enormous commercial potential for a range of industries, including pharmaceuticals, food and beverages, cosmetics, agriculture and industrial biotechnology. The region, with its high coastal and marine biodiversity, offers considerable opportunity for the exploitation of genetic resources. Most research, development and commercialisation of such resources are currently located outside of the region, as is the ownership of associated intellectual property rights. This represents an opportunity for countries in the region, provided they can form productive investment partnerships, and navigate the associated complex legal framework which is characterised by a multiplicity of legal

regimes and national and international laws. Marine genetic resources found within the exclusive economic zone (EEZ) are subject to national laws and coastal states have the sovereign right to allow or prohibit and regulate marine bioprospecting. Exploitation of genetic resources is subject to prior informed consent from the competent national authorities, and on mutually agreed terms and the sharing of benefits. In many countries of the WIO, comprehension of this and the supporting legal frameworks are not sufficiently developed to allow for substantive benefits arising from the exploitation of genetic resources.

The development and implementation of policies for the exploitation and sustainable use of resources as part of a WIO Blue Economy, broadly grouped, are listed below. The specific recommendations can be found in the individual chapters:

• **Knowing more about the resources**, the environment, the people using and exploiting such resources, and the way in which we govern. The development of a Blue Economy relies not only on scientific data, information and knowledge in many different scientific disciplines, but also mechanisms for integrating this cross-discipline information. National and regional research agendas should recognise the need for inter- and trans-disciplinary research.

• **Understanding the value of ecosystem services** and how it is influenced by environmental change. Decisions on the trade of free ecosystem services for constructed or human infrastructure services must be made using a comprehensive suite of estimations. This includes both monetary worth and societal values that are embedded in culture, tradition and religion.

• **Equitable access,** to and benefit-sharing of coastal and marine resources should be entrenched in all national policy and legislation.

• **Understand and managing hazards, vulnerability and risk**. This includes ecological, social and economic vulnerability to hazards incurred in human activities such as shipping and mining, as well as hazards caused by the proximity of coastal communities to the ocean climate. The consequences of global change also create vulnerability and the language of resilience, adaptation and mitigation should be reflected in policy and legislation.

• Development of mechanisms and tools for the **capture, exploration and archiving of data**, information and knowledge. Coastal and marine spatial data archiving, coastal atlases and information clearinghouses are some of the mechanisms that should be used to improve the return on investment in scientific research.

• A suite of **planning tools and mechanisms** for the management of:

- Coastal land-use and conversion at all scales – regional, national and sub-national. Forethought in coastal development and growth is a priority. Approaches such as seamless terrestrial and marine spatial planning should be part of a suite of adaptive management tools.

- Human activities and their usage and exploitation of resources. The city-port-environment interface needs to be recognised in policy. The many activities associated with shipping and tourism need careful, long-term planning to ensure compatibility with a multiplicity of coastal land- and sea-uses and users.

• An emphasis on the **production of spatial data** which will enable usage of scientific products for marine spatial planning and other similar mechanisms.

• **Relevant legal frameworks** that enable rather than frustrate efforts to develop environmental management solutions for sustainable development.

• The prioritisation of the management of coastal areas and associated human activities through the development and implementation of **integrated coastal management** (ICM). The plethora of coastal and marine activities require management approaches that are adaptive, rely on appropriate and scientifically defensible data and information, and include the entire spectrum of users, stakeholders, decision- and policy-makers to negotiate effective and sustainable use and exploitation of coastal and marine resources. These are the pillars of ICM.

Part VII
Scenarios, Policy Options and Capacity Building

José Paula

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32

Scenarios: WIO Coastal and Marine Environmental Futures

Washington O. Ochola

Opposite page: Can WIO coastal landscape paradises like this one in Seychelles still exist in the future under change scenarios? © Lawrence Hislop / www.grida.no

INTRODUCTION

The 45 649 km long coastline of Africa is shared by 33 mainland countries and six island states. The continents' coastal and marine resources support many economic activities such as shipping, transportation and recreation. The state of the coastal environment is an indicator of the potential economic benefit that can be derived from the natural goods and services that accrue to government accounts and their people. An analytical exploration of the future state of coastal resources is required to understand the relationship between the use and exploitation of natural goods and services and the concept of sustainable development. The western Indian Ocean (WIO) Regional State the Coast Report (RSOCR) presents an exploratory scenario and policy analysis to better inform anticipatory planning and management of coastal and marine resources. To address gaps and policy failures in the governance of ocean and coasts, there is a need to explore a more holistic approach to managing complex seascapes, such as spatial management approaches like the use of marine protected areas (MPAs) and marine spatial planning, which both seek to implement ecosystem-based management. This integrated approach to management that considers the entire ecosystem, including humans, can be employed across the WIO region through futuristic analyses.

Complex issues such as environmental change are best communicated by way of contrasting 'scenarios' or 'worlds', which explore future trends, trade-offs, implications and policy lessons derived from our understanding of the drivers of environment change. Scenarios are imagined 'futures'. They are seldom presented as a single forecast, but rather as a set of alternative plausible future pathways that can provide options for decision- and policy-making. The range of future options describes both optimistic and problematic futures in the hope of benchmarking both 'extremes'and 'middle-grounds' in order to steer decision- and policy-making to achieve a desirable future. For better results of an assessment process, scenarios should explore different ramifications and extensions of critical uncertainties and interaction of factors within specific themes.

Long-range planning, informed by scenarios, enables decision-makers to predict and explore a range of possible alternative futures in order to identify possible corrective actions and the subsequent and resulting consequences. In this regard, scenario analysis can be effective in supporting strategies for resource-use management and conservation. Scenario analysis goes beyond simple contingency planning, sensitivity analysis and computer simulations by presenting comprehensive exploration of alternative futures.

It is thus desirable for regional, national and sub-national stakeholders in the WIO region to mainstream scenario planning in order to anticipate weaknesses and inflexibilities in coastal and marine resources management towards growth and development. If understood and anticipated, such weaknesses can be avoided, or their impact reduced, through appropriately targeted and costed interventions, rather than engaging mitigation measures as they

emerge. One benefit of scenario planning is that by expanding the range of future outcomes considered in strategic decision-making, managers avoid the risk of "putting all their eggs in one basket". The results are more robust plans and decisions that allow for adaptation to changing circumstances. Furthermore, scrutinizing the underlying assumptions of current decisions and management practices enables policy-makers to test ideas, make mistakes, and learn from them without risking real-life management failures or collapsing resources.

This chapter aims to: 1) develop and explore explicit relationships between issues addressed throughout this report, 2) identify priority challenges, and 3) identify promising policy options and their plausible trajectories. Using a diametric scenario framework (considering opposite extremes), the chapter explores the emerging and future relationships between the opportunities, successes and challenges in the management of coastal resources in line with the Drivers, Pressures, States, Impact and Response (DPSIR) Framework (UNEP 2013). Two diametrically-opposed scenarios or pathways were explored, namely:

- The **'challenge scenario'** articulating longer-term options for achieving goals and targets and reversing /redirecting any undesirable; and,
- The **'business as usual'** pathways.

An indicator-based environmental future assessment is then used to elaborate the scenarios. The chapter presents the methodology and approach used in the scenario building process, theme-based future trends and an exposition of how to use and refine the scenarios going forward as well a set of scenario adaptation recommendations. Policy and management options emanating from this futures assessment process are also presented.

METHODOLOGY AND APPROACH

Overall Approach

Scenario building for the RSOCR was designed to offer an inclusive and systematic approach to think about the future of the WIO environment, using selected themes, issues and indicators as prioritized by stakeholders of the reporting process. The scenario approach adopted the DPSIR framework and was integrated based on variables, links, and feedbacks relevant to dynamic modelling of marine social–ecological systems. Adopting a systems approach, the process also included domains that influence human behavioural change, including society, knowledge systems, political and institutional setting, and the economy. The approach involved multi-disciplinary teams of experts, and authors, and representatives of stakeholders to design the scenario framework, scope (both temporal and thematic) and elaborate narratives as the building blocks for the storylines. This ensured the involvement of different individual and collective actors, including implementing organisations as well as the activities of actors such as capture fisheries, land use, and aquaculture, which will ultimately affect the ecological system assessed in the scenario building processes. As an example, Figure 32.1 illustrates the framework for exploring future interlinkages in fisheries.

The Two Pathways

The assessment explored the evolution of sector changes for creating social–ecological scenarios (future marine ecosystem dynamics) with respect to the physical environment, the biogeochemical environment, food-web dynamics (low- and high- trophic-level species), and the human dimension. Many recent environmental and socio-economic assessments have adopted this integrated approach (UNEP, IOC-UNESCO 2009). The assessment used two main scenarios (or worlds):

- The Conventional World Scenario (CWS) representing a business as usual pathway (BAU) with current trajectories extrapolated towards 2050; and,
- The Challenge Scenario or Sustainable World Scenario (SWS) representing sustainable future as captured in the Western Indian Ocean Strategic Action Programme (WIO-SAP) aspirations (UNEP/Nairobi Convention Secretariat 2009) and the Sustainable Development Goals (SDGs).

The main assumptions integral to the scenarios are summarized in Table 32.1.

Business as Usual – Baseline Scenario

Under this scenario (Conventional World Scenario), growth and development of the WIO moves along a trajectory representing a continuation of current trends, without major policy shifts. People aspire for personal independence, material wealth and greater mobility, to the detriment of wider societal and coastal environmental goals.

Challenge Scenario – Towards a Sustainable World

The Sustainable World Scenario (SWS) depicts a future where deliberate attempts are made to manage the coastal

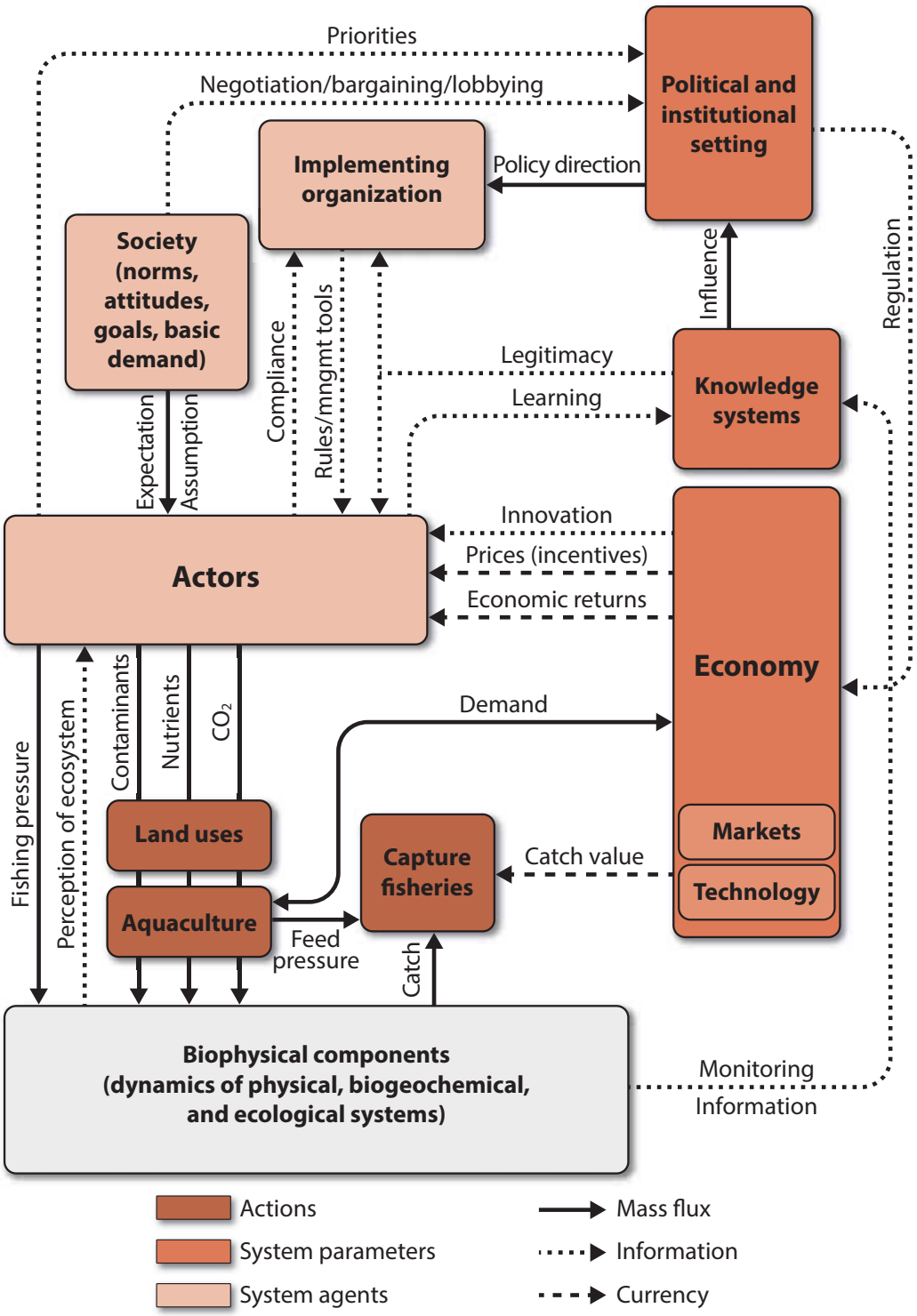


Figure 32.1. Framework for thematic assessment - human dimensions for creating social–ecological scenarios using the fisheries example. Source: Österblom and others (2013).

environment in ways that meet internationally agreed development goals with clear targets for associated coastal and marine activities. These targets are articulated, especially in the WIO-SAP document, but also the Sustainable Development Goals (SDGs), particularly the targets of goal 14 - *Conserve and sustainably use the oceans, seas and marine resources for sustainable development*), and related regional and national targets. SWS is based on the assumption that the management of coastal and marine resources will proceed in a manner that limits degradation and associated

Table 32.1. Key assumptions of the future trends in drivers and issues under two future scenarios.

Driver/Issues	Conventional World Scenario (CWS)	Sustainable World Scenario (SWS)
Climate Change and Ocean Systems	Global climate change +0.94°C by 2020 Surface temperature rises occasioning increase in ocean currents/wind speed Sea level rises in WIO	Global climate change +0.88°C by 2050 Surface temperature rises at a lower rate occasioning weaker increase in ocean currents /wind speed Sea level rises in WIO
Fisheries and Mariculture	Common Fisheries Policy plays only a minor role The industry becomes more industrialised and global in scale Indigenous supplies supplemented with increasing inputs	The main goal is local self-sufficiency The industry is heavily subsidised to protect local resources There is strenuous effort to protect wildlife and habitats Management responsibility transfers to regional committees An effort-based management system is introduced The number of small inshore vessels increases within sustainable range and under strict controls. This varies from country to country A network of closed areas to protect stocks, habitats and species Rapid growth in organic and low-input aquaculture
Oil & Gas	Primary energy consumption increases by 1.5% per year Emphasis is on maintaining national supplies, control over exports Drive to exploit all remaining domestic resources, including oil and gas Exploration throughout the WIO regional & into deeper waters Many new (short-lived) installations, wide scale decommissioning of rigs High energy prices associated with increased difficulty in extracting remaining resources	Primary energy consumption increases by 0.5% per year Some local coal and oil exploited, but with stringent environmental controls High energy prices lead to large-scale adoption of energy efficiency measures Reduced demand for oil and gas results in lower risk of spillage etc. Installations commissioned and decommissioned according to local/ regional needs
Ports and Shipping	Exports from the WIO expand to 35 % of regional GDP Growth in international trade and removal of trade barriers/constraints Port development largely market-driven Deep-water ports in WIO expand, smaller ports close Few environmental controls, greater pollution risks New shipping routes created	Exports from the WIO increases by over 40 % of GDP Sectors operating in global markets experience growth prospects Closure of some international ports and supply chains to increase efficiency Greater reliance on regional scale maritime activities Stakeholder input into port development plans More international vessels but stricter environmental regulations Increased monitoring and legal control of passing ships
Tourism	Few constraints on international travel Increased domestic tourism Domestic travellers more inclined to go overseas Cruise ship industry and use of marinas continue to expand More attractive resorts Competition between resorts for investment and development Resorts become more homogeneous	Focus on local and regional identity Unique selling points of destinations heavily drawn upon Increased visitation by domestic tourists Destinations will provide more eco-friendly activities Development in-keeping with existing natural landscape WIO residents support cultural heritage including historical sites Co-operatives and joint ventures encourage development
Energy	Renewable electricity generation viable, but not widely adopted Low priority attached to climate change 'Climate Levy' abandoned as it would constrain economic growth Slow growth in offshore electricity generation at today's level No regional electricity grid WIO energy generation and trading policy in place but challenges in implementation	Wide range of small-scale renewable technologies exploited, particularly wind Global climate targets viewed as being of primary importance Imported energy or electricity less important, local resources become main focus Offshore electricity generation expands contributing over 2% of global electricity in 2050 due largely to expansion of renewables such as wave power (Hammer and others, 2012) Growth in offshore wind/thermal/tidal and solar energy expand

deleterious human and ecological outcomes. The main objective of the scenario is to reveal the choices of policies and management programmes that would ensure the attainment of both the desired environmental and related human well-being outcomes.

A strong momentum already exists in drivers playing out in current trends (as outlined by the CWS), and as a result, to deflect such trends so as to meet WIO-SAP targets is expected to remain a daunting challenge. This is largely due to social and demographic dynamics, climate change, habitat changes, and other inland and offshore developments. There is a realisation that the attractive route to the future requires considerable investments, coupled with mind set and behavioural change of stakeholders, policy makers and other communities, institutions and nations and, that long-term goals are best achieved through cooperation at a regional level. The scenario reveals 'what it would take to overcome barriers to meeting sustainability goals' (UNEP 2013).

The WIO State of the Coast scenario analysis aimed at transforming the current baseline trends into the desirable WIO-SAP targets as they relate to regional and international goals, especially SDGS (see Box 32.1) and targets, using the following process:

- Selection of themes consistent with those found in the chapters of the WIO State of the Coast Report;
- Selection of relevant models or results from existing scenario analyses in order to provide qualitative and quantitative trends and storylines for each of the thematic areas; Identification of long-term goals including internationally agreed goals (eg 2ºC target, WIO-SAP targets), as well as environmental limits consistent with the scenario time line of 2050. Note that 2050 is the maximum long-range scenario time limit. Mindful that each theme/goal might have a different time horizon, the future explorations were guided by the specific target milestones for the theme;
- Analysis of possible synergies and trade-offs between the goals and targets in different coastal and marine domains by linking the different scenario findings with the goals and health targets in order to construct the narrative;
- Identification and analysis of possible alternative strategies (or wedges) – transformative policies – with necessary national, local and regional differentiation but globally consistent. The intention was to ensure that the alternative strategies and policies should close the gap between the current trend and the identified goals for 2050 through policy changes, technological solutions, lifestyle and behavioural changes and promotion of existing good practices. The associated risks, human and ecological benefits were then appropriately flagged along the way to complete the storyline; and,
- Identification and analysis of transformative policies necessary to realise long-term goals. The identified goals were developed from promising initiatives, decisions, actions and development that are already underway such as regional efforts to create marine protected areas (MPAs) and Locally Managed Marine Areas (LMMAs) (Rocliffe and others, 2014). The analysis also points out where desirable outcomes cannot be met in order to influence further research, capacity development and policy innovations.

The process of transforming the baseline trend towards achieving the targets identified under the Sustainability World (and WIO-SAP) scenario, is illustrated in Figure 32.2.

EXPLORING THE WIO COASTAL FUTURES

Drivers of Future WIO-Coastal Changes

The main regional drivers of change include destructive and unsustainable pelagic and coastal fishery practices (dynamite and overfishing), climate change, land-based sedimentation, watershed pollution and soil run-off, population growth and urbanisation, poorly planned infrastructure, tourism and shipping activities.

Demography and Socio-cultural inertia

Population growth, urbanisation and other demographic changes will invariably affect the state of the coastal and marine resources in WIO region. The current over 60 million inhabitants of the coastal area of the WIO region is expected to double by 2050. Complications from population growth will be felt in countries where a youthful cohort outstrips economic growth rates, resulting in increased unemployment and unprecedented pressure on resources with subsequent social consequences (Halpern and others, 2008). Tied to this is ongoing urbanisation and the growth and development of coastal "mega-cities". Expansion of military and naval presence in response to the growth and spread of militant Islamist movements will continue to pose challenges in relation to governance and population growth/economic opportunities. Increase in human pressure on coastal and marine resources in the WIO region is evident from decreasing fish catches, increasing use of destructive fishing practices and by the increasing volume of untreated sewage and nutrient runoff released into near-

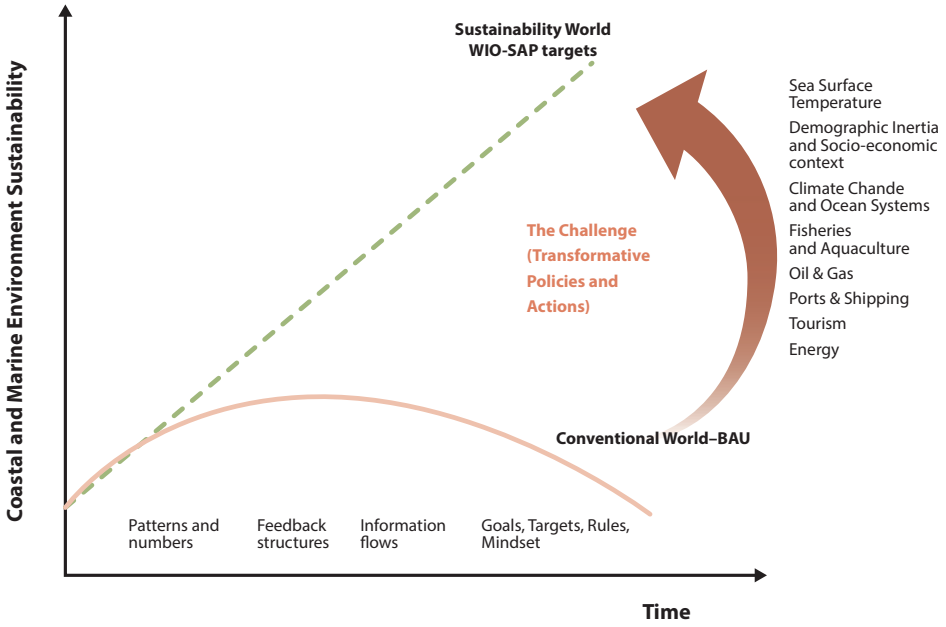


Figure 32.2. The WIO State of Coast Report Scenario Framework.

BOX 32.1. SDG 14 – CONSERVE AND SUSTAINABLY USE THE OCEANS, SEAS AND MARINE RESOURCES FOR SUSTAINABLE DEVELOPMENT

14.1: by 2025, prevent and significantly reduce marine pollution of all kinds, particularly from land-based activities, including marine debris and nutrient pollution

14.2: by 2020, sustainably manage, and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience and take action for their restoration, to achieve healthy and productive oceans

14.3 minimize and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels

14.4: by 2020, effectively regulate harvesting, and end overfishing, illegal, unreported and unregulated (IUU) fishing and destructive fishing practices and implement science-based management plans, to restore fish stocks in the shortest time feasible at least to levels that can produce maximum sustainable yield as determined by their biological characteristics

14.5: by 2020, conserve at least 10 per cent of coastal and marine areas, consistent with national and international law and based on best available scientific information

14.6: by 2020, prohibit certain forms of fisheries subsidies which contribute to overcapacity and overfishing, and eliminate subsidies that contribute to IUU fishing, and refrain from introducing new such subsidies, recognizing that appropriate and effective special and differential treatment for developing and least developed countries should be an integral part of the World Trade Organisation (WTO) fisheries subsidies negotiation

14.7: by 2030 increase the economic benefits to Small Island Developing States (SIDS) and Least Developed Countries (LDCs) from the sustainable use of marine resources, including through sustainable management of fisheries, aquaculture and tourism

14.8: increase scientific knowledge, develop research capacities and transfer marine technology taking into account the Intergovernmental Oceanographic Commission Criteria and Guidelines on the Transfer of Marine Technology, in order to improve ocean health and to enhance the contribution of marine biodiversity to the development of developing countries, in particular SIDS and LDCs

14.9: provide access of small-scale artisanal fishers to marine resources and markets

14.10: ensure the full implementation of international law, as reflected in UNCLOS for states that are parties to it, including, where applicable, existing regional and international regimes for the conservation and sustainable use of oceans and their resources

shore areas (Ausubel and others, 2010).

Climate Change

The fifth assessment report of the IPCC (2013, 2014) indicates that the climate of the WIO is already changing and different sectors are already feeling the impacts. Further climate change is inevitable in the coming decades and will continue to affect national growth and development of WIO states. Current plans for climate change adaptation can mitigate the impacts, but relative to the size of WIO national economies, the cost of adaptation is high (Jäger and others, 2013). The region will benefit from systematic integration of climate adaptation, mitigation and development approaches. This will require new patterns of coastal development to include low-carbon growth and clean investment while international cooperation will remain vital to reduce global carbon emissions.

The waters of the WIO have already warmed by over 1°C over the last 3 decades and the sea surface temperatures are projected to continue warming to more than 2°C by 2100 (Figure 32.3). The combined effects of changes in precipitation and evaporation patterns are highly likely to cause a greater freshwater deficit which in turn causes increased ocean water salinity (OSS), a potential increase of more than 0.5 units over the next five decades (Crooks and others, 2011). The projected changes in both temperature and salinity are likely to affect other oceanographic processes including thermohaline circulation, upwelling systems, ocean acidification and formation of deep-water masses. The uncertainty surrounding sea level rise, ocean water temperature and salinity with climate change make it difficult to predict the actual sea-level changes in the region, hence the wide range of values offered by IPCC (2014) and Jäger and others (2015).

Climate change has already affected the availability and stability of marine and coastal resources (IPCC 2014). Predicted long-term climatic changes include: rainfall and wind variation, intensity and frequency of cyclones, rise and fall of sea level, wave-height and temperature (atmospheric and sea surface). These changes will not only affect human activities such as fishing, agriculture, transport and the coastal communities but also coastal and marine ecosystems and habitats. Over the next two to three decades, regional coastal and marine ecosystems will continue to provide critical services and benefits to the well-being of the dependent communities. These include food security, climate regulation, water provision and recreation. These services will likely to be directly

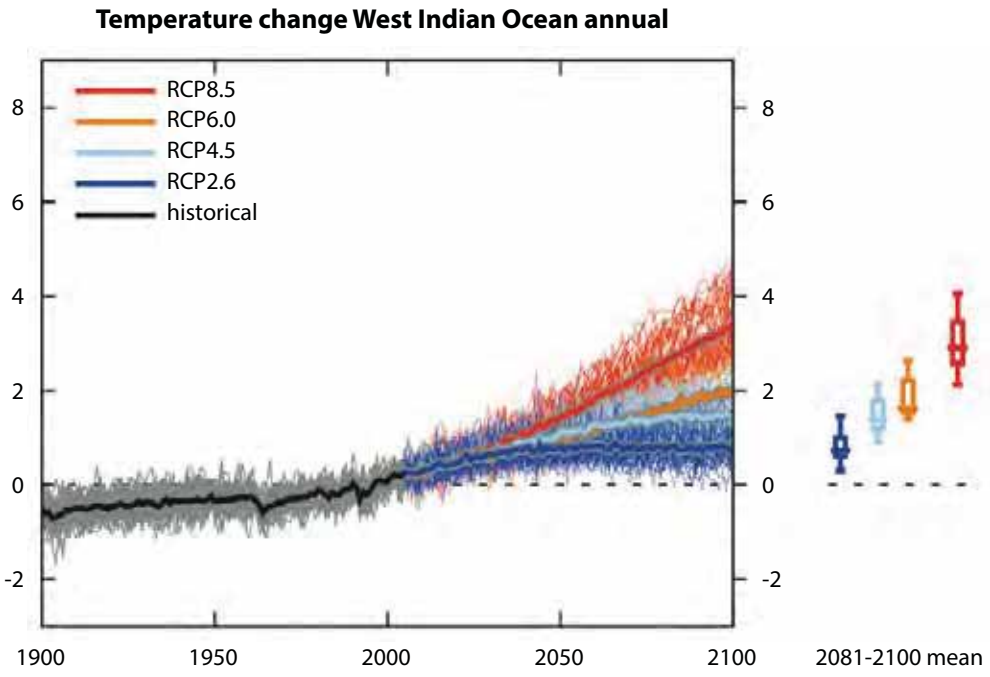


Figure 32.3. Time series of annual sea surface temperature change relative to 1986–2005, averaged in the West Indian Ocean (25°S to 5°N, 52°E to 75°E). Thin lines denote one ensemble member per model, thick lines the multi-model mean. On the right-hand side the 5th, 25th, 50th (median), 75th and 95th percentiles of the distribution of 20-year mean changes are given for 2081–2100 in the four Regional Climate Projection (RCP) scenarios. Source: IPCC (2013).

and indirectly affected by climate change and some of these are indicated below:

- *Fisheries*: Although the WIO fisheries are already overfished (75 per cent of stocks) or fully exploited, the vulnerability of fish diversity and fishing catches to climate change is likely to escalate due to the accompanying increases in salinity, acidification of the ocean, increasing sea temperatures and the spread of invasive species (FAO 2008, FAO-SOSA 2013). The small-scale fishing industry is expected to be less resilient to climate change;
- *Tourism*: Impacts of climate change on tourism are complex and multifaceted. The expected reductions in freshwater resources and local food shortages (through impacts on agriculture) may increase the costs of running tourism, while coastal erosion, flooding and habitat loss could significantly affect tourist access to beaches and other destination and sports attractions. The eminent aftermath would be consequences for revenues and job security; and,
- *Effects on oceans and coasts including protected areas:* The projected rise in temperatures and ocean acidification may lead to regime shift, moving from one stable state. Regime shifts are likely to be driven by a combination of human and natural factors, including increased nutrients from septic systems, drought, water diversion, and removal of grazers (IPCC 2013). A further complicating factor is that driver variables in marine ecosystems operate at different scales, with some variables responding to perturbation quickly, eg water clarity and salinity. Shifts in distribution of species may cause existing MPAs to be inappropriately sited.

Thematic Scenario Analysis

The goals and targets defined by the WIO-SAP for the Protection of the Coastal and Marine Environment of the region formed the basis for benchmarking future trajectories which are illustrated in Figure 32.4. Both the sustainable development goals (Box 32.1) and WIO-SAP goals (Box 32.2) focus on sustainable coastal and marine management through assessments and capacity building; development and implementation of ecosystem based management including MPAs; environmental governance including implementation of the protocol for the protection of the marine and coastal environment of the WIO from land-based sources and activities (LBSA protocol); development of protocol on integrated coastal zone management (ICZM) under the Nairobi Convention; information and awareness; policy options on climate change; ports and harbours development; oil and gas; green economy; and partnerships for activities on description of Eco-



Figure 32.4. Images of the future: Selected targets of WIO scenario analysis

logically or Biologically Significant Marine Areas (EBSAs), Vulnerable Marine Ecosystems (VMEs), Areas Beyond National Jurisdiction (ABNJ), and Particularly Sensitive Sea Areas (PSSAs).

BOX 32.2. WIO-SAP PROJECT GOALS. SOURCE: UNEP/NAIROBI CONVENTION SECRETARIAT (2009)

Objective A: Critical coastal habitats in the WIO region protected, restored and managed for sustainable use

1. Incentives to encourage compliance with best practice in critical habitat management established
2. Coastal zoning based on integrated economic, social and environmental considerations implemented
3. Critical habitat management strategies in place and contributing to ecologically sustainable ecosystem services and regional protection
4. A regional monitoring and evaluation plan established and implemented for critical habitats, coasts and shorelines
5. Integrated Coastal Zone Management legislation in place in all countries
6. National legislation to improve management of bilateral and regional issues strengthened
7. Awareness of the importance of critical habitats raised significantly

Objective B: Water quality in the WIO region meets international standards by year 2035

1. Effluent discharge standards developed and regionally harmonized
2. Marine water standards developed and regionally harmonized
3. Regional best practice framework models for municipal wastewater management developed and adopted
4. Collection, treatment and disposal of effluents undertaken in accordance with regional standards
5. Environmental Management Systems and Cleaner Production Technologies encouraged
6. Stakeholders sensitized and political support harnessed in favour of pollution prevention

Objective C: River flows in the WIO region are wisely and sustainably managed by the year 2035

1. Awareness of Environmental Flow Assessment (EFA) as a tool for wise river basin management raised
2. Capacity for applying EFA increased amongst key stakeholders
3. EFA conducted and operating rules integrated into river basin management plans for selected basins
4. Methodologies agreed upon and tools developed for coherent application of EFA in both freshwater and coastal management
5. Policy discussion on coastal and marine issues catalysed through collaboration between

Shared Water Courses Institutions and the Nairobi Convention secretariat

6. National freshwater management and coastal zone management frameworks fully integrated.
7. Effects of impoundments and dam operations on river flow variability and sediment discharge analysed and results implemented
8. Significance of identified wetlands on flow variability, sediment discharge and coastal and marine productivity investigated and wisely managed
9. . Impacts of catchment management on coastal habitats, shorelines and water quality investigated and results adopted in river basin and coastal and marine management

Objective D: By 2015, stakeholders will collaborate effectively at the regional level in addressing

transboundary challenges

1. Capacity for ecosystem-based management improved
2. Appropriate legal and regulatory frameworks for LBSA management in place and implemented at the national level
3. Awareness of the importance of good marine and coastal management raised among policy makers and legislators, civil society and the private sector
4. Regional legal frameworks for LBSA management updated and harmonized with multilateral environmental agreements
5. Regional coordination and inter-sectoral governance improved
6. Appropriate financial mechanisms developed and implemented
7. Knowledge management undertaken effectively

Conventional World Scenario

Current inadequacies in governance frameworks remain unaddressed and result in ongoing degradation of the coastal and marine environment of the WIO. The prevailing governance issues include poor coordination of government, lack of environmental awareness amongst policy-makers, inappropriate and weak legislation and a lack of adequate institutional frameworks and capacities for managing development pressures. Major developments, such as Lamu port construction, oil and gas infrastructure, Bagamoyo and other projects, are implemented without evidence of appropriate mitigation, or risk analyses.

With these trends, the decline in capture fish production and diversity continue. Damage of reef quality and extent may affect reef fish resources, and further affect reef-based tourism and associated livelihoods, while reduction in reef formation may reduce coastal protection from storms and increase erosion and storm damage.

The diversity of nearshore habitats (including beaches, rocky shores, muddy shores and mangroves, coral reefs and seagrass beds) continue to diminish due to continued impact of climate, alteration of nearshore geomorphology and unsustainable coastal land-use. Direct exploitation of coastal resources lead to greater vulnerability of species such as sea turtles. Non-compliance with regulations and inappropriate fisheries methods continue to be a major cause of turtle mortalities. Other species affected by habitat destruction/degradation include molluscs and crustaceans, invertebrates, cephalopods and various seaweeds. Table 32.2 illustrates a comparison of the level of exploitation of the stocks of three invertebrate groups in WIO countries, under the two scenarios.

The projected exponential increase in population, coupled with a high reliance on coastal and marine resources for sustenance and livelihoods is likely to compound the challenges facing biodiversity conservation in the WIO. This is in addition to other human activities such as continued mining and exploration, sand harvesting, trawl fishing and mega developments such as ports and oil rigs.

Major maritime activities such as shipping and development of ports and communication infrastructure, such as submarine cables, continue without any evidence of risk minimisation or of mitigative action to reduce costs to the coastal environment. The volume of seaborne trade in the WIO is expected to increase by over 5 per cent annually

Table 32.2. The status of invertebrate stocks in WIO countries. Source: data from FAO-SWIOFC (2012).

Country	Invertebrate	Current Status (2012)	Conventional Worlds	Sustainability Worlds
Comoros	Cephalopods	Under-exploited	Fully exploited	Moderately exploited
	Bivalves		Moderately exploited	
Kenya	Octopus	Fully exploited	Over-exploited	Fully exploited
	Sea Cucumbers	Over-exploited	Depleted	
	Bivalves	Fully exploited		
Madagascar	Octopus	Fully exploited	Over-exploited	
	Sea cucumbers	Over-exploited	Depleted	
	Bivalves	Fully exploited	Over-exploited	
Mauritius	Octopus	Moderately exploited		Moderately exploited
	Sea cucumbers	Depleted	Depleted	Fully exploited
Seychelles	Sea cucumbers	Over-exploited		
South Africa	Octopus	Under-exploited	Fully exploited	Moderately exploited
	Bivalves	Fully exploited	Over-exploited	Fully exploited
Tanzania	Octopus	Over-exploited	Depleted	
	Cuttlefish and squid	Fully exploited	Over-exploited	
	Sea cucumbers	Over-exploited	Depleted	
	Bivalves			

KEY: Under-exploited; Moderately exploited; Fully exploited; Over-exploited; Depleted

towards 2040. More merchant ships of 100 Gross Tonnage and over will increase their operations in the region, with the capacity of the fleet expected to increase by over 60 per cent by 2030 (DNV 2012). The majority of the increased shipping will be cargo vessels and oil tankers. Consequently, the concerns about pollution, resulting from day-to-day operational activities and accidents, as well as translocation of invasive alien species through ballast water and hull-fouling, will remain. Various socio-economic concerns continue to prevail under CWS including piracy, the illegal dumping of toxic waste and potential impacts of climate change on shipping and uncontrolled growth in urbanisation and port infrastructure.

Sustainability World Scenario

Implementation of the WIO-SAP has supported the adoption of legislation and development of management tools and training for the domestication and implementation of ICZM and LBSA. The empowerment of inter-ministerial committees and regional task forces strengthened implementation of ICZM or EBM approaches. As a result, the region is arresting ecological disturbance and in some cases has seen the restoration of ecosystems and habitats with high levels of biodiversity and endemism. Thus, the WIO region maintains its value as a 'global refuge' of coastal and marine biodiversity. On-going regional dialogue and implementation of normative frameworks for policy reforms will limit degradation of the coastal and marine environment of the region.

The value of healthy, critical, coastal and marine habitats is secured through the development of tools and methodologies to support their sustainable management and restoration critical coastal and marine habitats. National Plans of Action (NPAs), Integrated Coastal Zone Management (ICZM) plans or National Environmental Management (NEM) plans should be developed by all WIO countries by 2025. Development of tools and skills contributes substantially to the understanding and sustainable management of critical habitats. Importantly, transboundary collaboration and harmonized management within the region, including on-the-ground site-specific management interventions and habitat restoration such as the management of Tana Delta (Kenya), Tanga Coastal Area (Tanzania), and the Zambezi Delta (Mozambique), provide an opportunity to sustain ecosystem health using a "ridge-to-reef" approach, alongside other WIO-SAP interventions.

The WIO region has a very active Coral Reef Task force, that promotes the protection of coral reefs from further degradation by supporting governments to manage marine water quality, pollution, siltation as well as through concerted reef restoration based on lessons-learned from work that begun in 2012 in Cousin Island, Seychelles and in Tanzania. Further work on local, national and regional environmental conservation, maintenance of connectivity corridors through sustainable MPAs, fisheries and coastal management, will all contribute to healthy coral reefs.

Regionally, the Coral Reef Task Force, under the Nairobi Convention, coordinates the Global Coral Reef Monitoring Network (GCRMN) and partnerships through diverse but well-coordinated projects, such as the Indian Ocean Commission's ISLANDS project. It is anticipated that by 2020 all WIO countries will have achieved 10 per cent CBD target of coverage of marine zones under effective management as per the Aichi Target 11 (*By 2020, at least 17 per cent of terrestrial and inland water areas and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscape and seascape*).

Despite an increase in shipping activities in the region, consideration given to management of related environmental risks has been achieved through the strengthening of port and flag state controls. This is being implemented in order to realise the African Union's 2050 Africa's Integrated Maritime (AIM) Strategy of increasing African ownership of ships, but at the same minimising environmental risks. Countries have intensified efforts towards the development of a regional maritime surveillance system and establishment of pollution monitoring and reporting systems. Further efforts targeted the development of a regional approach to the management of ships as vectors of alien and invasive species, as well as mainstreaming of climate change adaptation of the maritime sector.

Adequate capacity to regulate ships, provide them with appropriate maritime services (such as navigational aids) and respond to shipping accidents were built continuously throughout the period 2015 – 2040. The draft Regional Contingency Plan developed under the WIO Marine Highway Project in 2012 was established within the framework of the Emergency Protocol and establishment of a Regional Coordination Centre (RCC) for Marine Pollution Preparedness and Response in the Western Indian Ocean by

2018. All countries in the region, including Somalia, will develop and operationalize National Oil Spill Contingency Plans by 2017 and update them continuously towards 2040 to better serve the region.

USING THE SCENARIOS

How might the WIO 2050 scenarios be used?

The WIO scenarios presented in this chapter can be used by stakeholder throughout the WIO region and beyond. Potential users include conservation managers, regional land-use planners, as well as coastal and flood-defence managers. The analytical approach, discussion document and tools developed as part of the scenarios approach is combined and presented as a 'scenarios gateway'. The WIO coastal scenarios targeted government departments, fisheries organisations, offshore oil and gas operators, coastal engineers, marine biologists, conservationists, regional development agencies and tourist authorities, amongst others. The information and decision-making needs of these stakeholders will determine how they use the futures assessed in this chapter. The various users should employ the scenarios as a starting point of discussions but should draw their own conclusions through elaboration and evaluation in tune with their own needs.

The use of the scenario framework in this chapter must be adaptive and respond accordingly as new challenges, opportunities or threats emerge. The various management and policy platforms of the Nairobi Convention can adopt the scenario framework for engagement between actors. It can also be used to communicate evidence for decision-making and as a tool for medium- and long-term planning and environmental monitoring. This will make the qualitative exploration of trends more participative; draw from the experience of practitioners (policy, science and management practice); and use the scenarios as powerful communication tools.

To achieve the benefits of this approach there's a need for 'champions' of scenario planning at a senior level of stakeholder organisations, in order to attract interest and to stimulate creative thinking. The scenarios could also be instrumental in motivating for monitoring and research programmes. Scenarios provide heuristic frameworks and approaches for addressing uncertainty in climate change impact assessments and supporting research. Research and development for coastal management will thus benefit from robust quantitative assessment of potential outcomes, application of scientific methods combined with consultation as well as effective use of data, simulation methods and expert knowledge.

Options for Policy and Management

As presented in this chapter, there is bound to be varying degree of change, and regional stakeholders will therefore need to adopt policies, strategies and long-term plans to take account of these future changes. Guidelines are needed on dealing with uncertainty in decision-making, risk assessment packages and cost-benefits analysis for stakeholders. This chapter documented a 'scenario gateway' to aid the development and assessment of possible adaptation strategies.

The use of scenarios is new to most regional stakeholders and the state of coast reporting. It is therefore necessary to expand its use within the context of existing programmes, processes and tools developed and adapted for coastal and marine management. This may require provision of a guidance document and appropriate consultative platforms to engage stakeholders in exploring future changes and undertake a constant review of principles of good adaptation strategies based on the scenarios. The documentation and platforms should showcase long-term adaptation case-studies, and interactive tools and methodologies for costing the effects of current decisions/actions, risk-uncertainty and the use of decision-making frameworks. The proposed fora for science-policy engagement could disseminate the scenarios among organisations with responsibilities to manage coastal and marine resources. In this regard, scenarios will highlight the importance of consultation and inter-disciplinary thinking.

The following options emerged from the scenario analysis:

- Application of the principles of good governance within WIO countries but also globally.
- Control and sustainable management of coastal and marine goods and services and other activities in WIO region that have or may have a negative impact on the status of coastal and marine environment. These activities must not compromise uses and activities of future generations nor the capacity of marine ecosystems to respond to changes.
- Improved management and control of pollution in the WIO in order to reduce impacts or risks to human and/or on ecosystem health and/or uses of the ocean.
- Protect and, where practicable, restore the function-

ing of marine ecosystems in order to achieve and maintain good environmental status of these ecosystems.

Managing the Coasts and Oceans- MPA example

Current trends in coastal development, climate change and other pressures are poised to disrupt the functioning of ecosystems and the goods and services they offer. This will have adverse impacts on human interest especially in coastal areas where MPAs are located and human dependencies on marine resources are high. There is need for immediate and substantive actions to increase the adaptive capacity of coastal marine ecosystems and the people that depend on them, especially in relation to MPAs. To do this, SWS indicate that, it will be prudent to address the options for strengthening MPAs in the WIO, as listed in Box 32.3.

Adaptive Management

Adaptive management is an environmental management strategy that attempts to reduce the inherent uncertainty in ecosystems (Green and Garmestani 2012, Garmestani and Harm 2013). Adaptive management operates in an iterative manner, rather than providing discrete conclusions based on science, acknowledging that our understanding of natural systems is constantly evolving (Benson and Garmestani 2011a, 2011b). On the other hand, adaptive governance is a form of governance that is dependent upon adaptive management and incorporates formal institutions, informal groups/networks, and individuals at multiple scales for purposes of collaborative environmental management (Folke and others, 2005). Cosens (2010) notes the broadened understanding of adaptive governance to include not only formal legal frameworks and institutions but also collaboration and cooperation across different levels of government, as well as nongovernmental and individual action.

Refining the WIO Scenarios

An important aspect of the scenario approach is its subsequent and on-going elaboration and quantification. For any scenario to be robust and defensible, it is important to include as much quantitative data as possible. It should be understood that the scenarios must be used beyond numbers as numbers alone may reduce the utility of the scenarios beyond shear sensitivity analysis. Qualitative complementation of quantitative trends normally solves this dilemma, especially since there are clear, highly significant qualitative differences in the pathways and their implications to biophysical processes and human well-being as presented in the state of the coast. It is therefore prudent to build the scenarios with subsequent and continuous refinement for policy and management use. This is a balance that involves seamless and consistent integration of quantification and modelling versus flow and imaginative speculation - something that cannot be achieved with one round of scenario development.

Stakeholder consultation revealed some isolated cases

BOX 32.3. OPTIONS FOR STRENGTHENING MARINE PROTECTED AREA (MPA) MANAGEMENT IN THE WIO

- Create no-take zones (as vital pulse of MPAs) and adjust buffer zones to protect areas of upwelling and nursery habitats that provide high marine productivity and protect areas that are naturally resilient to climate change;
- Implement communication and education programmes for communities, stakeholders (fishers, divers, tourists and tourism operators, developers) to create consensus and an awareness that the issue of coastal environmental change, monitoring and management are complex and require the involvement and cooperation of all stakeholders;
- Limit fishing gear and species-specific catches that are detrimental for sensitive fish species, for species that have major ecological roles or those in competition with alien species;
- Minimize modification of the coastline to retain natural habitats that protect water and species and regulate local climate;
- Identify and reduce impacts and stressors on sensitive species;
- Identify and set up monitoring programmes for sentinel species, climate-sensitive indicators and invasive species, to track changes and inform management decisions. Species monitoring should be integrated within overall coastal environmental quality monitoring; and,
- Understand the impacts on the environment by tourism and global trade activities and what future scenarios may hold. This will require assessments of climate-induced impacts and future scenarios specific to particular MPAs for developing management adaptation strategies.

of scepticism about the precision of some indicators. There was however general agreement on many of the trends, indicators and implications for a shift towards sustainable management of coastal resources in the WIO region towards 2050. To further strengthen the WIO scenarios, the following will be required:

i) Human capacity building and research investment in relevant sectors in order to strengthen the evidence-base for continued futuristic exploration of policy and natural resource management;

ii) On-going identification, refinement and description of major drivers of change in the various sector (such as international markets, social preferences, new legislation, coastal governance) that might necessitate a shift in the trends explored in this chapter; and,

iii) The intermittent assessment of the relationship between the drivers (new and old) and relevant trends in regional and national priority level themes and sectors.

The two selected scenarios enabled wider and deeper consultation and refinement for their development. It was deemed that the conventional four-scenario process could limit the depth of the analyses. The choice of this pair of diametrically-opposed scenarios (Baseline – CWS and Best Case – SWS) may have, by reducing complexity, narrowed down the imaginative thinking. It is therefore recommended that future use of the scenarios should include broadening the understanding of each scenario variant to further explore other pathways within the two chosen scenarios.

The scenarios developed for the WIO State of Coast Report have been primarily a 'scoping exercise' to outline basic but coherent storylines reporting of relevant issues without providing comprehensive quantification. This will be a priority as the scenarios are used and advanced for refinement at a later stage, including their use in integrating engaging science and policy, and for specific issues identified in the report. As more comprehensive and standard indicators are developed, the scenario refinement processes will become apparent, especially as more data becomes available. Stakeholder consultation will also continue and more elaborate additional modelling work may be conducted to improve the present scenario outlines. Specifically the following could be performed to improve the current scenarios:

- Spatial analysis of baseline coastal and marine habitat maps and plausible vulnerabilities under each scenario as linked to climate change, offshore development, maritime development and other drivers of change;
- Refinement of the 'cause and effect' chains and interlinkages between sectors and processes as well as their financial costs and human and ecological benefits;
- Deeper analysis of impacts and opportunities of specific development projects, risks and potential uncertainties under the two scenarios and their variants;
- Indicators of 'where we are now' and possible legal implications of actions or non-actions;
- Improving the development, use and capacity for deploying models/simulations and other scenario-based tools for coastal management decision making; and
- Further research and capacity development on spatial-temporal coastal planning tools (above sea-level, below sea-level as well as offshore).

CONCLUSION

The cross-cutting narratives of the diametrically-opposed scenarios offer valuable insight for the development of regional coastal management strategies, policies and other frameworks. The scenarios will assist with defining the logical implications of following, or not, a particular policy route. They also help to highlight internal conflicts and inconsistencies, for example between the aspirations of different resource users or nations.

Globalisation, including world-trade, is having significant impact on marine ecosystems the need for port facilities and cargo vessels, the ability of non-native species to be transported around the world. Whether local resources are exploited for local use, exported or imported from elsewhere, there will be an ever-increasing demand for ecosystems goods and services, which will in turn cause localised overexploitation, land-based sources and activities that lead to habitat loss, degradation or pollution. Intensity from human use, coupled with climate change, will invariably lead to impacts on marine ecosystems. Planning for the future use of the goods and services offered by the coastal and marine ecosystems will always be influenced or disrupted by unpredictable events, whether in the human environment (eg wars, famines or new discoveries) or in the natural environment (eg rapid climate change and extreme events, tsunamis, disease/pests).

By adopting an exploratory and synthetic approach to the two pathways, uncertainties in future, especially drastic changes or shocks, may demand greater resilience within

the WIO. It will be beneficial to follow plausible future shocks, and integrate anticipatory management actions and policies in response. These include: changing human environment; climatic events; biological and ecological events, major infrastructural developments such as port, oil and gas drilling installations, urban expansion; global socio-economic changes; and other geological and astronomical events such as earthquakes, volcanic activity, tsunamis, cyclones and floods.

There is a need to initiate a scenario based 'Network of Excellence' within future science policy fora of the Nairobi Convention with reference to management of WIO coastal and marine resources, to detail future foresight exercises in various themes, to define the key challenges and risks facing policies, research and development in the WIO region over the coming decades. This will allow more informed anticipation of the management, research and policy needs in various fields, including fisheries and aquaculture, tourism, climate change, energy and others, over the medium and long-terms. The WIO scenarios will also be of use to other national and international fora and processes and conventions.

References

Ausubel, J.H., Crist, D.T. and Waggoner, P.E. (eds.) (2010). *First census of marine life 2010: highlights of a decade of discovery*. Census of Marine Life, Washington, D.C.

Benson, M.H. (2010). Adaptive management approaches by resource management agencies in the United States: implications for energy development in the interior West. *Journal of Energy and Natural Resources Law* 28, 87-118

Benson, M.H. and Garmestani, A.S. (2011a). Can we manage for resilience? The integration of resilience thinking into natural resource management in the United States. *Environ. Manage.* 48, 392-399

Benson, M.H. and Garmestani, A.S. (2011b). Embracing panarchy, building resilience and integrating adaptive management through a rebirth of the National Environmental Policy Act. *J. Environ. Manage.* 92(5), 1420-1427

Cosens, B. (2010). Transboundary river governance in the face of uncertainty: resilience theory and the Columbia River Treaty. *J. Land Resources & Envtl. L.* 30, 229-265

Crooks, S., Herr, D., Tamelander, J., Laffoley, D. and Vandever. J. (2011). Mitigating Climate Change through Restoration and Management of Coastal Wetlands and Near-shore Marine Ecosystems: Challenges and Opportunities. Environment Department Paper No 121. The World Bank, Washington, D.C.

DNV (2012). *Shipping 2020. DNV report: Executive Summary*. Det Norske Veritas Norway. http://www.dnv.com/binaries/1shipping%202020%208%20pages%20summary%202012%2006%2004_tcm4-518883.pdf Accessed on 12 May 2015

FAO-SOSA (2013). *Report of the sixth session of the South West Indian Ocean Fisheries Commission*. Sub-regional Office for Southern Africa. 8-11 October 2012. Flic-en-Flac, Republic of Mauritius

FAO (2008). *Report of the FAO Workshop on Vulnerable Ecosystems and Destructive Fishing in Deep-sea Fisheries*. No 829. Food and Agriculture Organization of the United Nations. FAO, Rome

Folke, C., Hahn, T., Olsson, P. and Norberg, J. (2005). Adaptive governance of social–ecological systems. *Annu. Rev. Environ. Resour.* 30, 441–473

Garmestani, A.S. and Harm, B.M. (2013). A Framework for Resilience-based Governance of Social-Ecological Systems *Ecology and Society* 18(1), 9. http://digitalcommons.unl.edu/usepapapers/201 Accessed on 4 June 2015

Green, O.O. and Garmestani, A.S. (2012). Adaptive management to protect biodiversity: best available science and the Endangered Species Act. *Diversity* 4(2), 164-178

Halpern, B.S., Walbridge, S., Selkoe, K.A., Kappel, C.V., Micheli, F., D'Agrosa, C., Bruno, J.F., Casey, K.S., Ebert, C., Fox, H.E., Fujita, R., Heinemann, D., Lenihan, H.S., Madin, E.M.P., Perry, M.T., Selig, E.R., Spalding, M., Steneck, R. and Watson, R. (2008). A Global Map of Human Impact on Marine Ecosystems. *Science* 319(5865), 948–952

Hammar, L., Ehnberg, J., Mavume, A., Cuamba, B. C. and Molander, S. (2012). Renewable ocean energy in the Western Indian Ocean. Renewable ocean energy in the Western Indian Ocean. *Renew. Sust. Energ. Rev.* 16(7), 4938–4950

IPCC (2013). Annex I: Atlas of Global and Regional Climate Projections. In *Climate Change 2013: The Physical Science Basis*. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (eds. T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley) Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

IPCC (2014). *Climate Change 2014: Mitigation of Climate Change*. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (eds. O. Edenhofer, R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx) Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Jäger, J., Rounsevell, M., Omann, I., Harrison, P., Wesely, J., Pataki, G. and Dunford, R. (2013) *Assessing the robustness of climate adaptation measures in the face of uncertainties*. The CLIMSAVE - Climate Change Integrated Assessment Methodology for Cross-Sectoral Adaptation and Vulnerability in Europe. http://www.climsave.eu/climsave/doc/Report_on_policy_robustness_under_uncertainty.pdf Accessed on 12 April 2015

Jäger, J., Rounsevell, M.D.A., Harrison P.A. Omann, J. Dunford, R. Kammerlander, M. and Pataki, G. (2015). Assessing policy robustness of climate change adaptation measures across sectors and scenarios. *Clim. Change* 128, 395-407

Österblom, H., Merrie, A., Metian, M, Boonstra, W.J., Blenckner, T. and Watson, J.R. (2013). Modeling Social—Ecological Scenarios in Marine Systems. *BioScience* 63(9), 735-74

Rocliffe, S., Peabody, S., Samoilys, M. and Hawkins, J.P. (2014). Towards A Network of Locally Managed Marine Areas (LMMAs) in the Western Indian Ocean. *PLoS ONE* 9(7), e103000

UNEP (2013). *Africa Environment Outlook 3: Health and Environment. Summary for Policy Makers*. UNEP, Nairobi

UNEP, IOC-UNESCO (2009). *An Assessment of Assessments, findings of the Group of Experts. Start-up phase of the Regular Process for Global Reporting and Assessment of the State of the Marine Environment including Socio-economic Aspects*. Summary for Decision Makers. United Nations Environment Programme and Intergovernmental Oceanographic Commission/United Nations Educational Scientific and Cultural Organization. Malta

UNEP/Nairobi Convention Secretariat (2009). *Strategic Action Programme for the Protection of the Coastal and Marine Environment of the Western Indian Ocean from Land-based Sources and Activities*. Nairobi, Kenya



33
Governance: Legal and Institutional Frameworks

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Opposite page: Aerial view of Dar es Salaam and the entrance of the port. © Matthew D. Richmond.

BACKGROUND AND CONTEXT

The Western Indian Ocean (WIO) region, also referred to as Eastern and Southern Africa, region includes the coastal states of Kenya, Mozambique, Somalia, Republic of South Africa and the United Republic of Tanzania on the continental mainland; and the island States of Mauritius, Comoros, France-Reunion, Seychelles, and Madagascar (see Figure 33.1).

The WIO region is recognized globally for its biological richness, and high ecological and socio-economic value. Recognizing this uniqueness, and the threats to the integrity of the coastal and marine environment due to pollution and habitat degradation, the governments of the WIO region, in 1985, signed the Nairobi Convention. This Convention offers a regional legal platform for the protection, management and development of the marine and coastal environment in the Eastern and Southern African region.

The Nairobi Convention framework is one of the many frameworks and institutions of governance in the WIO region. Others include national, regional and global institutions, and regulatory or policy frameworks with a mandate for governance as a practice of trade-offs for shared resources between transnational, national and sub-national institutions and actors. This chapter reviews the various governance frameworks, including the legal, institutional, and regulatory, while the Chapter 34 focuses on policy options for better governance of the coastal and marine environment of the WIO region.

Understanding governance of oceans and coasts

Governance of oceans and coasts is better understood as the process for policy making by competent institutions in a system of negotiation between nested governmental institutions at several levels (international, (supra) national, regional and local) on the one hand and market parties and civil society organizations on the other. Oceans and coastal areas include complex ecosystems with large networks of components that respond to human impacts in a non-linear, uncertain, and unpredictable way (Levin 1999) at all scales, from species to the Earth's subsystems, such as the biosphere and atmosphere. Governance of oceans and coasts is thus about sectorial activities and policy domains, such as fishing, shipping, non-renewable and renewable energy production (oil and gas production), sand extraction, and nature conservation. To realize the sustainable use of marine resources, it requires the cooperation and involvement of market parties, civil society actors and governmental actors at the national and sub-national levels. Consequently, the management of such complex systems requires adaptive governance, which is considered best suited for enhancing institutional synergy to manage the complex dynamics of Earth's social-ecological systems. Centralized governance structures using traditional top-down, "command and control" approaches that do not take social-ecological linkages into account are of limited effectiveness as they are premised on a false assumption of ecological equilibrium. Such

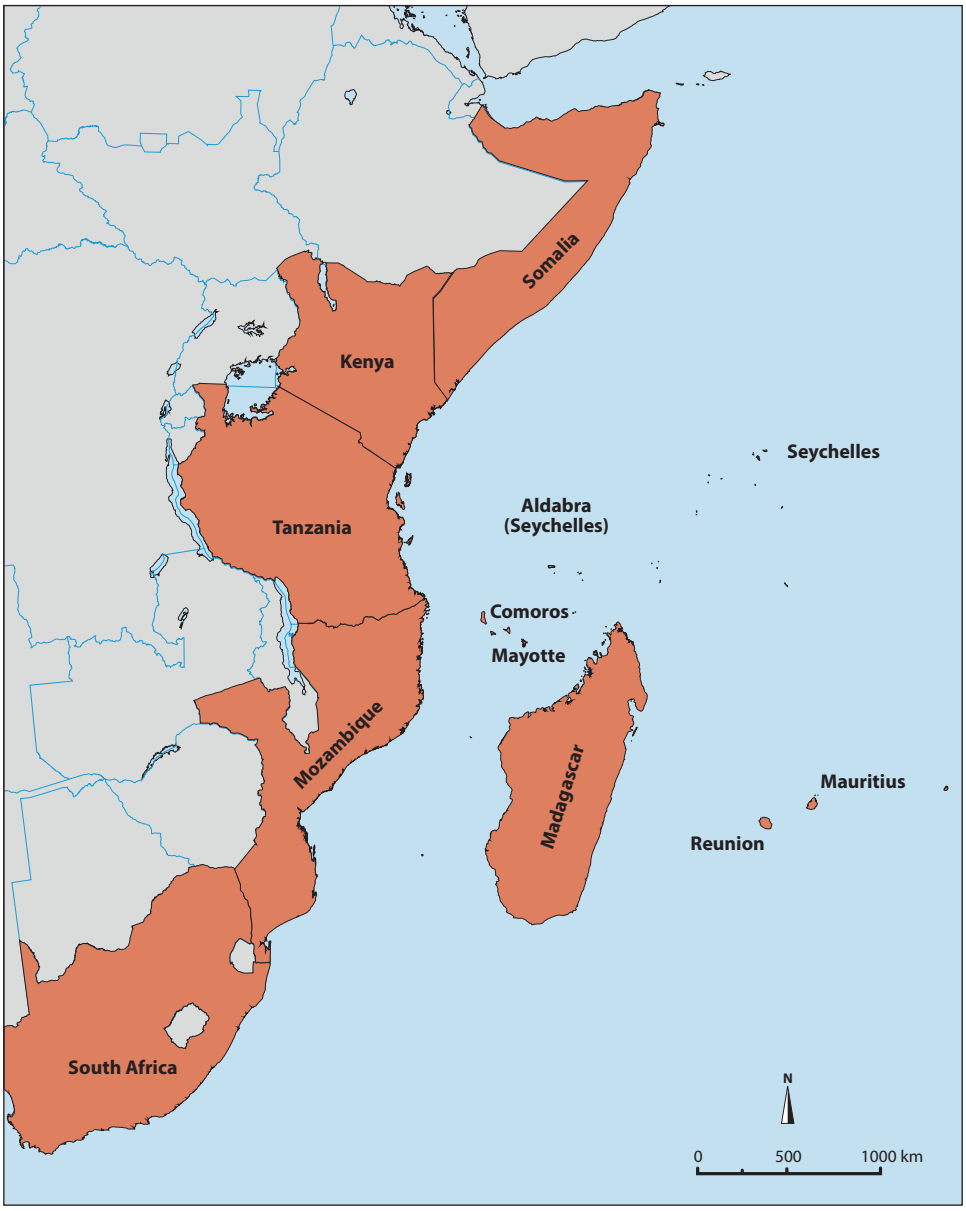


Figure 33.1. The Western Indian Ocean Region.

approaches have resulted in problems with compliance and increased conflict between ocean uses, and in some cases, governance failures.

The regional approach

The regional approach to environmental governance through regional environmental agreements has an advantage over global agreements, as there is greater similarity of interests, norms, perceptions, and values at the regional level that fosters international cooperation. Regional agreements use the conferences of the parties, the highest decision-making authorities of multilateral environmental agreements, to enhance institutional cooperation and coordination. These agreements are managed by secretariats that use information provided by competent international organizations and intergovernmental and non-governmental bodies to influence change and to harmonize policy and legislative frameworks in the regions.

KEY GOVERNANCE CHALLENGES

The major concerns related to environmental integrity in the marine and coastal environment in the WIO are associated with three types of threats, namely, habitat destruction, pollution and weak governance structures. The major pollutant categories responsible for degradation of the coastal and marine environment in the region include

microbial contamination, high suspended solids, chemical pollution, marine litter and eutrophication.

In a study conducted by UNEP/Nairobi Convention Secretariat and WIOMSA (2009a) in the WIO region, under a project to address land-based sources and activities, eight key sectors (urbanization, tourism, agriculture, industry, mining, transportation (including harbours), energy production, and fishing and aquaculture) were found to contribute to environmental degradation. Consequently, effective governance and management of eight key sectors will directly mitigate against habitat destruction and pollution in the region.

Identifying ocean and coasts governance problems

The main problems and issues related to governance of oceans and coasts have, for the most part, been related to the intensifying nature of human interactions with the oceans and coasts and the in-ability of governance institutions to adapt. Governance processes have in the past primarily focused on regulating individual sectors, ignoring interactions between sectors and ocean ecosystems. While governance effectiveness varies, based on institutional architecture, often specific to a given place, socio-political context, legal and policy regime, ignoring interactions among sectors and their combined impacts on the coastal and marine ecosystems, has placed at risk the heritage, livelihoods, and cultures of coastal communities that rely on healthy marine environments.

Major governance weaknesses impinging on the coastal and marine environment of the WIO region have been identified and include policy and legislative inadequacies, limited institutional capacities, inadequate awareness, inadequate financial resources and mechanisms, as well as poor knowledge management (UNEP/Nairobi Convention Secretariat and WIOMSA 2009a).

An analysis of the legal and policy frameworks in many of the countries reveals that there are many policy and legislative gaps. The credibility of the scientific record from knowledgeable science institutions is limited and states are unable to verify or adopt decentralized evidence-based environmental policies, and secondly, institutions empowered to make legal rules and adopt cooperative policies are weak and the coordination with relevant science institutions is poor.

Adaptive governance operates in an iterative manner rather than providing discrete conclusions based on science, acknowledging that our understanding of natural systems is constantly evolving (Benson 2010). Consequently, there is an absence of relevant legislation and policy instruments for key sectors, coupled with weak coordination structures between knowledgeable scientific institutions and legal institution, as well as insufficient updating, implementation, enforcement and monitoring of existing legislations across the countries of the WIO region. Moreover, despite WIO countries being signatories to many international and regional instruments there is inadequate domestication of relevant international commitment and obligations into national laws. With regard to limited institutional capacities, there is apparent lack of mechanisms for effective coordination and inter-sectorial governance among the institutions involved in the governance of the coastal and marine environment. Also there is inadequacy of human and technical resources and capacity in institutions charged with responsibilities over the coastal and marine environment in the countries of the region.

The experience with marine Ecosystem Services Valuation (ESV) is extremely limited in the WIO region. Valuation experience is unevenly distributed across types of marine habitats, ecosystem services and geographic locations, with traditionally more studies assessing values of near-coast provisioning, regulating and cultural (especially recreational) services, such as coral reefs, beaches, fisheries and coastal properties. There are far fewer studies investigating the deep sea or the less well recognized cultural services such as spiritual well-being and heritage. Awareness understanding and appreciation of the economic value of coastal and marine ecosystem goods and services is extremely low. Awareness of ecosystem service valuation is low among policy makers and the limited use of valuation as a management tool among decision makers, legislators, the private sector and civil society, is a major governance concern.

Finally, it is apparent that there is poor knowledge management concerning coastal and marine issues in the WIO region, including inadequate scientific and socio-economic data to support policy making, monitoring and enforcement (UNEP/Nairobi Convention Secretariat and WIOMSA 2009a). All the foregoing problems are severely complicated by the large and diverse stakeholder groups involved, especially at the national level, which often results in incoherent and inefficient management approaches (UNEP/Nairobi Convention Secretariat and WIOMSA 2009a).

Regional institutions for governance of oceans and coasts

Global environmental changes are inherently unpredictable; hence, governing institutions at the regional level and the national level are required to be sufficiently flexible and able to adapt rapidly when necessary to, for example, nonlinear changes. At the same time, institutions must be stable and rigid enough to ensure that humanity stays within the "safe operating space". Further, the globalization of market systems and global environmental change has made it difficult for local or national-level governance systems to manage effectively the threats and pressures placed upon marine ecosystem. Commonly cited institutional gaps in the governance of the coastal and marine environment at the regional/international and national levels include poor coordination and weak legal, institutional and policy frameworks. It is noted that there are only a few regional inter-governmental agreements, however, at the national level there is poor implementation of these agreements, which include non ratification of agreements that are specific to land-based sources and activities (LBSA), sea-based pollution, physical alterations and destruction of habitats, biodiversity conservation and other aspects of the coastal and marine environment. At the national level, absence or limitations in legal and regulatory frameworks, often being fragmented or sectorial as opposed to comprised of integrated legislation, and poor enforcement of legislation, are some of the key governance issues across the region (UNEP/Nairobi Convention Secretariat and WIOMSA 2009a).

On policy frameworks there is apparent absence of coherent regional strategies, as well as lack of awareness and recognition of the economic values of coastal and marine resources, particularly at the policy-making levels.

A UNEP report (UNEP/Nairobi Convention Secretariat and WIOMSA 2009b) identified legal and institutional governance challenges in the region (see below). These are exacerbated by large numbers of stakeholders with diverse needs and interests; and governing their use of the environment without adequate systems in place frequently gives rise to incoherent and inefficient management approaches and efforts. Key generic governance challenges and their effects at national or regional levels are:

• *Inadequate technical capacity* – This constrains drafting, negotiation, ratification and/or implementation of relevant conventions. State legal services are often overstretched, so that conventions are not ratified, and even when ratified, are not adequately implemented. Technical capacity needs to be enhanced through training and participation at technical meetings of relevant conventions (UNEP/Nairobi Convention Secretariat and WIOMSA 2009b).

• *Lack of sufficient financial resources* - Countries provide inadequate financial resources to institutions that govern activities in the oceans and coastal space. Some countries allocate insufficient budgets to the work related to ratification and implementation of the conventions. This undermines the ability to negotiate, ratify or implement conventions and protocols. Some countries are unable to meet their subscription requirements, or are years behind on financial contributions to conventions (UNEP/Nairobi Convention Secretariat and WIOMSA 2009b). Only small budgets are available for operational expenses, so that mandates cannot be dealt with efficiently.

• *Overlapping or uncoordinated institutional mandates* – Regional governments with devolved political systems (eg Comoros, Kenya, South Africa) tend to have several institutions with similar mandates falling under various government layers (eg national, provincial or local) or different departments. Such polycentric governance structures lay emphasis on the need for systems of governance to exist at multiple levels, yet preserve levels of autonomy in each. Coordination is equally a problem in countries with more centralized systems such as Tanzania, Mauritius and Mozambique.

• *Multiple sectors affecting coastal and marine issues* – Sectors and stakeholders include local government/authorities, agriculture, tourism, mining, oil and gas and renewable energy, forestry, fisheries, regional development and transportation. The sectors may compete for space and resources in coastal areas and their management objectives may differ and fall under different authorities. Hence, the coordination of governance objectives is complex, and not easily resolved.

• *Political goodwill and prioritization* – Some governments regard coastal and marine issues as of secondary importance, as reflected in allocations of small budgets and limited technical resources. Few countries (eg South Africa, Tanzania, Mozambique and Kenya) have sought to elaborate integrated coastal zone management (ICZM) policies, whereas an over-arching policy framework is lacking in others (UNEP/Nairobi Convention Secretariat and WIOMSA 2009b). The lack of political good will is also reflected in the low level of public education and aware-

ness of coastal and marine conventions and protocols (UNEP/Nairobi Convention Secretariat and WIOMSA 2009b).

• *Language and legal system constraints* – Mainland states of the WIO are mainly Anglophone, except for Mozambique (Lusophone, whereas island states are all Francophone. In addition, most countries in the region are bilingual, with strong traditional languages such as Swahili or Malagasy. Language, cultural differences and different legal systems complicate negotiations towards agreements, or collective bargaining potential.

• *Multiple regional affiliations* – WIO countries affiliate with different regional economic blocks, such as: Small Island Developing States or SIDS (Comoros, Mauritius, Seychelles); Indian Ocean Commission or IOC (all island states); East Africa Community or EAC (Kenya, Tanzania); Southern Africa Development Community or SADC (South Africa, Mozambique, Mauritius, Tanzania); and Common Market for Eastern and Southern Africa or COMESA (Comoros, Madagascar, Mauritius, Seychelles, Kenya, Tanzania, Mozambique).

Further to the economic blocks, the WIO countries equally subscribe to the Nairobi Convention; the South Western Indian Ocean Commission and the Indian Ocean Tuna Commission. These affiliations come without a common regional approach to tackling coastal and marine environmental and related issues (UNEP/Nairobi Convention Secretariat and WIOMSA 2009b).

• *Political instability* - Political instability can lead to a general breakdown of legal and institutional systems, and can affect participation in regional conventions and protocols (eg, the political situation in Somalia prevents it from participating in regional programmes).

LEGAL AND INSTITUTIONAL FRAMEWORKS

Constitutional Provisions

Environmental or related provisions are included in the constitutions of Kenya, Mozambique, Seychelles and South Africa (UNEP/Nairobi Convention Secretariat and WIOMSA 2009c). For example, Kenya's recently promulgated constitution (2010) fundamentally changed the legal landscape for environmental conservation, management and dispute resolution. The constitution implicitly includes coastal and marine environmental protection, access to environmental justice, and obligations of the state with regard to international legal commitments.

Nevertheless, constitutional provisions are generally not explicit, and specificity and detail is addressed in framework legislation or sectorial laws. Constitutional recognition will arguably raise the profile and effect of environmental legislation, policies and institutions and lead to better protection of environmental resources.

Framework Environmental Laws

All WIO countries have framework legislation and instruments for environment affairs, including coastal and marine environments (UNEP/Nairobi Convention Secretariat and WIOMSA 2009b). Many of these laws are relatively recent enactments, such as the Environmental Management and Coordination Act (EMCA in Kenya, 1999); La Charte de l' Environnement Malagasy (LOI No. 90-033 in Madagascar, 1990); Environment Protection Act and Environment Conservation Act (ECA No. 73 of 1989), National Environmental Management Act (NEMA No. 107 of 1998) and the Marine Living Resources Act (MLRA, No. 18 of 1998) in South Africa; Environmental Management Act (Tanzania, 2004); and the Lei do Ambiente (No 20/97 in Mozambique, 1997). These laws incorporate recent international environmental law principles, such as the "polluter pays" and the "precautionary principle", as well as sustainable development, the establishment of environmental crimes, dispute resolution and avoidance, key institutions and environmental impact assessment (EIA) rules and processes. An important challenge in the region is to align framework legislation, and related instruments, to give more deliberate focus to coastal and marine environmental affairs.

Sector based laws

All the WIO countries have sector-based legislation and regulatory frameworks, including for coastal tourism, forestry including mangroves, manufacturing industry, coastal urban developments, agriculture, fishing, mining, oil and gas, and ports and harbours.

Tourism - Commitments to the tourism sector are located in policy rather than legislative instruments. The most relevant laws are concerned with land tenure, land use and planning (eg the Physical Planning Act [Chapter 286] in Kenya; and the Town and Country Planning Act and Licences Act, in Seychelles). In South Africa, Mozambique, Seychelles, Mauritius, Comoros and Madagascar, land use and planning legislation do not deal directly with tourism, except that tourism infrastructure and development are subject to land use and planning legislation.

Framework legislation in most countries obliges developers of tourist establishments to obtain EIA authorization.

Most national tourism legislation is administered by central government or departments under their control. Legislation tends to encourage development and expansion of tourist activities and infrastructure. No WIO country prohibits tourist developments in its coastal zone, as long as government authorization procedures are followed. Sanctions and penalties are sometimes inadequate, so as not to discourage tourism development – this inconsistency may have longer-term consequences for coastal environments.

Effective enforcement of land-use and planning requires a system of policing or voluntary compliance based on incentives. Currently, local authorities deal with the regulation and policing of environmental standards in most tourist developments - though this system is not always effective. A regional challenge is to guide commercial coastal tourism towards a sustainable regime, using focused legislation, and institutions and policy instruments that are sufficiently sensitive to coastal and marine environmental concerns (UNEP/Nairobi Convention Secretariat and WIOMSA 2009c).

Biodiversity – Relevant legislation and regulatory instruments for the protection of biodiversity are fragmented, sparse and indirect. For example, protection of mangroves is dealt with in framework legislation, where it is treated as part of the natural environment (forests/flora). However, mangroves are also threatened by competing land uses, such as salt works, aquaculture, mariculture and agriculture (UNEP/Nairobi Convention Secretariat and WIOMSA 2009c). Therefore, a legal dilemma might arise when private landowners insist on changing land use at the expense of mangroves or other forests. At present, this would be possible if the area lies outside a designated protected forest or wetland, under direct state control. Better-focused laws and regulatory frameworks are required to protect biodiversity and avoid further deterioration (UNEP/Nairobi Convention Secretariat and WIOMSA 2009c).

Ports and harbours - Legislation dealing with ports, harbours, land reclamation and damming of rivers, and particularly in the case of ports and harbours, is usually explicit. Ports are important in political, military or strategic terms because of the maritime zones claimed by coastal states (UNEP/Nairobi Convention Secretariat and WIOMSA 2009c). Development and expansion of physical infrastructure, port capacity and administrative structures is the focus of port legislation. Port authorities are traditionally state enterprises, acting in national or public interest. There are, however, some weaknesses in terms of environmental impact requirements and enforcement thereof, because both the port authorities and enforcers are public enterprises. Consequently, important coastal and marine environmental issues (such as dredging and port expansion into vulnerable habitats) might not receive requisite attention (UNEP/Nairobi Convention Secretariat and WIOMSA 2009c).

Mining, land reclamation and related sectors - Mining legislation is often extensive and direct, whereas that for land reclamation, irrigation and damming of rivers is less direct. Because there are frequently compelling socio-economic reasons for land reclamation (for example agriculture, development of ports facilities, damming of rivers for irrigation), legislation tends to have weak and inoperative provisions or ineffective enforcement mechanisms. Perhaps the most effective legislation is EIA Regulations, and to a lesser extent, legislation that creates protected areas such as forest reserves, marine national parks and nationally controlled coastal or marine zones (UNEP/Nairobi Convention Secretariat and WIOMSA 2009c).

The Land Reclamation Act 1991 (Cap 106) of Seychelles provides a framework for the authorization of land reclamation, rather than prohibition of reclamation. In Mauritius, sand mining from lagoons is prohibited. In South Africa, prospectors and miners are obliged to undertake environmental restoration programmes (Mineral and Mines Act, 1991, Part VI). Apart from a Minerals Act in Seychelles, there is also a Removal of Sand and Gravel Act (1982) (UNEP/Nairobi Convention Secretariat and WIOMSA 2009c). Recent developments, such as the exploration and discovery of offshore oil and gas reserves, will likely have profound environmental consequences, with major legislative and governance challenges.

Agriculture and manufacturing industry – These sectors can pollute coastal and marine areas by introducing chemical by-products and other wastes. Fortunately, most coastal agriculture is rural and of subsistence level, with fairly low chemical concentrations, while manufacturing is concentrated in urban centres. Agriculture and manufacturing are high-profile socio-economic activities, and the focus of governance is on facilitating development, rather than imposing environmental standards (UNEP/Nairobi Convention Secretariat and WIOMSA 2009c). Most countries have laws, institutions and policy frameworks for agricul-

ture, fisheries and forestry. A challenge is to systematically include best environmental standards and principles in sectorial laws and regulatory frameworks. Adopting the concept of integrated coastal area and river basin management (ICARM) may be a way forward.

Fisheries and marine living organisms - The South Africa Marine Living Resources Act (MLRA), 18 of 1998 (MLRA) provides for the declaration of marine protected areas (MPAs) by the Minister (sect 43). The Minister is empowered to establish such areas in order to protect the marine fauna and flora and the physical features on which they depend, to facilitate fishery management, to provide pristine communities for research; and to diminish any conflict that may arise from competing uses in the area in question, and related matters (sect 43(1) (a) to (c)).

Various "closed areas" have been declared by the Minister under the MLRA, with geographic details of such areas detailed in the regulations. Activities prohibited within MPAs without the requisite permission include fishing, destruction of fauna or flora other than fish, extraction of sand or gravel, depositing of waste or disturbing the natural environment, erecting structures within the MPA, and conducting any activity that adversely impacts on the ecosystems of the area (sect 43(2)(a) to (e)) (UNEP/Nairobi Convention Secretariat and WIOMSA 2009c).

In the Tanzania fisheries sector there is some legislation such as the Fisheries Act 2003; Tanzania Fisheries Research Institute Act 1980; Marine Parks and Reserves Act 1994; and the Deep Sea Fishing Authority Act, 1997. Other national fisheries legislation includes Mozambique's law No 3 of 1990: Licensing and control of fishing industry; and Kenya's Fisheries Act chapter 378 (1991); and Mauritius' 1998 Fisheries Resources Act and the 1998 Marine Resources Act (UNEP/Nairobi Convention Secretariat and WIOMSA 2009c).

Water quality and pollution – Laws and regulatory frameworks directly concerned with water resources include the Seychelles' Public Utilities (Sewage) Regulations 1997, Maritime Zones (Marine Pollution) Regulations, and EPA 1994 (Impact Assessment) Regulations 1981. Laws in South Africa include the Environment Conservation Act 73 of 1989, which deals with pollution control generally; and, the Services Act and the Dumping at Sea Act. In Kenya, the Water Act 2002 has also introduced rules for the protection and preservation of water resources, including subsidiary regulations on water quality and wastewater (UNEP/Nairobi Convention Secretariat and WIOMSA 2009c).

NATIONAL INSTITUTIONS AND OVERSIGHT

The national institutions in most of the countries exist as overseers of the entire spectrum of the national environment, even in fairly decentralized systems such as the Comoros and South Africa. This arrangement sometimes obscures the importance of coastal and marine environments in national resource allocation and priority setting. Consequently, technical personnel and financial means are often insufficient to deal with the myriad of challenges posed by the use of coastal and marine environments – many of which are multi-sectorial and multi-disciplinary. An important challenge is to align institutions to give more deliberate attention to the use of coastal and marine environments. Alternatively, specific institutions to address issues in a more focused manner might be considered.

In Kenya, institutions with mandates on coastal and marine environment management have evolved with time. The Environmental Management and Coordination Act (EMCA, 1999) established the National Environmental and Management Authority (NEMA) to exercise general supervision and co-ordination over environmental matters. EMCA supports a National Environment Council (NEC), and Provincial and District Environment Committees as fora for stakeholder engagement in environmental protection and conservation (GOK: ICZM Action Plan 2010-2014). Other institutions are sector- or resource-specific, for example, the Kenya Forest Service (KFS), State Department of Fisheries and Kenya Marine and Fisheries Research Institute (KMFRI), Kenya Maritime Authority (KMA), Kenya Ports Authority (KPA) and Kenya Wildlife Services (KWS).

The Tanzanian legal system creates several institutions and vests them with a variety of responsibilities and environmental management tasks, through rather scattered legislation. Overlapping jurisdiction in enforcement reduces management efficiency. The Vice Presidential Office is responsible for the environment docket, through the Division of Environment, tasked with development of policy options and coordination of broad-based environmental programmes, including civil involvement in environmental activities, research and monitoring. The National Environment Management Council (NEMC) interacts with relevant sector ministries. All government ministries have an environmental section, for compliance. The Division of Environment, relevant sector ministries and local government authorities, use different laws and instru-

ments. Sector ministries work through the environmental sections established in each ministry while local government authorities are created under local government laws. Meanwhile, district and urban authorities are empowered to control pollution in rivers, streams, watercourses, wells or other water supplies in their areas. Still other regulatory institutions have similar functions under the different laws. Whereas institutions have the opportunity to function cooperatively this is not a legal condition.

In Mozambique, the main public bodies constituting the institutional framework are the Ministry for the Coordination of Environmental Affairs (MICOA), which is the main framework institution; National Directorate of Environmental Impact Evaluation (NDEIE); Centre for Sustainable Development of Coastal Zones; Centre of Sustainable Development of Urban Zones; Centre of Sustainable Development of Natural Resources; and National Institute of Hydrography and Navigation. MICOA is the central organ of the State apparatus (Presidential Decree nº 6/95) which directs and executes the environmental policy, and coordinates use of natural resources. MICOA interacts with various sector institutions, such as maritime administration, fisheries, mining, agriculture and forests, which also have environmental responsibilities (UNEP/Nairobi Convention Secretariat and WIOMSA 2009c).

The primary national environmental institution in Comoros is the Directorate General of the Environment ("La Direction General de l'Environnement, DGE") established under Decree No. 93-115 and elaborated by subsidiary regulation No. 93-20/MDRPE-CAB. The DGE is responsible for the management and implementation of the national environmental policy and action plan, and falls under the Ministry of Production and Environment. The ministry also houses the "Le Service de la Réglementation et du Contrôle (SRC)", which elaborates on environmental legislation and their application, and a national institution for research in agriculture, fisheries and environment ("INRAPE") (UNEP/Nairobi Convention Secretariat and WIOMSA 2009c).

In Madagascar, the most relevant institutions are the Inter Ministerial Committee on Environment; National Council for the Environment; National Committee on Coastal and Marine Affairs; National Committee on Mines and Inter Ministerial Committee on Mining. Others are the National Office for Tourism, Marine Ports Agency, and the Fisheries Surveillance Agency (UNEP/Nairobi Convention Secretariat and WIOMSA 2009c). Moreover, the Ministry of Environment, Water and Forests is responsible for national policy formulation and ensuring general compliance and enforcement. At the local and regional/provincial level, there are corresponding institutions with mandates over their defined geographical territories (UNEP/Nairobi Convention Secretariat and WIOMSA 2009c).

In Mauritius, the Ministry of Environment and National Development Unit (MOE) has overall responsibility for protection of the environment, under the Environment Protection Act. It is supported by the Ministry of Agro-Industry and Fisheries, Mauritius Ports Authority (MPA), and the parastatal Waste Water Management Authority (WMA) operating under the aegis of the Ministry of Public Utilities (UNEP 2009c).

The Seychelles Ministry of Environment and Natural Resources is the parent ministry to several agencies: the Marine Parks Authority; Solid Waste and Cleaning Agency; Seychelles Fishing Authority; Island Development Corporation; and Water and Sewerage Division of the Public Utilities Corporation. The Ministry has several divisions, including pollution control and EIA division; pollution prevention and control; and conservation. The Seychelles Bureau of Standards is responsible for setting standards.

In South Africa, the Department of Environmental Affairs (DEA) administers the Sea-shore Act 21 of 1935, Environment Conservation Act 73 of 1989, and National Environmental Management Act 108 of 1998. Its mandate includes marine pollution and dumping at sea. DEA has a number of vessels and aircraft with which to patrol and enforce laws (UNEP/Nairobi Convention Secretariat and WIOMSA 2009c). The Department of Agriculture, Forestry and Fisheries (DAFF) administers fisheries exploitation according to the Marine Living Resources Act (18 of 1998).

The Marine Traffic Act, Merchant Shipping Act, Marine Pollution (Control and Liability) Act and the Marine Pollution (Prevention of Pollution from Ships) Act fall under the Department of Transport (DoT). A statutory authority, the South African Maritime Safety Authority (SAMSA), deals with maritime navigation, including the maintenance of standards by vessels, including oil tankers (UNEP 2009c). Commercial seaports fall under the National Ports Authority (NPA) and the South African Port Operations (SAPO) (formerly Portnet). The Directorate of Water Quality (Department of Water Affairs) deals with pollution of the marine environment from land-based sources (eg point sources or

seepage). The Mineral and Petroleum Development Act 28 of 2004 pertains to authorizations to mine terrestrially or offshore. The four coastal provinces administer certain legislation through provincial departments.

REGIONAL INSTITUTIONS

African Ministerial Conference on the Environment (AMCEN) - Established 1985, its mandate is to advocate for environmental protection in Africa. AMCEN led the process for the development of the action plan for the Environment Initiative for NEPAD (see below), and endorsed a framework NEPAD Environment Action Plan which commenced in 2002. AMCEN promotes a comprehensive regional report on the state of Africa's environment, the Africa Environment Outlook (AEO). AMCEN facilitated the revision of the 1968 African Convention on the Conservation of Nature and Natural Resources (Algiers Convention). Linkages between AMCEN and the African region's two marine and coastal conventions, namely, the Nairobi Convention and the Abidjan Convention, are being strengthened. The UNEP Regional Office for Africa serves as the AMCEN secretariat.

New Partnership for Africa's Development (NEPAD) - The NEPAD Environment Action Plan proposes four strategic directions: capacity building for environmental management; securing political will to address environmental issues; mobilizing and harmonizing international, regional and national resources, conventions and protocols; and supporting best practice and pilot programs. Priority sectors and cross-cutting issues are combating land degradation, drought and desertification, wetlands, invasive species, marine and coastal resources, cross-border conservation of natural resources, and climate change (UNEP/Nairobi Convention Secretariat and WIOMSA 2009a).

African Ministerial Conference on Water (AMCOW) - AMCOW is a regional inter-governmental response on use and management of water resources for social and economic development and maintenance of African ecosystems. Functions include facilitation of regional and international cooperation through coordination of policies and actions amongst African countries regarding water resource issues; to review and mobilize additional financing for the water sector in Africa; and to provide a mechanism for monitoring the progress of major water resource, supply and sanitation initiatives (UNEP/Nairobi Convention Secretariat and WIOMSA 2009a). The AMCOW institutional set-up consists of a Full Council of Ministers.

REGIONAL ECONOMIC INTEGRATION ORGANIZATIONS

Four main regional economic integration units are relevant to the WIO region: the Southern Africa Development Cooperation (SADC), Common Market for Eastern and Southern Africa (COMESA), Eastern African Community (EAC) and Indian Ocean Commission (IOC) (UNEP/Nairobi Convention Secretariat and WIOMSA 2009a).

Southern African Development Community (SADC) – The objective of SADC (established in 1992, with headquarters in Gaborone, Botswana) is to "achieve development and economic growth, alleviate poverty, enhance the standard and quality of life of the peoples of southern Africa and support the socially disadvantaged through regional integration" (Article 5(1)(a)). In the preamble, member states commit to "coordinate, harmonise, and rationalise their policies and strategies for sustainable development in all areas of human endeavour…" and "agree to co-operate in the areas of natural resources and the environment" (Article 21(3)(e) (UNEP/Nairobi Convention Secretariat and WIOMSA 2009a). The SADC Protocol is the key instrument for transboundary water management, including shared rivers and watercourses. There are currently fifteen members of SADC, six of which are also members of the Nairobi Convention (UNEP/Nairobi Convention Secretariat and WIOMSA 2009a).

Sectorial sub-committees include Environment and Land Management, and Fisheries. There is no sector dedicated specifically to the marine environment but the Fisheries and Shared Water Courses Protocols are relevant to the coastal and marine environment. Similarly, there is no environmental assessment protocol for transboundary pollution and impacts. The Revised Protocol on Shared Water Courses follows from the International Water Courses Convention and encourages the establishment of institutions for all river basins in the region, to manage shared resources sustainably (UNEP/Nairobi Convention Secretariat and WIOMSA 2009a). Specific agreements include the Permanent Joint Technical Commission between Angola and Namibia on the Kunene River Basin; the Limpopo Basin Permanent Technical Committee between Botswana, Mozambique, Zimbabwe and South Africa; and the Incomati Tripartite Committee. In addition, a number of multi- and bi-lateral treaties have been entered into by SADC that include countries of the WIO region (UNEP/Nairobi Convention Secretariat and WIOMSA 2009a).

Common Market for Eastern and Southern Africa (COMESA) - The focus of COMESA is 'economic' integration (recently 'development integration') by 'the attainment of a fully integrated economic community through a combination of trade development and investment promotion and co-ordination'. Of 19 member states, 5 are from the WIO (Seychelles, Mauritius, Madagascar, Kenya and Comoros). Due to its "development" mandate, COMESA is unlikely to play a central role in marine and coastal governance (UNEP/Nairobi Convention Secretariat and WIOMSA 2009a).

East African Community (EAC) - A regional economic integration organization with 5 member states (Kenya, Uganda, Tanzania, Rwanda and Burundi). Environmental aspects (including coastal and marine issues) fall outside its focal area (UNEP/Nairobi Convention Secretariat and WIOMSA 2009a).

Indian Ocean Commission (IOC) – Established in 1984 and comprising of 5 island states (Comoros, Madagascar, Mauritius, Seychelles and French islands of Reunion and Mayotte), its objectives are cooperation in diplomatic, economic, commercial, marine fisheries, agriculture, scientific, technical and cultural fields, and conservation of resources and ecosystems. Inevitably, the principal focus of the five IOC countries is marine fisheries, to which most efforts and development are targeted. Fisheries Partnership Agreements (FPAs) are supported (UNEP/Nairobi Convention Secretariat and WIOMSA 2009a).

REGIONAL AND INTERNATIONAL CIVIL SOCIETY ORGANIZATIONS

Non-state actors often lack traditional forms of political power or authority (legislative and executive). The key skills and resources that non-state actors possess derive from their intellectual, membership, political, and financial bases. More specifically, the different sources of non-state actor power are believed to include knowledge and information (Betsill and Corell 2008, Keck and Sikkink 1999); economic resources and position in the global economy (Falkner 2010, Newell 2000); organizational capacity, transnational networking and mobilization capacity (Falkner 2010); and legitimacy (Gough and Shackley 2001). The governance profile of environmental non-governmental organization (NGOs) stands out as particularly strong on raising awareness and, representing public opinion.

Western Indian Ocean Marine Science Association (WIOMSA) - WIOMSA is a non-governmental and non-profit regional organization for promoting the educational, scientific and technological development of marine science throughout the WIO region (www.wiomsa.org). Among its flagship programmes are the Marine Science for Management programme (MASMA); several marine scientific symposia (notably the WIO Marine Science Symposium); publication of the WIO Journal of Marine Science; and joint initiatives on the Jakarta Mandate for implementation of the 1992 Biodiversity Convention (UNEP/Nairobi Convention Secretariat and WIOMSA 2009a).

Consortium for Conservation of Coastal and Marine Ecosystems in the Western Indian Ocean (WIO-C) – A consortium of existing regional, coastal and marine conservation programmes, to strengthen influence on decision-making processes. The 9 founding members (IUCN, WWF, WIOMSA, CORDIO, WCS, UNEP-Nairobi Convention, IOC, NEPAD, and Inter-Governmental Oceanographic Commission (IOC-UNESCO), are committed to anchor the Consortium in the Nairobi Convention.

The World Conservation Union (IUCN) - The IUCN was established in 1948 and brings together 83 States, 110 government agencies, over 800 non-governmental organizations (NGOs), and some 10,000 scientists and experts from 181 countries in a unique worldwide partnership (www.iucn.org).

The IUCN has played an important role in developing treaties to protect wildlife, and for the conservation of natural resources. It has also undertaken numerous studies and produced many publications or assisted in their development. Its key global contributions include the 1992 Convention on Biodiversity, the World Conservation Strategy which has been published since 1980, and an on-going series of Red Data Books listing endangered species of plants and animals.

The IUCN East African Regional Programme Office (EARO) was established in 1985, and through its ability to galvanise funds from international donors, and to coordinate and manage implementation of programmes and activities, the EARO has contributed to several important interventions in the WIO region. These include advocacy for rare, threatened and endangered species and habitats, as well as education and awareness programmes. Examples are numerous and include the facilitation of the Tanga Coastal Zone Conservation and Development Programme in Tanzania; the Eastern Africa Marine and Coastal Ecosystems Programme; its partnership with other organizations

to implement the Jakarta Mandate for the implementation of the 1992 Biodiversity Convention; its support of the Kisite Marine Park in Kenya; and, its support of Tanzania's Mnazi Bay-Ruvuma Estuary Marine Park and the Moheli Marine Park in the Comoros. In addition, the organization has been assisting the region in the development of marine protected areas (MPAs), and particularly with the production of a 'Toolkit' to help MPA managers find the resource information they need; as well as also working in collaboration with the IUCN World Commission on Protected Areas to introduce the concept of 'assessment of management effectiveness'. All these initiatives have a direct bearing on land-based marine pollution.

World Wide Fund for Nature (WWF)

WWF was established in 1961 and operates in more than 100 countries. It has a global marine and coastal component with several initiatives. These include a dedicated marine programme in WIO Region. The the WWF projects that have specific coastal and/or marine interventions include those in coastal forests in Kenya and Tanzania, on threatened marine turtles and on and climate change. The WWF works in close partnership with the Nairobi Convention and other stakeholders to promote the marine and coastal environment of the WIO region.

GLOBAL INTER-GOVERNMENTAL INSTITUTIONS

United Nations Environment Programme (UNEP) - UNEP is a specialized UN programme with an environmental mandate. Its main role is generally that of a catalyst for action by other institutions or states. It normally undertakes studies on environmental issues, but implementation of projects is undertaken by the UN as a whole, often with the aid of regional governmental or non-governmental organizations and individual states. UNEP's mandate on management of the environment includes the legal and policy regulation of human activities that have any measurable impact on the environment. UNEP has played an influential role in the development of various instruments of environmental law. As early as 1974, UNEP adopted a regional approach to the management and protection of the oceans and seas of the world, which led to the Regional Seas Programmes (RSPs), including the 1985 Nairobi Convention framework for the WIO region.

Although it is an international institution with a global environmental mandate, the location of its physical headquarters in Nairobi makes it a central player at African, regional, and WIO levels. UNEP's key strength is unparalleled, especially in convening on environmental issues within the region and beyond. However, it does not have individual country offices or presence, unlike other UN agencies, detracting from its country-level efficiency.

International Maritime Organization (IMO) - The IMO was established in 1948 to "promote adoption of high standards in maritime safety, navigation efficiency and prevention and control of marine pollution from ships." IMO's framework of conventions and soft law instruments do not establish any international enforcement or regulatory authority for coastal and marine environments. Much of the responsibilities and obligations defined in these instruments devolve to coastal, flag and port states. Kenya, Mozambique and Tanzania fit into at least two of the foregoing categories. The Eastern Africa regional office in Nairobi deals with vessel-based pollution, maritime safety and ports in the region.

The Food and Agriculture Organization (FAO) - Established by the 1943 UN Conference on Food and Agriculture, the FAO is a specialized agency dealing with the sustainability, monitoring and improvement of agriculture and fisheries production on a global scale. It gathers and analyses production figures, and disseminates statistics, promotes international action with respect to research and management (for example the SWIO Commission) and supports resource use education and administration. FAO has also promoted international environmental law making (Birnie and Boyle 2009) and was involved in the development of the 1958 Convention on Fishing and Conservation of the Living Resources of the High Seas, the 1993 Agreement to Promote Compliance with Conservation Measures on the High Seas, the 1995 Code of Conduct for Responsible Fisheries and the Agreement on Straddling and Highly Migratory Fish Stocks. In collaboration with UNEP, it developed the 1998 Rotterdam PIC Convention.

Inter-Governmental Oceanographic Commission of the United Nation Educational, Scientific and Cultural Organization (UNESCO-IOC) - Provides scientific advice based on research, a "diversity of knowledge and expertise," and an independent source of publicly accessible information. UNESCO-IOC is active in marine scientific research projects and has increasingly involved developing countries in joint research. Usually UNESCO-IOC conducts research at the regional level through inter-governmental commissions such as those dealing with land-based pollution, pol-

lution from dumping, and fisheries. The research organization is visible and active in the WIO region. UNESCO was responsible for the adoption of, and performs secretariat functions, for the 1971 Ramsar Convention and the 1972 World Heritage Convention.

UN Development Programme (UNDP) - A specialized UN agency with a mandate to advance socio-economic development. Unlike the UNEP, it has individual country presence, and has offices in the countries of the WIO region. It is therefore visible and arguably influential, especially in socio-economic spheres. Its involvement in the WIO region is as the principal channel of multilateral, technical and investment assistance to developing countries. This includes environmental programmes, such as the Global Environmental Facility (GEF), which makes funds available to developing countries, and supports capacity-building.

GOVERNANCE RESPONSES AND INTERVENTIONS

Numerous national, regional and global institutions, laws and conventions operate in the WIO region, often with overlapping mandates, and all too often in an uncoordinated manner. Although multiple organs and levels might have been expected, given the complexity of human interactions with the environment (ie, many countries, cultures, resources, and interests), they give rise to inefficient use of governance instruments and resources. A common characteristic of national legislation is that they are scattered and fragmented across sectorial disciplines. This is in line with a sector-based approach to governance of public affairs, which has prevailed over the decades, and accounts for apparent overlaps, duplications and contradictions in national legislation and institutional frameworks.

Nevertheless, legal, institutional and policy responses appear to have been characteristically similar, both acknowledging that many anthropogenic activities causing coastal and marine pollution and degradation stem from legitimate socio-economic activities, and that these activities have environmental consequences that need to be regulated. At national level, there appears to be a dilemma regarding appropriate legal, institutional and policy responses. Some national legislation merely facilitates rational exploitation, while giving environmental considerations short shrift. In some cases, there is only peripheral legislation (for example tourism) while substantive legislation is absent, or reliant on general land use and planning legislation. In yet other cases, laws adopt a "command and control" approach rather than an integrated or participatory approach, which encourages voluntary compliance with incentives instead of prohibitions and penalties. Many of the legal instruments reviewed appear to play a regulatory role to facilitate orderly and rational access and utilisation of coastal and marine resources without degrading the environment. WIO countries have at least some form of EIA regulation, whether in the respective national framework or sector legislation or in subsidiary legislation or decrees. The evolving ICZM laws and policies are more participatory, and may bring a future paradigm shift.

References

Benson, M.H. (2010). Adaptive management approaches by resource management agencies in the United States: implications for energy development in the interior West. *Journal of Energy and Natural Resources Law* 28, 87-118

Betsill, M. and Corell, E. (eds.) (2008). *NGO diplomacy: The influence of nongovernmental organizations in international environmental negotiations*. MIT Press, Cambridge

Birnie, P., Boyle, A. and Redgewell, C. (2009). *International law and the environment*. 3rd edition. Oxford University Press.

Falkner, R. (2010). Business and global climate governance: A neo-pluralist perspective. In *Business and global governance*. (eds. M. Ougaard and A. Leander) pp. 99–117. Routledge, London

Gough, C. and Shackley, S. (2001). The respectable politics of climate change: The epistemic communities and NGOs. *International Affairs* 77(2), 329–346

Keck, M. and Sikkink, K. (1999). Transnational advocacy networks in international and regional politics. *Int. Soc. Sci. J.* 51(159), 89–101

Levin, S.A. (1999). *Fragile dominion: Complexity and the commons*. Perseus Books, Reading

Newell, P. (2000). *Climate for change: Non-state actors and the*

global politics of the greenhouse. Cambridge University Press, Cambridge

UNEP/Nairobi Convention Secretariat and WIOMSA (2009a). *Transboundary diagnostic analysis of land-based sources and activities affecting the Western Indian Ocean coastal and marine environment*. UNEP. Nairobi, Kenya

UNEP/Nairobi Convention Secretariat and WIOMSA (2009b). *Regional Synthesis Report on the Status of Ratification of International Conventions related to Land Based Sources and Activities in the Western Indian Ocean (WIO) Region*. UNEP. Nairobi, Kenya

UNEP/Nairobi Convention Secretariat and WIOMSA (2009c). *Regional review of policy, legal and institutional frameworks for addressing land-based sources and activities in the Western Indian Ocean region*. UNEP. Nairobi, Kenya

UNEP/Nairobi Convention Secretariat and WIOMSA (2009d). *Strategic Action Programme for the Protection of the Coastal and Marine Environment of the Western Indian Ocean from Land Based Sources and Activities*. Nairobi, Kenya 156 pp.


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Policy Analysis and Options

Akunga Momanyi

Opposite page: Opening a trench for electric cables in the coast of Zanzibar. © Matthew D. Richmond.

OVERVIEW OF NATIONAL POLICY FRAMEWORKS

In most, if not all, of the countries in the western Indian Ocean (WIO) region, there are established or evolving public policy frameworks that anchor or support the legal, institutional and other governance frameworks. For example, there is an evolving integrated coastal zone and river basin management policy framework for Kenya, while integrated coastal zone management (ICZM) policies and institutional regimes exist in Mozambique, Mauritius, Tanzania, and South Africa. Moreover, there are developments in that direction in the other countries of the region, as described in the following sections.

An important challenge facing the countries of the region is the need to align their framework policy instruments so as to give more deliberate attention to the coastal and marine environment. Alternatively, the countries should consider specific consolidated policies to address these issues in a more concerted, focused and sustainable manner. Either way, new or evolving policy instruments at the national level need to be as closely aligned to the Nairobi Convention framework as possible. It is interesting that, with the exception of the four countries mentioned above, none of the other WIO countries at present have specific policy instruments on the coastal and marine environment.

NATIONAL POLICY FRAMEWORKS

Kenya

The Draft National Environment Policy (2012) aligns sectorial policy with the Environmental Management and Coordination Act (EMCA). It is a framework for integrating environmental considerations into sectorial policies, development plans and decision-making processes and for regional and international cooperation in environmental management. It calls for sustainable management of terrestrial and aquatic resources to improve the livelihoods and raise the standard of living for coastal communities.

The National Oceans and Fisheries Policy (2008) is rooted in the provisions of the 1982 UN Convention on the Law of the Sea, the Maritime Zones Act (1989) Section 5, and the Presidential Proclamation of June 2005. It affirms Kenya's sovereignty over the exploration, exploitation, conservation and management of ocean resources and focuses on resource management in territorial waters and the Exclusive Economic Zone (EEZ). It addresses most aspects of fisheries management and development, including environmental conservation, regional cooperation, research, surveillance and monitoring, social responsibility and governance. The preparation of specific fishery management plans is given high priority, but certain regulations need to be adopted to allow these plans to be effective (Samoilys and others, 2011). This policy and the ICZM Action Plan have similar objectives and should be harmonized to avoid duplication.

The Draft Wetland Policy (2009) recognizes the economic importance of coastal, marine and inland wetlands

and proposes stringent measures to counter the (primarily human) threat to their long-term sustainability. Its integrated approach complements other sector policies and fulfils Kenya's obligations under the Ramsar Convention and other multilateral environmental agreements and protocols. Education on the importance of wetlands, a greater consultative process with civil society and political goodwill should pave the way for adoption of this policy. However, no clear legal framework governs wetland conservation and management, and different aspects of the Policy are handled by Kenya Wildlife Service (KWS), Kenya Forest Service (KFS), National Environment Management Authority (NEMA), the Fisheries Department, water sector institutions, regional development authorities and communities.

The National Land Policy (2009) underpins a system of land administration and management that allows all citizens to gain access to land and to use it. It calls for the equitable and environmentally sustainable use of land resources and requires policies, regulations and laws to be aligned with the EMCA. Its guidelines for formulating land use and management practices take into account the fragile nature of the coastal zone. Land use has major implications for the marine and coastal environment, thus reform in land tenure is imperative for achieving the ICZM Action Plan's objectives.

The Regional Development Authorities Policy (2007) calls for equitable socio-economic development through the sustainable use of natural resources by:

- Formulating integrated regional development plans in consultation with all those involved;
- Closing gaps in regional resource mapping; and,
- Attracting resource-based investment that benefits communities.

The policy is the framework for streamlining and strengthening the Coast Development Authority (CDA) and the Tana and Athi River Development Authority (TARDA) in coastal zone development and management. However, equitable allocation of government funds to socio-economic development in the new era of devolution is questionable, particularly in the case of marine fisheries. An assessment of the immediate development needs of marine fisheries is called for.

With regard to poverty-reduction policies and strategies, the government acknowledges the role that the environment plays in spurring economic growth and reducing poverty. This is recognized in the National Poverty Reduction Plan (1999–2015), the Poverty Reduction Strategy Paper (launched in 2001) and currently Kenya's over-arching policy framework, Vision 2030, which cites environmental degradation as a cause of poverty and argues for better environmental protection. Moreover, and of relevance to the coastal zone, the Draft Forest Policy (2012) calls for, among others, the sustainable use, conservation and management of forests and trees; sustainable land use through soil, water and biodiversity conservation; and the participation of the private sector, communities and others in forest management to conserve water catchment areas and create employment.

Finally, Kenya has an evolving Integrated Coastal Zone Management (ICZM) Policy, partly in acknowledgement of the numerous statutes relating to the conservation of the coastal zone that can result in duplication, overlap, inconsistency and ineffectual penalties. Although the EMCA (introduced above) prevails in cases where sectorial policies conflict, its effective implementation requires that statutes and financial and technical support be harmonized.

The ICZM Policy brings together all those involved in the development, management and use of the coastal zone within a framework that facilitates the coordination and integration of activities and decision-making processes. The ICZM Action Plan (2010–2014) was a first for Kenya, seeking to protect fragile ecosystems while pursuing sustainable development. Its thematic areas are integrated planning and coordination; sustainable economic development; conservation of coastal and marine environment; environmental risks and management of shoreline change; capacity building, information and public participation; and implementation through institutional and legal frameworks (UNEP/Nairobi Convention Secretariat and WIOMSA 2009a).

Mozambique

The National Strategy for Sustainable Development derives from the 2002 World Summit for Sustainable Development and integrates recommendations from the Johannesburg Plan of Implementation into the national agenda. It is an important national initiative rooted in local knowledge, local ideas, local expertise and local solutions. The priority areas are biodiversity conservation, land degradation, health, education, agriculture, water, energy and technology transfer. The National Council for Sustainable Development and the Council of Ministers are responsible for its implementation. Once approved, it will be incorpo-

rated into all sectorial plans.

The National Environmental Policy is the principal planning instrument for the environment sector. It calls on the state to provide incentives for the sustainable use of natural resources. It integrates environmental issues into economic planning, recognizes the role of the communities in environmental management and monitoring, and acknowledges a role for the private sector in managing the environment. It also defines the strategy that provides the framework for the Ministry for Coordination of Environmental Affairs (MICOA) and recommends multi-sectorial coordination.

The Strategic Plan for the Environmental Sector (2005–2015) combines nine instruments: the Action Plan for the Fight against Drought and Desertification; the Strategy for Urban Environment Management; the Coastal Zone Management Strategy; the Strategy and Action Plan Controlling the Fight against Soil Erosion; and, the Strategy to Combat Deforestation and Burning. Others are the Urban Solid Wastes Integrated Management Strategy; the Hazardous Wastes Management Strategy; the Biodiversity Strategy; and, the Action Plan for Biodiversity Conservation. Its priority areas are biodiversity conservation, land degradation, health, education, agriculture, water, energy and technology transfer.

There are 15 policy instruments relevant to environmental management, though not restricted to coastal areas. These are the National Action Plan to Combat Desertification and Drought; the National Forests and Wildlife Policy and Strategy; the National Tourism Policy and Strategy; the National Fisheries Policy; the National Land Policy; the Agrarian Policy; the National Water Policy; and the Strategy and Action Plan for Biodiversity Conservation in Mozambique. Others are the Energy Policy and Strategy (1998); the National Environmental Policy (1995); the Policy for Disaster Management (1999); the National Policy for Land Use Planning (1996); the National Action Program for Adaption to Climate Change; the Policy (1996) and Strategy (2006) for Meteorology Development; and the Conservation Policy and Implementation Strategy (2009) (UNEP/Nairobi Convention Secretariat and WIOMSA 2009a).

Tanzania

In Tanzania, the National Environment Policy (1997) provides the framework for introducing environmental considerations into the mainstream of decision-making. It stresses the importance of formulating legislation for effective and comprehensive environmental management. Its objectives are to:

- Achieve sustainability, security and equitable resource use to meet the needs of present and future generations without degrading the environment or risking health and safety;
- Prevent and control the degradation of land, water, vegetation and air to conserve and enhance natural and manmade heritage, including the biological diversity of unique ecosystems;
- Improve the condition and productivity of degraded areas, including rural and urban settlements;

Raise public understanding and community participation in the connection between environment and development; and,

- Promote international cooperation on the environmental agenda.

Other policies and instruments guiding environmental management are the National Forest Policy (1998); the Forest Action Plan (1990/91 – 2007/08); the Management Plan for the Mangrove Ecosystem in Tanzania (1991); the Agricultural and Livestock Policy (1997); the National Tourism Policy (1991) (reviewed 1996), and the Integrated Tourism Master Plan (1996–2005). Additional ones are the National Fisheries Sector Policy (1997), the Draft Investment and EIA Guidelines for Marine Parks and Reserves in Tanzania and the 2001 Mariculture Development Guidelines; the National Land Policy (1995), town and city master plans; district and village land-use plans; the Wildlife Policy of Tanzania (1998); and, the Sustainable Industrial Development Policy (1996).

Policies and regulatory instruments related to ICZM include the National Integrated Coastal Environment Management Strategy; the National Steering Committee on Integrated Coastal Management; the Integrated Coastal Management Unit; inter-sectorial working groups; the development of a climate change adaptation strategy; and several ICZM projects. In Zanzibar, the National Environmental Policy (2013) outlines the conservation and protection of environmental resources and an ICZM plan (even though there is no specific ICZM legislation).

Comoros

For the Comoros, a National Policy, an Environmental Action Plan and Environmental Strategy were elaborated in 1993. The basic principles and objectives of the National

Policy on the Environment may be summarized as follows:

- To ensure a rational and sustainable management of resources;
- To define or reinforce sectorial policies;
- To safeguard and protect the biological diversity and zones with ecological or cultural interests;
- To develop or promote environmental knowledge and awareness; and
- To put in place appropriate mechanisms for the management of marine and coastal areas by elaborating a development policy aimed at ensuring the protection of the coastal area, taking into account its tourist potential; rational management and exploitation of marine resources, and the control and regulation of pollution in marine and coastal areas.

The Environment Action Plan of Comoros (1993) includes the study of marine and coastal ecosystems; improvement of legislative and regulatory mechanisms; protection and development of biodiversity; alleviation of pressure on natural resources; and collection and treatment of household garbage/ domestic waste (Decree N°93-214/ PR of December 31 1993).

The National Policy and Action Plan on Environment exists but unfortunately the institutional structures charged with the responsibility of execution/implementation have some limitations, such as on human resources, technical and financial capabilities. The main limitations are essentially as follows:

- Inadequate personnel at the Directorate General of the Environment since it was instituted in 1993;
- Extent and complexity of problems that require resolving before implementation;
- Weak legal and regulatory systems;
- Weak and inefficient institutions;
- Low level of education and knowledge of actors in various environmental disciplines;
- Insufficiency in communication, information and sensitization between government and public entities on one hand and the population on the other; and,
- Constant and regular mobility or turnover of managers and directors in the administration of the environment (UNEP/Nairobi Convention Secretariat and WIOMSA 2009a).

Madagascar

Madagascar has a policy on the protection, management and measures against pollution. The Government, under the coordination of the Ministry of Environment, Waters and Forests, created the Steering Committee for the implementation of the policy in collaboration with financial partners, other concerned ministries and departments, and the executing agencies of the National Environment Plan.

However, the regulatory structures are less known, indeed absent in the policies on the protection of the environment in Madagascar. The existing structures that could respond meaningfully are the Environmental Mediators provided for by the Decree n°2000-028 of 14 February 2000. Nevertheless, to be more effective regarding protection of the environment, the role of the Environmental Mediators must be expanded to include management activities, to fight pollution of the environment, and in particular the marine and coastal environment (UNEP/Nairobi Convention Secretariat and WIOMSA 2009a).

Mauritius

Mauritius's first National Environmental Strategy and Action Plan (NEAP) was prepared in 1988 and the second NEAP was prepared in 1999, covering the period between 1999 and 2010. The NEAP 2 report represented an environmental diagnosis of the Republic of Mauritius, assessing the pressures and their subsequent impacts on the environment. The NEAP 2 sought to set the principles of sustainable development by providing environmental services, encouraging responsible environmental practices and enforcing appropriate environmental standards in order to conserve the heritage, safeguard health and welfare, and enhance the quality of life of all Mauritians.

The NEAP identified inadequate disposal of urban wastewater as a growing threat to the quality of groundwater, the principal source of domestic water supply of the country, as well as to marine and coastal zone ecosystems. As a follow up of the NEAP recommendations, the Government launched the Sewerage Master Plan (SMP) Study covering a period of 20 years. Completed in 1994, it identified the technical, institutional, legislative and financial constraints. The National Sewerage Program (NSP) was prepared, comprising priority projects to be implemented over the following decade.

In Mauritius, policy instruments incorporate key environmental principles, including "polluter pays" and "precautionary principles". Transparency, accountability and good governance practices are cornerstones of environmental policies, combined with strengthened joint public, private and community sector participation.

Other key policy instruments in Mauritius include the National Development Strategy (NDS) 2003, the National Biodiversity Strategy and Action Plan (NBSAP) 2006-2015, the National Environment Policy (NEP) 2006 and the Vision 2020 Tourism Strategic Plan (UNEP/Nairobi Convention Secretariat and WIOMSA 2009a).

Seychelles

In the Seychelles, the main policy document relating to the protection of the environment is the Environmental Management Plan of Seychelles (EMPS) 2000-2010. It aimed for the protection of the environment to be undertaken in a planned and coherent manner involving all stakeholders. One of the guiding principles of the EMPS was fulfilling international and regional environmental responsibilities pertaining to environmental management. The guiding principles of the EMPS include the following:

- Honouring and pursuing the Constitution of Seychelles, particularly Article 38 which states that it is the right of every person to live in and enjoy a clean, healthy and ecologically balanced environment;
- Integrating, developing and pursuing the provisions of Agenda 21 into its national environmental management plans and programmes in order to strengthen Seychelles' commitment to Agenda 21 and compliance with its principles;
- Maintaining and managing conservatively the diversity, health and productivity of Seychelles' ecosystems in order to safeguard its basic ecological integrity; and,
- Controlling and minimising pollution, particularly of coastal and marine waters to reduce negative impacts to receiving ecosystems.

Ten thematic areas were included to cover all major social and economic sectors as well as certain key subjects of relevance to environmental management such as environmental economics. The thematic areas include Land Use, Coastal Zones and Urbanisation; Biodiversity, Forestry and Agriculture; Energy and Transport; Water, Sanitisation and Waste; Tourism and Aesthetics; Environmental Economics, Mainstreaming and Sustainable Financing; Regulatory, Policy and Institutional Mechanisms; and, Commerce, Industry and Production. The Plan also covers cross-cutting themes such as education, awareness and advocacy; partnerships, public consultation and civil society participation; training and capacity building; management; science, research and technology; monitoring and assessment; and vulnerability and global climate change. Programmes were proposed for the thematic areas.

The EMPS 2000-2010 seeks to integrate environmental issues into all development sectors, though it lacks the profile and institutional backing of previous EMPS. Furthermore, it was originally prepared with the expectation of major programme funding which never occurred. Implementation currently depends on the available programme budgets of the Government and the initiatives of non-governmental organizations in finding funding for biodiversity projects.

The National Biodiversity Strategy and Action Plan (NBSAP) was prepared in 1997 pursuant to Article 6 of the Convention on Biological Diversity (CBD), which requires all contracting Parties to "develop national strategies, plans or programs for the conservation and sustainable use of biological diversity." The NBSAP summarised the descriptive data and information in the Biodiversity Assessment and identified the country's vision for biodiversity and its objectives, needs and gaps and the actions required to bridge the gaps. It provided a timetable for action over a plan period of 5 years (1997-2003). Issues common to both the NBSAP and the EMPS include sustainable management of marine resources including coral reefs as well as capacity building for assessing, monitoring and forecasting.

The Seychelles Plan *d'Aménagement du Territoire* or National Land Use Plan, finalised in 1993, is the primary guide to land use decision-making by the Town and Country Planning Authority. It covers only the three main islands of Mahé, Praslin and La Digue. The plan provides a guide for land uses in sensitive and protected areas, though it is an advisory document without legally-binding status. Several reviews have noted that the scarcity of level land has created competition for land and pressure for land reclamation along the shoreline. The EMPS states that "the lack of planning, zoning and integrated management of government land leads to *ad hoc* land and water development, resulting in pollution, erosion and conflicting uses." It recommends "better integration of land use planning and environment through updating the National Land Use Plan and cross-linking it with EMPS; and updating and better implementation of the Town and Country Planning Act 1972 and the Environment Protection Act 1994, with cross-referencing to MENR legislation and EMPS."

In spite of the Town and Country Planning Act 1972, the land use plans only seem to be used as planning instruments on an *ad-hoc* basis and plans are not followed through with detailed land use/development plans. Inappropriate

land use has occurred throughout the island, leading to deforestation, erosion, pollution and aesthetic problems, especially in the coastal zones.

The land use planning system in Seychelles is apparently in urgent need of reform to provide a professional basis for transparent land use decision making that separates technical planning from political decision making, and that places an emphasis on ensuring effective long-range plans are established and used to guide approvals for individual developments. There is a need to legalise the National Land Use Plan.

The other major policy document is the Solid Waste Master Plan which includes incineration, storage, and disposal of hazardous and medical waste. This minimises the movement of waste and disposal at source (UNEP/Nairobi Convention Secretariat and WIOMSA 2009a).

South Africa

An extensive public participation process known as the Consultative National Environmental Policy Process (CONNEPP) was carried out relatively soon after the birth of South Africa's post-apartheid Constitution which culminated in the *White Paper on an Environmental Management Policy for South Africa* (N/749 in *Government Gazette* No. 18894 dated 15 May 1998) ("White Paper on Environmental Management"). This in turn led to development and enactment of the National Environmental Management Act No 107 of 1998 (NEMA).

Two important general features underpin the White Paper on Environmental Management and thus the NEMA: the notion of "sustainable development" and the specific endorsement of the definition and analysis offered by the 1987 Brundtland Report; and secondly, it reflects the sentiments behind the transition to democracy and its socio-economic implications.

An altogether separate policy process was initiated soon after with respect to the coastal zone. This started in 1997 and was firstly underpinned by a discussion document titled *Our Coast Our Future: Coastal Policy Green Paper: Towards Sustainable Coastal Development in South Africa*, Department of Environmental Affairs and Tourism September 1998 (the "Green Paper"). This Coastal Policy Green Paper formed the basis of an extensive public consultation process in which all interested and affected parties were invited to comment. These were collated and condensed to produce the *White Paper for Sustainable Coastal Development in South Africa* which was promulgated in 2000.

The Coastal Policy White Paper in turn led to the preparation and finalization of the Integrated Coastal Zone Management Act No 24 of 2008 which came into effect in 2009. The Act plays a pivotal role in improving the management of the coastal zone of South Africa (UNEP/Nairobi Convention Secretariat and WIOMSA 2009a).

GLOBAL AND REGIONAL POLICY INSTRUMENTS

Montreal Guidelines

After the 1982 UNCLOS was adopted, the Montreal Guidelines for the Protection of the Marine Environment against Pollution from Land-based Sources were prepared by an expert group under the auspices of UNEP and adopted by its Governing Council in 1984. These Guidelines represented the first attempt to address the problem of land-based pollution at a global level (UNEP/Nairobi Convention Secretariat and WIOMSA 2009b).

Agenda 21

One of the documents adopted at the 1992 Rio Summit was Agenda 21. Chapter 17 on the marine environment includes some key elements, emphasizing the focus on sustainable development and an integrated approach to the protection and preservation of the marine environment. Although Agenda 21 is a 'soft' law or policy instrument and not a 'hard' convention, many of its provisions have laid the foundation for incorporation in subsequent 'hard' law as evidenced by a number of multilateral environmental agreements (MEAs) entered into over the last twenty years (UNEP/Nairobi Convention Secretariat and WIOMSA 2009b).

Washington Declaration and Global Programme of Action

In 1995, at an inter-governmental conference in Washington, United States, dealing specifically with land-based marine pollution, two key documents were adopted: the Washington Declaration on the Protection of the Marine Environment from Land-based Activities, and the Global Programme of Action (GPA). The latter is a 'soft' law agreement or policy instrument reflecting the resolve of nations to address the impacts of land-based sources and activities (LBSA) and physical degradation of the coastal and marine environments. As such, it is an action-oriented programme with the over-arching goal to address the negative effects of land-based activities. Though it has a coordination office

based in the Netherlands, it is not an international institution. Rather, it is an inter-governmental programme that addresses the inter-linkages between freshwater and the coastal environment and has a close working relationship with the UNEP Regional Seas Programme (RSP). Chapter 2 of the GPA (paras. 29 to 35) sets out its objectives which include the strengthening of regional cooperation agreements, such as the Nairobi Convention, and where necessary to create new ones to support effective action, strategies and programmes (GPA 1995).

The GPA has identified at least nine pollutant or source nodes across most of the UNEP's RSPs, including the WIO region. These include municipal wastewater, heavy metals, litter, nutrients, oil, physical alterations and destruction of habitats (PADH), sediment mobilization and persistent organic pollutants (POPs) (UNEP/Nairobi Convention Secretariat and WIOMSA 2009b).

World Summit on Sustainable Development and Johannesburg Plan of Implementation

The third significant development was the 2002 World Summit on Sustainable Development (WSSD) held in Johannesburg. This adopted the Johannesburg Plan of Implementation (JPOI) which included provisions dealing with oceans, coasts and islands (Recommendations 30-36). It also endorsed the provisions of Agenda 21 and reiterated the importance of sustainable use and management of the marine environment in reducing poverty and achieving the goals of sustainable development (eg UN 2015). Furthermore, the JPOI specifically endorsed the GPA.

Rio+20

The issues and commitments under Agenda 21 and JPOI were revisited during the Rio +20 conference held in Rio de Janeiro in 2012 to mark 20 years since the 1982 Rio Summit. Some of the outcomes of the Rio+20 directly affect the governance of coastal and marine environments, including that of the WIO region.

CHALLENGES AND GAPS, INCLUDING KEY ISSUES FOR POLICY IMPROVEMENT AND REALIGNMENT

It is interesting that although the WIO countries are closely connected geographically, ecologically, historically, economically, and even culturally and politically, their national legal, institutional and policy frameworks are not adequately synchronized or integrated, in the manner, for example, of the European Union (EU). While there are significant differences in the models of the WIO region and the EU, what is needed, as a minimum, is a forum or framework for pursuing policy commonality on coastal and marine environment. That framework is currently the Nairobi Convention, its protocols and Action Plan. The main challenge is the extent to which countries are willing to align their national frameworks to the emerging regional legal and policy frameworks.

Another important challenge for policy across the WIO region is the existence of widespread and often serious pollution and degradation of the coastal and marine environment both from land-based and sea-based sources and activities, with very similar causes, effects and manifestations. This is in spite of the existing legal, institutional, policy and other governance frameworks.

Moreover, the legal, policy and institutional responses from the WIO countries has been characteristically similar. On the one hand, there is acknowledgement that a lot of the LBSAs and sea-based sources causing coastal and marine pollution are largely legitimate socio-economic activities which should be protected, encouraged and enhanced; and on the other, that these activities have environmental consequences, and therefore ought to be controlled or regulated. In all national cases, there is obvious legal, institutional and policy dilemma as to the appropriate middle ground. In efforts to create the middle ground, sometimes national legislation and policy frameworks are merely facilitative of the rational exploitation of these activities and sources, while giving environmental considerations a lukewarm treatment. In some cases there is only peripheral legislation for the sectors (for example tourism) while any substantive legislation is absent or is otherwise general land use and planning legislation. In yet other cases, laws adopt a "command and control" approach rather than an integrated or participatory approach which encourages voluntary compliance with incentives instead of prohibitions and penalties (UNEP/Nairobi Convention Secretariat and WIOMSA 2009b). The evolving ICZM policies are probably the most significant changes for the future.

The traditional sector approach to policy formulation, legislation and even institutional set up remains problematic, with numerous areas of overlap, duplication and contradiction among the legislature (UNEP/Nairobi Convention Secretariat and WIOMSA 2009b). The main policy dilemma is how to encourage or enhance integrated

policy, legal or institutional approaches without undermining governance structures that have been established over long periods.

Fortunately, there is increasing understanding and adoption of integration, and particularly ICZM. Up to fairly recently, the concept of ICZM did not exist and or find expression in most of the WIO countries. The major issues in the Region which necessitate ICZM include destructive fishing methods and associated ecosystem/habitat destruction; marine oil pollution from tanker traffic and ballast discharge; eutrophication and siltation of coastal waters; and spiralling population growth in coastal zones, especially in urban centres, fed by high birth rates and massive in-migration (Linden and Lundin 1996). Existing institutional constraints include short-term planning horizons and lack of participation; weak policy and regulatory environment for encouraging rational resource use and restraining the impacts of growth; administrative weakness and lack of coordination across sectorial agencies; and, limited opportunities for developing human potential in the growing populations of the region. A Workshop and Policy conference on ICZM in Eastern Africa took place in Arusha, Tanzania in 1993. A key outcome of the Arusha meeting was to encourage the establishment and development of ICZM as the best vehicle to deal with the multiple and complex issues of the coastal zones in the region (Linden and Lundin 1996). Consequently, some countries in the WIO region including Kenya, Madagascar, Mauritius, Seychelles, Mozambique and South Africa, have established multi-sectorial environmental policies backed by a fairly strong legal regime for resource management (UNEP/Nairobi Convention Secretariat and WIOMSA 2009b).

A further challenge for policy improvement and alignment is that most national legislation tends to create huge pools of authority or power in central government line ministries (sometimes with sweeping ministerial powers) and in public entities (usually parastatal organizations) which are almost exclusively controlled by the executive. This means that decision making, implementation and enforcement remain a government prerogative and function. It is probable that many national institutions have been ineffective or inefficient because of so much central government interference in their operations (UNEP/Nairobi Convention Secretariat and WIOMSA 2009b).

However, although most of the existing policies, legislation and institutions are sector specific (such as tourism, fisheries, mining, water or forestry) there is an increasing trend towards multi-sectorial legislation, policy and institutional arrangements to facilitate a more cohesive vertical and horizontal co-ordination and integration. Each of the countries has established key national institutions responsible for policy formulation and co-ordination of environmental activities, including within coastal zones. They include ministries responsible for environment (with responsible state ministers); environmental protection agencies with statutory powers; and inter-ministerial committees. Examples include South Africa's DEAT; Mozambique's MICOA; Seychelles' MOET; Kenya's Ministry of Environment and Natural Resources and NEMA; and, Tanzania's Division of Environment (DOE) under the Office of the Vice-President, and NEMC. Many of these institutions work on established framework policies and action plans, with deliberate reference to coastal and marine environment. Good examples of such policy instruments with significant emphasis on the coastal and marine environments are in the island states of Comoros, Madagascar, Mauritius and Seychelles. However, only Mauritius and Mozambique seem to have created distinct coastal zone management units, in 1999 and 1995 respectively, in apparent efforts to institutionalise coastal zone management (UNEP/Nairobi Convention Secretariat and WIOMSA 2009b). In addition to the national institutions, some of the larger countries in the region, such as South Africa, Madagascar, Mozambique and Kenya do have regional or provincial, county and local, environment and coastal management institutions. In Madagascar and Kenya there is a recent deliberate move towards decentralised government and this also affects environmental governance.

Finally, there are several regional and international laws that should be of interest to the region. They include the Nairobi Convention and its protocols (1985, revised 2010), under which the region is organized as a UNEP Regional Seas Programme and, the United Nations Convention on the Law of the Sea (1982). Also relevant are the Ramsar Convention on the Protection of Wetlands especially as waterfowl habitat (1971) (reviewed 2000), the Convention on Biological Diversity (1992), and the 1972 Convention on International Trade in Endangered Species (CITES), among others. Many of these conventions and treaties have been signed, ratified or acceded to by the countries of the region and are at various levels of national and regional implementation. However, it is arguable that the full potential of these instruments has not been felt in

the protection and promotion of the coastal and marine environment of the WIO region. It is expected that the global and regional instruments should constitute a firm basis for concerted regional action against LBSA and sea-based sources of pollution and degradation, and synergize with national arrangements to establish firmer ground for a healthier coastal and marine environment for the WIO region (UNEP/Nairobi Convention Secretariat and WIOMSA 2009b).

SYNERGIES AND TRADE-OFFS BETWEEN POLICIES

In view of the challenges discussed above, there is justification and scope for policy synergies and trade-offs. It is accepted that legitimate socio-economic activities within the coastal zone of the WIO region should be protected, encouraged and enhanced. Examples include urban and infrastructure developments, tourism establishments, ports and harbours, agriculture and mariculture, fisheries and others. It is recognized that because these activities have environmental consequences, they ought to be controlled or regulated. The challenge for WIO countries is to build in synergies and trade-offs in the processes and details of policy instruments. For example, there should be synergistic and integrated formulation of conservation policies dealing with natural resources such as water, forests, wildlife, fisheries or other biodiversity resources. Such synergies should also affect the legal, regulatory and institutional frameworks that concern the conservation policies.

There also needs to be a deliberate effort to introduce synergies and trade–offs within policies which promote developments and extraction of natural resources. The latter include policies related development of ports and harbours, urban and infrastructure developments, fisheries, water supply and sanitation, tourism, agriculture and irrigation, land-use and planning, among others. Perhaps an approach that combines ICZM and ecosystem based management (EBM) and their related frameworks and tools, would offer the best solution.

While sector-based approaches are common in the countries across the WIO region, it is feasible to integrate policy synergies and trade-offs in regional and national over-arching policy frameworks, including ICZM frameworks. Each important natural resource pool and socio-economic sector concerning or affecting the coastal and marine environment should be elaborated with synergies and trade-offs kept in perspective. Fortunately, there is an increasing trend towards multi-sectorial legislation, institutional and policy arrangements to facilitate better co-ordination and integration at various levels. This should mitigate the conventional tension between 'conservation' or environmental policies and 'development' or socio-economic policies, as well as inter- and intra-sectorial policy instruments.

POLICY OPTIONS AND THEIR IMPLICATIONS

From the foregoing review of policy, legal and institutional frameworks, various policy options exist with regard to the protection of the coastal and marine environment both at the national and regional level. Each of these is described below, highlighting their merits and shortcomings. The policy options available at the national level include:

Having an overarching policy instrument for the protection of the coastal and marine environment with sector players taking primary responsibility for their respective components;

- Maintaining sectorial policies and providing a coordinating mechanism (inter-sector coordination and integration); and
- Maintaining sector policies as well as sectorial implementation of the policies without having a coordinating mechanism (that is, business as usual).

National Level Options

i) Over-arching policy instrument with involvement of sector players

This entails having a single, national, over-arching policy instrument with sector players taking primary responsibility for their respective components, addressing all aspects of the coastal and marine environment and natural resources and human activities, including forests, fishing, land, mining, wildlife, agriculture, ports and harbours. Such a national environment policy would guide sectorial institutions on how resources under their jurisdiction are to be used in a sustainable manner that will ensure that the environment is conserved. The rationale for such a policy is that all aspects of the environment are connected in one way or another thus, having one central policy can identify the points of convergence and ensure sustainable environmental resources use, and that one form of pollution or degradation affecting a particular resource pool does not change to pollute or degrade other resource pools.

The consequences of an over-arching policy frame-

work include, on the positive side, better coordination of all environmental sectors, greater scope for participation of relevant stakeholders (including private sector and civil society), less government involvement in the details of implementation of policy measures, and greater focus by government on the core mandates of regulation, oversight and enforcement. Potentially there would be relatively large financial and other resource allocations. Conversely, there is evidence that in practice, large and centralized policy frameworks often suffer from operational inefficiencies, poor levels of ownership by stakeholders, expensive and often unwieldy implementation and other operational arrangements, and, weak levels of monitoring and evaluation.

ii) Maintaining sectorial policies and providing a coordinating mechanism

Here, the various environment-related sector institutions maintain their respective legal, institutional and policy frameworks but have a coordinating mechanism between the various sectors. Such an approach would ensure that the different sector policies are implemented, while bearing in mind the consequence of their activities on other sectors. The disadvantage of adopting such an option is that it could lead to "business as usual" as the various sectors have different laws, institutions and regulations that can make coordination and integration an insurmountable challenge.

However, the main argument in favour of this option is that it is central to a transformational response to decades of pollution, degradation and unplanned urban development under the typical sectorial approach to policy making. It will require a movement from sectorial coastal and marine management, to a joint approach that merges the seemingly competing interests for ocean and coastal resources and space. The coordinating body can provide oversight over activities in the coastal and marine environment and it can engage and develop internal dialogue as well as coordinate efforts with civil society, the private sector, ministries and other national bodies that serve as focal points for relevant national, regional and global programmes. Thus, an inter-sector policy coordination and integration framework can potentially contribute immensely to the effective implementation of environmental policies and programmes affecting the coastal and marine environment of the individual countries and the larger WIO region.

Implementing a Regional Policy Paper

In addition to the development and implementation of policies that attempt to integrate multi-sector instruments at the national level, much can also be achieved from policies and programmes that are embedded at the wider, regional level. Ideally, regional initiatives should support and strengthen national efforts. The scenarios described below, build on existing institutions and policies, were relevant, but also include new approaches and concepts.

The basis of this scenario entails developing an overarching regional policy that will guide the WIO region in terms of setting standards for the protection of the marine environment. This policy could be spearheaded by the contracting parties and the Nairobi Convention Secretariat. Various mechanisms and institutional arrangements could be constituted at the regional level for the purposes of coordination, implementation, oversight, monitoring and evaluation. Undertaking mutually reinforcing policies in the WIO region works to the region's advantage because, for nations faced with limited resources, the maximization of policy synergies will help deliver social, ecological and economic benefits, reduce trade-offs and provide multiple paths for addressing common drivers and pressures.

An example of a policy that can be adopted at the regional level is the Ecosystem Based Management (EBM) approach which lays out principles that guide management towards long-term sustainability of coastal and marine ecosystems. This management cannot be single-sector but must be integrated, just as ecosystems are interconnected. The EBM can be a cross-sectorial mechanism that would facilitate the overall planning and coordination of sector policies. EBM of terrestrial systems began in the 1950s, however, its application to the marine environment is relatively new.

There are some agreements that encourage parties to adopt an ecosystem approach. These include the Implementation Agreement on Parts V, VII, XI and XII of the 1982 UN Convention on the Law of the Sea; the 1995 UN Agreement on Straddling and Highly Migratory Fish Stocks; the UN Code of Conduct on Responsible Fisheries; and the 1995 Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities. In addition to these commitments to adopt EBM, many nations have declared their commitment to reaching various protection targets, including the 2020 target for representative marine protected areas under the CBD. The CBD Strategic Plan and Targets also go beyond MPAs, providing guidance on many tools and approaches

to implementing EBM (UNEP 2011).

The disadvantage of building a robust EBM that involves integrating and coordinating management across various sectors and at large scales is that it can prove to be costly. On the other hand, economies of scale are achieved in having different agencies working together to undertake training, research, monitoring and evaluation. However, ineffective management can prove to be more costly in the long-run because every time habitats and services are lost, it represents a sizeable cost to the society.

With regard to coordination mechanisms, a Regional Activity Centre (RAC) could be established as a special entity, whose work program is decided by the countries in the WIO region and involves the implementation of regional agreements. This decentralized model is widespread in the Mediterranean, the Black Sea, the Caribbean and the Northwest Pacific regions. Experiences from these regions show that this model serves as a focal point in the protection of the coastal and marine environment by various stakeholders and organizations. It allows for cohesion and synergy between different working groups that are undertaking varied activities.

There are three other external institutions that can assist states in the implementation of regional policies and agreements. As discussed further below, they include regional professional organizations, think tanks and hybrid models.

a) Regional Professional Organizations

For the WIO region, WIOMSA is an example of a professional organization that supports regional governance. It is a non-governmental organization that is dedicated to promoting the scientific, educational and technological development of all aspects of marine sciences throughout the WIO, with a view towards sustaining the use and conservation of its marine resources. In achieving this, WIOMSA a) provides a forum for communication and exchange of information amongst its members that promotes and fosters inter-institutional linkages within and beyond the region; b) supports marine research by offering research grants; c) implements programmes to build the capacity of marine scientists and coastal management practitioners; and d) works to promote policy dialogue on key topics by organizing meetings and seminars (Rochette and Bille 2012b).

b) Think tanks

Think tanks are organizations that position themselves at the interface between research and policy-making. Often, they conduct in-house research to support policy design. In the marine sphere, the Centre for Ocean Solutions (in California, USA) was created by three leading marine science and policy institutions namely, Stanford University, the Monterey Bay Aquarium and the Monterey Bay Aquarium Research Institute. The Centre combines Stanford's expertise in marine biology, oceanography, engineering, economics, law and policy with the Aquarium's experience in public education and outreach, leadership in deep-sea technology, exploration and monitoring. In addition to developing new knowledge, the Centre's researchers and staff reach out to decision-makers including governments, businesses and the non-profit sectors to translate the results of marine science and policy research into action. The Centre for Ocean Solutions works to highlight these issues in the media and outreach programmes of sponsors to inform and empower action by the general public and local, state, national and international decision makers (Rochette and Bille 2012b).

Creating a regional think tank can be original and advantageous as it is highly flexible and can address a wide spectrum of issues by building partnerships with various regional institutions such as the Indian Ocean Commission (IOC) or regional fisheries management organizations.

c) Hybrid Models

A hybrid model is an institution that is halfway between think tanks and RACs. GRID-Arendal is an official UNEP collaborating centre established in 1989 by Norway, with a mission to communicate environmental information to policy-makers, support informed decision-making and raise awareness. These are achieved through environmental information management and assessment, capacity building services as well as outreach and communication (Rochette and Bille 2012b).

All the institutional structures presented in the three categories above can contribute technical assistance and support for implementation of regional legal instruments and environmental policies for the protection of the marine environment. Each structure emerges in a specific context and therefore the WIO region must analyse the options and be innovative to ensure regional benefits are maximised. It is however important to note that the adopted coordination and cooperation framework must be acceptable to other regional organizations to which WIO countries belong, if significant strides in the protection of the marine environment are to be achieved.

POLICY EMPHASIS SCENARIOS

Whichever policy options exist at the national or regional levels, there are further scenarios that WIO region countries need to consider. Firstly, countries may consider policy instruments which largely or primarily provide incentives for voluntary compliance. This may target private sector players in the commercial sectors such as tourism, fisheries, shipping, manufacturing, oil and gas, etc. Some of the incentive and disincentive mechanisms include, amongst others, public-private partnerships which give the private sector greater latitude and involvement in coastal and marine environmental governance; tax holidays and rebates to encourage environmental protection and conservation; and higher taxation levels for certain sea-based or coastal activities or undertakings aimed at reducing pressure on sensitive coastal and marine environments. The implication is that these will be market driven, self-regulatory frameworks devoid of too much government control. However, government still performs its primary role of regulation, oversight and enforcement, although in certain sectors, such as ports and harbours, oil and gas and tourism, the government is also often a participant.

Secondly, countries may consider strengthening the "command and control" approach in their policy formulation. Greater government control over environmental decision making, regulation, oversight and enforcement may require less consultative and participatory processes; and instead require larger policing machinery, complete with heavy penalties and fines. This approach could become very expensive and stifling of enterprise and stakeholder participation, and possibly undermine coastal and marine environmental protection in the affected countries and across the region. Finally, a scenario where a hybrid system, with both elements of incentives and policing co-existing, is presented, however, this runs the risk of essentially creating a rather weak system both ways.

The time has come for countries in the WIO region to clearly mainstream coastal and marine issues for the future. Environmental integrity of the coastal and marine areas, ecosystem services and goods, green energy, offshore resources, maritime security and others must increasingly become central pillars of national policy formulation. The region as a whole should engage in policy discussions on the foregoing issues in a concerted manner. Economic development and population projections, as well as trends in environmental degradation and/or recovery and climatic change implications, should be included in the analyses that contribute to the much-needed guiding policies of the future.

References

GPA (1995). *Global Programme of Action for the Protection of the Marine Environment from Land-based Activities*. UNEP. Washington D.C.

Linden, O. and Lundin, G.C. (eds.) (1996). *Integrated Coastal Zone Management in Tanzania*. SIDA SAREC and World Bank

Rochette, J. and Bille, R. (2012a). ICZM Protocols to Regional Seas Conventions: What? Why? How? *Mar. Policy* 36(5), 977-984

Rochette, J. and Bille, R. (2012b). *Strengthening the Western Indian Ocean Regional Seas Framework: A Review of Potential Modalities*. Indian Ocean Commission/European Union/French Global Environmental Facility, Study No 02/12. IDDRI. Paris, France

Samoilys, M., Osuka, K. and Maina, G.W. (2011). *Opportunities and challenges of current legislation for effective conservation in the Tana Delta: Pate Island coast of Kenya*. CORDIO Status Report. Mombasa, Kenya

UN (2015). *General Assembly - Report of the Open Working Group of the General Assembly on Sustainable Development Goals*. 12 August 2014. Sixty-eighth session. United Nations

UNEP (2011). *Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication - A Synthesis for Policy Makers*. Available at http://www.unep.org/greeneconomy/Portals/88/documents/ger/GER_synthesis_en.pdf

UNEP/Nairobi Convention Secretariat and WIOMSA (2009a). *Regional synthesis report on the review of the policy, legal and institutional frameworks in the Western Indian Ocean (WIO) region* UNEP. Nairobi, Kenya

UNEP/Nairobi Convention Secretariat and WIOMSA (2009b). *Transboundary Diagnostic Analysis of Land-based Sources and Activities Affecting the Western Indian*

Ocean Coastal and Marine Environment. UNEP. Nairobi, Kenya

UNEP/Nairobi Convention Secretariat and WIOMSA (2009c). *Regional synthesis report on ratification and implementation of international environmental conventions relevant to land based activities/sources of pollution of the coastal and marine environment of the WIO region*. UNEP. Nairobi, Kenya



35

Coastal and Marine Research and Capacity Building

Julius Francis, Louis Celliers and Sérgio Rosendo

Opposite page: Crossing hands for action, Reunion. © Anne Lamahieu.

Most, if not all, of the recommendations contained in this State of the Coast Report, relies on two cross-cutting and fundamental qualities. Firstly, managers, decision- and policy-makers and the various end-users have access to the products of scientific research in order to wisely govern and manage the use and exploitation of resources. In this context, data, information and knowledge are the basis for realising the benefit of an Ocean Economy. Secondly, both the management of resources and the underpinning knowledge base relies on the availability of people with the appropriate capability to be responsible custodians of such resources. Accordingly, education, awareness and training offer a long-term solution for the sustainable development of a coastal and ocean economy.

The core objectives of this chapter are first, to help in the understanding of how national and regional research agendas can contribute to a consistent and complete "bigger picture" of data, information and knowledge required to manage the coastal and marine resources of the Western Indian Ocean (WIO), and secondly, present processes that contribute to the regional and national knowledge-base. The first part of the chapter will examine the past, current and future coastal and marine research priorities at various scales and how research has been or is conducted in the region. The second part of the chapter will explore the development of regional capacity for coastal and marine research and how existing research has been supported in the past. The chapter will conclude with successes on how science has contributed to decision- and policy-making in the region.

NATIONAL AND REGIONAL RESEARCH

National research and development (R&D) activities and supporting institutional frameworks in the WIO are not homogenous. Each nation has distinctive R&D characteristics, which are a reflection of the heterogeneity of structures and the concentration of R&D by region, institution, sector and even project (UIS, 2010). The heterogeneity of the R&D landscape is reflected in the supporting institutional frameworks and directly influences the coastal and marine research landscape.

Despite the differences in how countries structure their research infrastructure and priorities, Davis and Carden (1998) point out three related and common characteristics of developing countries also relevant to the WIO region. They suggest that not only is R&D in many developing countries highly constrained by funding, but also, that resource allocation procedures are sensitive to personal or political affiliations or entitlements. This is often not balanced out by considerations of efficiency, effectiveness, relevance, utility, or excellence. Secondly, they suggest that developing countries depend on international scientific assistance, which has its own frequently changing investment agenda. Finally, Davis and Carden (1998) argue that to be effective, R&D must be part of an "innovation system" or "innovation community", in which active relationships and communication exists between researchers

and other actors such as intermediaries, coordinating institutions, educators, extension agents and, especially, users.

Research Investment

Socio-economic disparities between WIO states are stark, especially comparing literacy and unemployment rates. There are also large disparities in key socio-economic indicators that can influence R&D potential such as Gross Domestic Product (GDP), which varies from US$ 592 000 million for South Africa to less than US$ 1 000 million for Comoros. According to the World Bank (The World Bank, undated) R&D expenditure (per cent of GDP) is defined as the current and capital expenditures (both public and private) on creative work undertaken systematically to increase knowledge, including knowledge of humanity, culture, and society, and the use of knowledge for new applications. R&D covers basic research, applied research, and experimental development. Based on this indicator, less than 1 per cent of GDP is provided to R&D in all of the WIO countries (see Table 35.1). South Africa spends on average 0.8 per cent on R&D (intermittently measured between 1997 and 2009) while most other WIO countries report expenditure between 0.1 and 0.4 per cent on R&D. This does not compare favourably to developed countries which spend between 1.5 and 3 per cent of GDP on R&D. Encouragingly, Kenya has taken a formal position on the value of R&D for national development by passing into law the Science, Technology and Innovation Act of 2012, which mandates a 2 per cent GDP spend on R&D.

Systems of Innovation

Most countries in the WIO hold some level of institutionalised science, technology and innovation (STI) "system". These are primarily organised by ministries assigned to manage science and technology. In many cases, there are institutions specifically constituted to facilitate and develop STI. These innovation systems often attempt to create a relationship between national growth and development objectives, and scientific research priorities.

Over and above our understanding of the regional R&D landscape as demonstrated by the examples in Table 35.2, some general comments can be made relating to countries in the region:

- The extent to which the coastal and marine environment is acknowledged as an important element of national growth and development varies between countries;
- Most countries in the WIO spends less than 1 per cent of GDP on R&D activities;
- National science, technology and innovation strategies and institutional frameworks exist in some WIO countries;
- The connectedness between coastal and marine research institutions and the national STI frameworks of the WIO is often weak;
- Coastal and marine research needs are not always clearly expressed within national STI frameworks.

A HISTORY OF MARINE RESEARCH AND CAPACITY BUILDING IN THE WESTERN INDIAN OCEAN

Despite being regarded as the least studied region of the Indian Ocean, the WIO region has a long history of coastal and marine research and capacity building. Associates of Carl Linnaeus undertook the first known investigation of

Table 35.1. Research and development (R&D) expenditure (per cent of gross domestic product) of selected countries in the Western Indian Ocean compared with India, Portugal and the United States of America.

Country Name	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Mean %
India*	0.6	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.8	0.8	0.8					0.7
Kenya												0.4					0.4
Madagascar		0.2	0.1	0.1	0.1	0.2	0.2	0.3	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.2
Mozambique							0.5				0.5		0.2		0.5		0.4
Mauritius		0.3	0.3	0.3	0.3	0.4	0.4	0.3	0.4	0.4							0.3
Portugal*	0.6	0.6	0.6	0.7	0.7	0.8	0.7	0.7	0.7	0.8	1.0	1.2	1.5	1.6	1.6	1.5	1.0
Tanzania												0.4					0.4
United States*	2.6	2.6	2.6	2.6	2.7	2.7	2.6	2.6	2.5	2.6	2.7	2.7	2.9	2.9	2.8	2.8	2.7
South Africa		0.6				0.7		0.8	0.8	0.9	0.9	0.9	0.9	0.9			0.8

Table 35.2. Science, technology and innovation in selected countries (in alphabetic order) of the Western Indian Ocean.

Recognisable Science, Technology and Innovation System	Legislation and Policy	Status in relation to Coastal and Marine Relevance
Comoros - Science and technology is primarily driven by the Ministry of National Education, Research, Culture, and Arts charged with youth and sports.	National Policy of Higher Education and Research 2020 (UDC 2013)	The focus is on strengthening the higher education and research systems which are considered extremely weak. Does not identify research priorities in any particular area. The concept of identifying or recognising coastal land marine issues with the national system of innovation is weakly developed.
Kenya – The National Commission for Science, Technology and Innovation (NACOSTI, undated) has the goal of establishing a strong foundation on science, technology and innovation (STI), with research playing a key role in generating a critical mass of technical and skilled manpower.	Science, Technology and Innovation Act, 2013 Science, Technology and Innovation Policy and Strategy (RoK 2008).	The Kenya Marine and Fisheries Research Institute is listed as an institution to which the act applies. This institute deals with natural resources, water development, health, and power and communications. Research into the marine and coastal environment features strongly in their mandate, as does environmental and ecological management studies. The STI policy specifically mentions the need for environmental management in order to provide a clean and safe environment for citizens while also protecting livelihoods.
Mauritius - There are a number of agencies dealing with STI ie Ministry of Industry, Science and Research, Mauritius Research Council, Rajiv Gandhi Science Centre.	Transforming Mauritius into a Knowledge Hub (HRDC 2006)	The concept of identifying or recognising coastal land marine issues with the national system of innovation is weakly developed.
Mozambique - Explicit policy measures are integrated into the Mozambique Strategy for Science, Technology and Innovation, which was proposed by the Ministry of Science and Technology.	Mozambique Strategy for Science, Technology and Innovation (RoMZ 2006)	The ability of the Strategy to drive coastal and marine research was difficult to assess but appears to be limited. The concept of identifying or recognising specific coastal land marine issues within the national system of STI is weakly developed. It does not appear to facilitate a process for the expression of national research priorities, and the engagement of research with national research funding instruments appears to be limited.
South Africa – The Department of Science and Technology (DST) is responsible for scientific research in the country and oversees the management of the country's relatively well-developed science system. The key institution, in the context of this strategy, for promoting science, is the National Research Foundation, which is linked to the higher education sector through the National Plan for Higher Education	National Research and Development Strategy (RSA 2002)	The strategy document does not make any special mention of the biophysical environment or the coastal/ marine environment. The concept of identifying or recognising coastal land marine issues with the national system of innovation is moderately developed.
Tanzania – The Commission for Science and Technology (COSTECH) is a semi-state organization with the responsibility of co-ordinating and promoting research and technology development activities in the country (COSTECH, undated). It is the chief advisor to the Government on all matters pertaining to science and technology and their application to the socio-economic development of the country. Major national research and development institutes are affiliated to COSTECH.	National Research and Development Policy (URT 2010)	It's quite difficult to discern the relevance of this organisation to coastal and marine environment issues in Tanzania. Very few of the R&D institutions listed on their website deal specifically with the coastal environment (Tanzania Fisheries Research Institute for example) while the majority of them are focused on agriculture and livestock, industry and energy, and medicine and public health.

marine life in the WIO region in the mid-1700s (Richmond 2011). Further investigations followed years later and were undertaken as part of major global exploratory expeditions. These include expeditions such as H.M.S. Endeavour (1768-71), H.M.S. Beagle (1831-1935) and Challenger (1873-76) (Richmond 2011). Since then, scientific cruises and expeditions have continued to be an important means for conducting scientific research, particularly in offshore areas. Importantly, most of the cruises in the region were conducted by foreign countries such as Belgium, Norway, Germany, the Netherlands and United Kingdom. South Africa is the only country in the region that has organized regional cruises. In the other countries, locally organized cruises have concentrated on waters within national bor-

ders. Accordingly, most of the marine research conducted in the region to date has encompassed nearshore waters using small vessels that are limited in range and technical capacity. One outcome of this situation is that there is some reasonable understanding of a few of the key habitats and ecosystems close to shore, but the regional knowledge of deep-water habitats and resources is rather limited.

By the early 1960s, only five research institutions/stations existed in the WIO region. These were: the Maritime and Fisheries School of Mogadishu; the East African Marine Fisheries Research Organization (EAMFRO), with substations in Mombasa and Zanzibar; the Institut de Recherche Scientifique (Madagascar); the Inhaca Island Marine Biological Station (Mozambique) and the Oceanographic Research Institute (ORI) (South Africa). Their main focus was to compile inventories of marine life and resources, particularly fisheries. The situation is different today, as the number of academic and research institutions that deal with different aspects of marine science has increased significantly, with all the WIO countries having more than one institution (Table 35.3).

Most of the research institutes in the region have basic field instruments, boats, diving gear, and specialized laboratories, with infrastructure and laboratories in most cases developed intermittently through externally funded projects. Various capacity-building activities have been undertaken within and outside the region under the auspices of a range of donor organisations. Examples include support from the governments of Sweden (through Sida and SAREC), Norway (through NORAD), Japan (through JICA), and overseas development assistance (ODA) facilities offered by many other governments, as well as structured partnerships between local and foreign universities (historic), and China and South Korea, more recently. Within these initiatives, short-courses and training workshops (1-3 weeks), with some longer-term degree courses (1-4 years) has been a primary vehicle for improving local capacity.

The relationship between science and policy in the region has changed considerably over the years. Traditionally the pipeline mode existed in which scientists set the research agenda, conduct the research, and then transfer the results to potential users. This has evolved into co-production of knowledge under a more modern approach, whereby scientists and decision-makers define the research agenda and on a regular basis scientists provide feedback to the policy community. Whilst the full gains from this transition have not yet been totally appraised or audited (accounted) for, the extent to which this new approach has improved awareness and engagement in marine resource management is reflected by the investments being made in this domain. This change has been possible due to the associated change occurring in the way in which research topics are selected. Historically, research topics were commonly selected to meet academic criteria and most of the times reflected the interests of either students or supervisors with limited or no links to priority resource management questions. In the recent past, and through programmes such as Marine Science for Management (MASMA), through WIOMSA, inter and multi-disciplinary research has been promoted to address urgent societal and resource management issues.

Pre-independence

Prior to the 1960s most countries in the WIO region were under colonial rule. Accordingly, marine and coastal research in these countries was driven by the perspectives of remote decision-makers who relied on reports rather than direct local engagement. Importantly, however, a number of developments which took place during this period are the foundation for some of the institutional capacity currently existing in the region.

The notable pre-independence scientific cruises and expeditions that took place from 1789 to 1960 (described above), were followed by the 20th century expeditions of H.M.S. Mabahiss (1933-34) and the International Indian Ocean Expedition (IIOE) (1959-1965). The IIOE involved scientists from 23 countries, 44 research vessels and numerous airborne data-collecting devices and satellites (Morcos 2002). Whilst early expeditions focused mainly on the collection of biological specimens and plankton, the study of biological and chemical processes, inventories of marine life and resources, particularly fisheries, and recording of basic oceanographic processes, the later IIOE encompassed almost all marine science disciplines, except perhaps fishery research and marine microbiology (Rao and Griffiths 1998). The IIOE contributed a wealth of knowledge on many aspects of the WIO including the discovery of the mid-Indian Ocean ridges (including the Southeast Indian Ocean Ridge) the famous triple junction south of the Seychelles, where the southern end of the Carlsberg Ridge meets the Southwest Indian Ocean Ridge (Rao and Griffiths 1998), the effects of the monsoons on the Somali Current, and upwelling off the Somalia coast.

In addition to oceanic expeditions, this period was also characterised by the establishment of the first initiatives leading to the founding of marine biological stations. These were:

• The founding of the Zanzibar Marine Station in 1948 with the Mombasa Marine Station and the ensuing formation of the East African Marine Fisheries Research Organization (EAMFRO), in 1953. The Zanzibar Marine Station has become the Institute of Marine Science (IMS) of the University of Dar es Salaam and the Mombasa Marine Station is now the Kenya Marine Fisheries Research Institute (KMFRI).

• The Inhaca Island Marine Biological Station, established by the Portuguese administration in 1953 in conjunction with the University of the Witwatersrand, is now part of the Universidade Eduardo Mondlane (UEM).

• Between 1962 and1973, the French organization 'Office de la Recherche Scientifique et Technique d'Outre-Mer' (OSTROM) established and managed a marine station in Nosy-Be, Madagascar, later reopened in 1978 as the Centre National de Recherches Oceanographiques (CNRO).

• In 1961, the University of Marseille established 'Station Marine de Tuléar', attached to the Faculty of Science, University of Antananarivo. This station became L'Institut Halieutique et des Sciences Marines de l'Universite de Tuléar.

• The Oceanographic Research Institute (ORI) was established as the research wing of the South African Association for Marine Biological Research, a non-profit NGO affiliated to the University of Natal, in 1953/4.

Despite the existence of these stations during the IIOE, their limited human resources and technical capacity largely prevented them from participating in the expedition or benefitting directly from training and educational opportunities provided by the International Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO).

In addition, there were no universities or colleges in the region offering courses in marine sciences during this period, such that apart from ORI, all of the scientists working in these research stations were foreigners.

Post-independence to the 1980s

Most of the countries in the WIO region achieved independence between 1961 and 1976. As governments across the region strived to consolidate their economies and infrastructure in the early 1960's, marine science research was not given priority. For instance, in 1962, a decision was taken to close the EAMFRO as it was argued that marine science was unlikely to provide immediate economic benefit to East Africa. This decision was later rescinded (EAMFRO 1965).

From the 1970s onwards, a change in thinking began to emerge, resulting in the implementation of a range of initiatives that played a catalytic role in the development of marine science in the region, including capacity-building programmes. In April 1974, the International Centre for Marine Resources Development of the University of Rhode Island organized the International Conference on Marine Resource Development in East Africa in collaboration with the University of Dar es Salaam. This conference was specifically aimed at providing a discussion forum for scientific and developmental issues pertaining to marine science capabilities in the region. It also encompassed issues related to the marine resource potential and capacity needs of the East Africa region. Notably, the conference recommended the establishment of an institute of marine sciences at the University of Dar es Salaam (Morcos 2002). Three years later, with the collapse of the East African Community (EAC) and EAMFRO, the University of Dar es Salaam took over the facilities in Zanzibar and established the Institute of Marine Sciences in 1978.

Another important event that played a key role in the development of scientific research in the region was the creation of a regional body, the Cooperative Investigations in the North and Central Western Indian Ocean (IOCINCWIO), by the IOC of UNESCO. Two preparatory meetings were held to prepare for the establishment of the IOCINCWIO, the first in Zanzibar in 1975, and the second in Nairobi the following year. Several oceanographic and atmospheric research programmes were undertaken in the region between these meetings and the first session of the IOCINCWIO was convened in 1982. The initial research programmes included the Special Observing Period Program of the Monsoon Experiment (MONEX) which took place in 1978 to 1979 and carried out oceanographic and atmospheric observations on the whole of the Indian Ocean north of 10°S. In the WIO region, the studies focused on phenomena such as the Equatorial Current, Somali Current and upwelling currents off Somalia (Morcos 2002).

Throughout the 1970s governments in the region increasingly recognised the importance of marine science and awareness of coastal and marine issues grew widely.

This was significant in influencing the Third UN Conference on the Law of the Sea, which started in 1973, and culminated with the adoption of the UN Convention for the Law of the Sea in 1982. The latter resulted in the establishment of the United Nations Environment Programme (UNEP) in 1973 and subsequently a Regional Seas Programme by UNEP that also helped to enhance technical support on marine research from UN organizations and developed countries. Between 1970 and 1980, technical assistance and financial support for national and regional marine science projects came from UN organizations such as the IOC, UNESCO, FAO, and World Meteorological Organization (WMO). Developed countries, such as the US, Norway, UK, Canada and France provided technical assistance and opportunities for undergraduate and postgraduate training through bilateral programmes. The Norwegian Government provided the R/V Fridtjof Nansen to the Mozambique Government, and later to other governments, to conduct fisheries and oceanographic surveys in Mozambican waters in 1977-1978.

The 1970s were also marked by missions to the region by developed countries on their own initiative or in collaboration with the UN organizations. These commonly aimed to investigate the priorities and needs for capacity-building in the marine sciences and included visits to Kenya, Madagascar, Somalia and Tanzania.

From the 1980s to the present

As a reflection of the importance of marine and coastal resources, the past 35 years has seen a remarkable growth in marine science research across countries in the WIO region. This is exhibited by both the enhancement of existing programs and the development of new initiatives. This has encompassed regional legal and institutional frameworks, academic and research institutions, regional research programmes, increased financial and technical support, and increased partnerships.

New and Existing Regional research and management Frameworks for marine and coastal environment

A number of collaborative activities between funding agencies, donors and regional governments were implemented between 1997 and 2001. Notably, the IOC-INCWIO, funded by IOC, Sida, the Belgian Government and UNEP implemented a number of activities. These included providing funds for regional cooperation in scientific information exchange, ocean mapping, a regional nutrient and water quality monitoring network, the installation and maintenance of sea level stations and strengthening regional institutions such as WIOMSA. Activities on scientific information exchange were built on the foundation laid by the Belgium Government-supported project 'Regional Cooperation in Scientific Information Exchange in the Western Indian Ocean region' (RECOSCIX-WIO), which was established in 1989 and focused on the development of capacity and infrastructure for the collection, processing, archiving, analysis, interpretation and dissemination of data and information. The RECOSCIX-WIO project ended in 1997 and was replaced by the Ocean Data and Information Network for Africa (ODINAFRICA), which started in 1997 and is now in its fourth phase. The focus of the current phase of the project is on product development and dissemination and strengthening of the Pan African network of National Oceanographic Data Centre (NODCs). The project has produced directories, catalogues, atlases and portals.

With more of a focus on management and coastal protected areas, the Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Eastern Africa Region (Nairobi Convention) was enacted in 1985 and came into force in 1996 through its East Africa Action Plan. This initiative supported the implementation of a number of projects focusing on management and protection of coastal areas (EAF/5), the control of marine pollution (EAF/6) and a regional database and atlas of coastal and marine resources (EAF/14). In contrast to the historic situation in the 1970s and 1980s, the projects in this program were implemented by research and academic institutions in the Convention countries rather than by external research organisations or institutions.

In 2004, the Nairobi Convention facilitated the establishment of the Forum of Heads of Academic/Research Institutions (FARI). Core objectives of the Forum were to facilitate the sharing of information between these institutions and the Nairobi Convention, as well as amongst themselves; engage and facilitate opportunities for collaborative research that are relevant to the Nairobi Convention; and offer scientific and technical advice on priorities for management, assessments and information dissemination within the Nairobi Convention.

The Nairobi Convention Secretariat was the Executing Agency for the GEF-funded project "Addressing land-based Activities in the Western Indian Ocean," (WIO-LaB

Project), which undertook a region-wide assessment of transboundary problems and issues affecting the marine environment in the WIO region between 2004 and 2010. The outputs of these assessments led to the formulation of a Transboundary Diagnostic Analysis (TDA), detailing key problems and causes of degradation of the coastal and marine environment in the WIO region, with special emphasis on land-based sources and activities (LBSA) and the Strategic Action Programme (SAP) to address the challenges faced by governments in the region.

Both IOCINCWIO and the Nairobi Convention leveraged national support by involving research and academic institutions in the region in the implementation of their activities and, thereby, contributed to strengthening national institutional and human capacity.

New and Existing Legal and Institutional Frameworks

Both the 1992 UN Conference on Environment and Development in Rio de Janeiro, and the 2002 World Summit for Sustainable Development in Johannesburg, prompted many countries, including the WIO countries, to revise or develop national legal instruments, on environment, by incorporating principles of sustainable development. For instance, Tanzania developed the following environmental-related policies and acts after these major conferences: the Marine Parks and Reserves Act (1995), the National Environment Policy (1997), the National Fisheries Sector Policy (1997) and the National Integrated Coastal Management Strategy (2003). Similar action was taken by the other WIO countries.

Research and academic institutions were involved in the revision and development of new legal instruments, and further provided technical inputs to the processes and benefitted from the policy-making community thereby strengthening the relationship between science and policy making. Research and academic institutions have contributed to the implementation of some of the aspects of the legal instruments. In Tanzania, research and academic institutions were actively involved in the drafting of the Marine Parks and Reserves Act and the National Integrated Coastal Management Strategy and their implementation. As an example of the latter, the Institute of Marine Sciences played an important role in the establishment of the Mafia Island Marine Park and Mnazi Bay Marine Park between 1995-2000 as part of the implementation of the Marine Parks and Reserves Act.

New and Existing Academic and Research Institutions

The increase in human capacity for marine science research, as well as increasing recognition of the importance of the marine ecosystem goods and services by governments has led to the establishment of new academic and research institutions (Table 35.3). More universities in the region are now offering postgraduate degree programmes in areas of marine and coastal science and associated resource management disciplines. For instance, in Kenya, the number of universities that teach courses with a marine and coastal focus has increased from one before 1980 (ie University of Nairobi) to more than five. In the 1980s, the University of Dar es Salaam offered courses on marine systems in the Department of the Zoology and Marine Biology but this was changed first to the Faculty of Aquatic Sciences and Technology and later to the Department of Aquatic Sciences and Fisheries, which currently offers two degrees programmes at the undergraduate level. Both the Department of Aquatic Sciences and Fisheries and the Institute of Marine Sciences now offer Masters and PhD degree programmes. In Mauritius, both the Albion Fisheries Research Institute and the Mauritius Oceanography Institute were established after 1980.

At present, there is at least one University offering degree programmes on marine related field in all the countries in the region except Somalia. Additionally, a number of non-governmental organizations have increased their support to research by publishing seminal papers to complement the traditional academic and research institutions. The Wildlife Conservation Society, through its Kenya and Madagascar offices, and CORDIO have been the most active.

Development of Bilateral and Regional Research Programmes

Since the 1980s the region has benefited from a number of bilateral and regional research programmes which have contributed significantly to strengthening of human and institutional capacity in regional academic and research institutions. Perhaps just as importantly, these programmes have also underpinned the development of strong partnerships between regional institutions and their counterparts in developed countries. Examples of such programmes include the following:

- The **Sida/SAREC Regional Marine Science Programme** started in 1993 with the aim to carry out

research on the sustainable use of coastal and marine resources, and environmental management of the coastal zone. This Programme supported the two Ministerial Conferences on Integrated Coastal Zone Management (ICZM) in Arusha, Tanzania (1993), and the Seychelles (1996). These events set the stage for coastal management initiatives at local and national levels in the region and successfully initiated dialogue between the scientific community and high-level policy-makers. The programme made modest investments in capacity building in the social sciences, which resulted in notable achievements in this arena. This Programme also facilitated the establishment of WIOMSA and CORDIO.

• The **Sida/SAREC Marine Science Bilateral Programme for Tanzania and Mozambique**. The Bilateral Program for Mozambique was initiated in 1985 while the Bilateral Program for Tanzania started in 1990. Both programmes are still ongoing. Their combined impact has produced significant advances towards the goal of a diversified resident capacity in the marine sciences that will contribute towards effective management of coastal ecosystems. This has, in turn, prompted greater local investments in the natural sciences to increase this diversity and the wider local capability in coastal resource management disciplines. The programme's most notable achievement has been the transformation of the Institute of Marine Sciences (IMS) of the University of Dar es Salaam into an internationally recognized institution. IMS is attracting funds from a diversity of sources, hosts visiting scholars from many nations, and is making significant contributions to public policy and resource management in Zanzibar, Tanzania and the region.

• The **Kenya – Belgium Programme in Marine Sciences**. This programme started in 1985 and involved the Free University of Brussels (VUB) and the KMFRI, resulting in the training of a number of Kenyan students to Masters and PhD level. The programme also supported a number of studies in Kenya undertaken by Kenyan and Belgium scientists. It also constructed and equipped laboratories at KMFRI.

• **GEF-funded regional programmes**. The region implemented three regional GEF-funded projects during the ten years from 2004 to 2014. These were 'Addressing Land-Based Activities in the Western Indian Ocean' (WIO-LaB), 'the Southwest Indian Ocean Fisheries Project' (SWIOFP) and the Agulhas and Somali Current Large Marine Ecosystems Project' (ASCLME). Scientists and experts from regional universities and research institutions, as well as government agencies, were closely involved in project activities including through participation in regional and national task forces and working groups, preparation of the TDA and SAP and in advisory roles to the demonstration projects. The project collaborated closely with WIOMSA and facilitated creation of the Forum of Heads of Academic and Research Institutions (FARI) in the region as a mechanism to coordinate research activities and assure the quality of scientific work in the region. The ASCLME and SWIOFP Projects, together with partners in the EAF Nansen Project, NOAA, NIOZ, IUCN and the IRD, undertook or co-funded over 50 offshore expeditions in the WIO region (Box 35.1).

• **EU-funded projects.** From the mid-1990s up to 2010, the European Union supported a number of research programmes in the region through its framework programme: Specific Measures in Support of International Cooperation (INCO-DEV). These included the 'Transboundary networks of marine protected areas for integrated conservation and sustainable development: biophysical, socio-economic and governance assessment in East Africa (TRANSMAP)' and the 'Peri-urban mangrove forests as filters and potential phytoremediators of domestic sewage in East Africa (PUMPSEA)'. A total of 24 research and management authorities in regional participating countries and European institutions were involved in these projects. They supported a number of Masters and PhD candidates, undergraduate students, provided equipment, and produced a number of high quality publications and scientifically based advisory documents for application in policy development and management.

• **Marine Science for Management (MASMA).** In 2001, WIOMSA initiated a regional programme known as Marine Science for Management (MASMA) with financial support from Sida/SAREC. A principal component of MASMA is a competitive grants programme to support regional research. In addition to this, there are three other related and mutually reinforcing operational components of MASMA: 1) Institutional strengthening of WIOMSA to administer and coordinate research activities; 2) training and outreach in the region, regional networking, research priority setting and professional development through short courses, seminars, and workshops; and 3) the communication and dissemination of research results and information. WIOMSA has organized eight Scientific Symposia through this programme, which have been held triennially since 1997, it has established the Western Indian Ocean

Journal of Marine Science in 2002, produced 16 books under its Book Series, and supported other books published by prominent publishing firms such the Oxford University Press and University of Cape Town Press. Between 2000 and 2014, WIOMSA supported at least 210 Marine Research Grant (MARG-I) projects and 46 large regional research projects, which were implemented in all the countries in the region except Somalia. Over 600 publications have been produced through these grants (Figure 35.1).

Increased financial and technical support

In most of the countries in the region budgetary allocations for research and capacity-building by governments are generally insufficient and highly variable. Government funds are almost exclusively sed to pay for salaries alone. This funding limitations means that most of the research and capacity-building initiatives in the region have been, or are funded by bilateral and multilateral funding agencies, international NGOs and foundations.

As indicated previously, marine sciences and capacity-building initiatives in the WIO region have historically received significant levels of support from these external sources. This support has been directed towards research projects, the provision of scholarships for postgraduate training, organisation of workshops and courses, and, in some cases, the provision of physical infrastructure (including laboratories, libraries and lecture rooms) and supplies. To illustrate the increasing levels of support received in the WIO through WIOMSA, the Government of Sweden financial support to WIOMSA from its establishment in 1995 to 2011 is used as an example (Figure 35.2).

Increased Partnerships

Different types of partnerships have been developed through bilateral and regional programmes, including south-north and south-south partnerships. These partnerships have resulted in enhanced collaboration in research and capacity-building amongst experts, both within the region and between the region and outside. Successes of these partnerships are reflected in the increased number of joint proposals developed and implemented, an exchange of students and staff, and the joint production of publications.

The Sida/SAREC Regional Marine Science Programme, Sida/SAREC Marine Science Bilateral Programme for Tanzania and Mozambique, the Kenya–Belgium Programme in Marine Sciences, EU-funded programmes under the Framework programme and MASMA, have all contributed to strengthen the collaboration between research and academic institutions in the WIO and those in Europe (such as the Stockholm University in Sweden, University of Lisbon, Free University of Brussels), Australia (the University of Queensland and James Cook University) and USA (University of Rhode Island).

Partnerships between and among institutions in the region have also improved over the last decade. This improvement is also largely attributable to the bilateral and regional programmes that have catalysed exchange, inter-

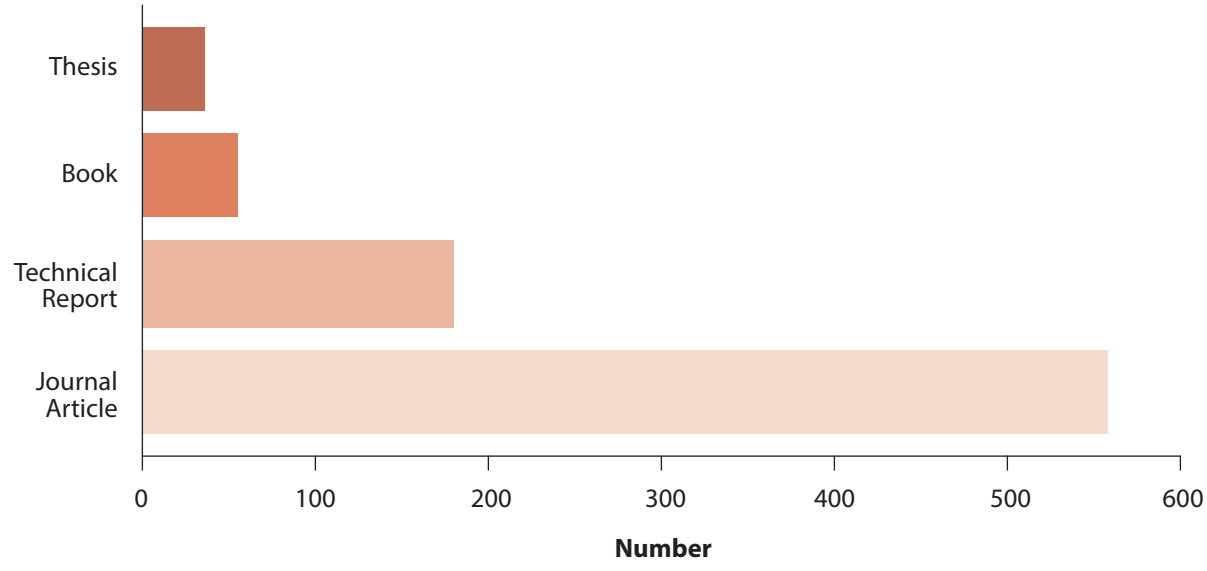


Figure 35.1. Publications produced with support of WIOMSA between 2000 and 2014. Source: data from Google Scholar.

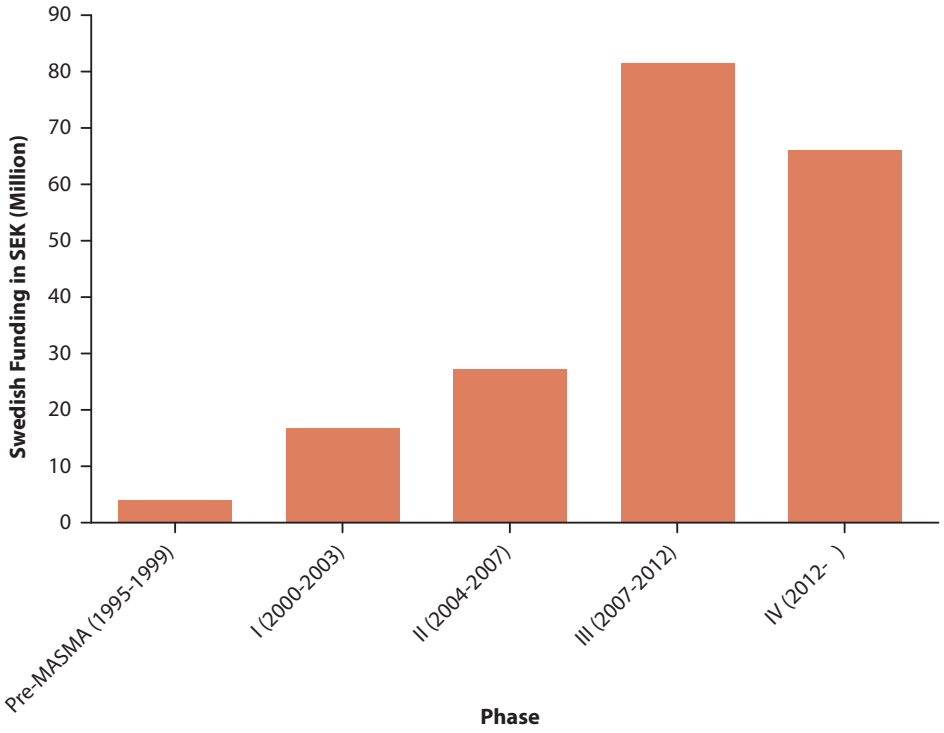


Figure 35.2. Government of Sweden support to WIOMSA from 1995 to 2015.

action and dialogue between organisations such that new relationships have been supported to become strong long-standing partnerships (eg KMFRI-IMS, ORI-UEM). MASMA has also played a key role in strengthening south-south partnerships by having this prerequisite as one of its main requirements to secure funding. Partnerships between academic and research institutions in Kenya and Tanzania, Tanzania and Mozambique, Mozambique and South Africa and South Africa with Mauritius and Reunion have been established through MASMA and EU-funded projects, a number of which are on-going.

WHO IS CONDUCTING RESEARCH?

In the WIO, government research institutions are important actors in the production of knowledge relevant to the coastal and marine environment. This is particularly the case in fisheries, but some countries also have research institutions concerned with a variety of coastal and marine environment domains. In some government-affiliated research institutions, and in particular kinds of research, there is a direct linkage between the production of knowledge and its application. Management authorities in the region often meet their knowledge needs by commissioning studies to government research institutions, consultants and, sometimes, universities (Figure 35.3). In this case, there is also a direct link between research and its application. However, there are also a number of institutions producing unsolicited research that could contribute to coastal and marine management but there are no formal mechanisms that could be used to channel them through.

RESEARCH UPTAKE

The use of research outputs by decision- and policy-makers cannot be represented as a linear relationship between supply and demand. How and why science is produced and balanced between national and local needs is influenced by, amongst other things, the availability of funds which may or may not be linked to national and sub-national (provincial, district, local) priorities. Given the significant percentage of the research budget that comes into the WIO from external sources, and not national budgets, research agendas may sometimes not be well harmonised with national or sub-national needs. In the WIO, lack of clearly expressed national research priorities for marine and coastal management is an important factor that limits the potential to improve this alignment need and, accordingly, the applicability of research for management, decision and policy

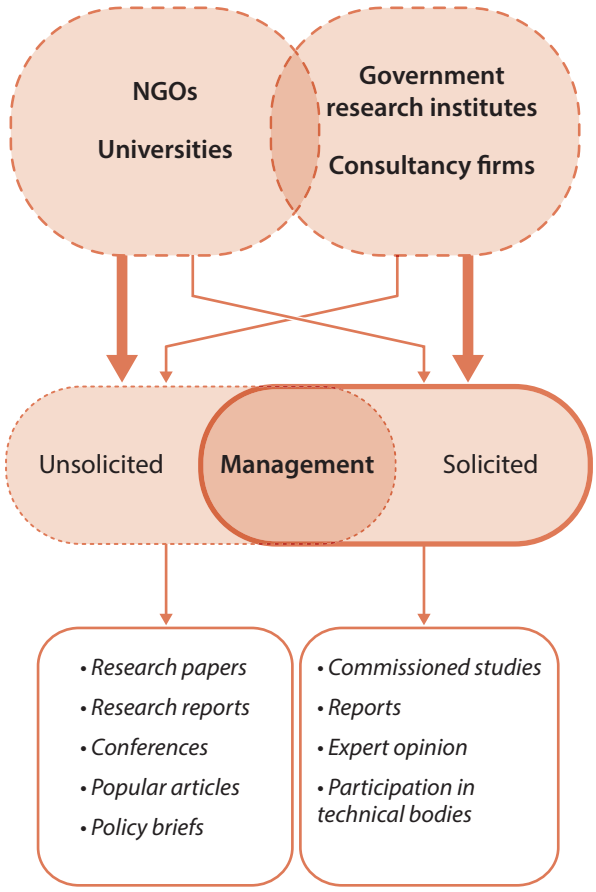


Table 35.3. Research and academic institutions in the WIO region (those with degree programmes in marine sciences are bulleted).

purposes.

The mechanisms used by research institutions to couple science to management, and barriers to achieve this, are contextual and vary between countries. Research institutions in the region are generally committed to producing research that contributes to national development needs, including those related to the sustainable management of the coastal and marine environment. Similarly, scientists in both government-affiliated and academic institutions recognise the importance of undertaking applied research and transmitting research results to potential users. Despite wide acceptance of the need to link science and management, the mechanisms to identify research priorities in the coastal and marine environment and to communicate research results to managers and policy-makers are often still poorly developed.

It is also clear that simply transmitting scientific results to decision-makers, while important, is not sufficient to effectively enable their uptake by managers. The use of science by decision-makers in the region, and elsewhere in the world, is influenced by many procedural, technical, and political factors. The role of individual and institutional values is also important. In this context, there continues to be a need for the development of new and innovative approaches to better integrating research agendas with management planning and decision-making processes such that both the development of research and the products it delivers are better integrated into an overall approach to natural resource management.

Examples of science that supports management can be gleaned from cases involving institutions and procedures that explicitly connect science to management. These can take many forms, but often involve mechanisms to identify and fund emerging research. Studies linked to extension or that include a demonstration of the feasibility of new approaches and solutions, and are ultimately aimed at replication, appear to be more successful in their 'uptake'. For instance, the MASMA-funded project, *"Determination of the Distribution and Characteristics of Fish Spawning Aggregation Sites (FSAS) and their Importance to the Artisanal Fisheries Resources of Seychelles"*, successfully convinced the Islands Development Company (IDC) of Seychelles (that was

Figure 35.3. Reported flow of communication between institutions producing science and agencies that use science related to research, development and management of the coastal and marine domain of the Western Indian Ocean states.

Country	Government research institutions and Universities	Non-governmental organizations
Comoros	University of the Comoros	
Kenya	Kenya Marine and Fisheries Research Institute (KMFRI) Technical University of Mombasa BSc (Marine Resource Management & Fisheries and Oceanography) MSc (Fisheries and Aquaculture) Eldoret University BSc (Coastal and Marin e Resource Management) South Eastern Kenya University BSc (Fisheries Management and Aquaculture Technology; Aquatic Sciences) MSc Aquaculture Pwani University BSc (Marine Biology and Fisheries) PhD (Fisheries) Jomo Kenyatta University of Agriculture & Technology (JKUAT) BSc (Fisheries and Aquaculture Sciences and Marine Engineering) MSc (Aquatic Ecology and Fisheries and Phycology)	
Madagascar	Institut Halieutique et des Sciences Marines (IHSM), University of Tuléar BSc, MSc and PhD Centre National de Recherche Oceanographic (CNRO) Station de Recherche Oceanographique de Vangaindrano (SROV)	Blue Ventures, CETAMADA
Mauritius	University of Mauritius BSc (Marine Science and Technology) MSc and PhD Albion Fisheries Research Institute Mauritius Oceanography Institute	Marine Conservation Society
Mozambique	University of Eduardo Mondlane BSc (Marine, Aquatic and Coastal Biology; Oceanography; Marine Chemistry; Marine Biology; Environmental Engineering; Fisheries Production) MSc (Sustainable Aquaculture; Applied Oceanography; Marine Biology and Fisheries Management; Coastal and Environmental Geology; Environmental Engineering; Aquatic Biology and Coastal Ecosystems) Nautical College of Mozambique BSc (Marine Engineering; Law of the Sea; Maritime Shipping) Polytechnic Institute of Gaza BSc (Fish Farming) National Institute for Hydrograph and Navigation (INAHINA) National Fisheries Research Institute (IIP) Centre for Research of Marine and Costal Environment (CEPAM)	CTV Ocean Revolution
Reunion	University of Reunion MSc (Biodiversity, Ecology & Evolution) IFREMER IRD	ARVAM Globice ARDA CapRun CRPMEM BIOTOPE Ocea-Consult BRGM Pareto Vie Oceane Ocea Consult
Seychelles	University of Seychelles BSc in Environmental Science Seychelles Fishing Authority	Nature Seychelles
South Africa	Council for Scientific and Industrial Research University of KwaZulu-Natal University of Cape Town Nelson Mandela Metropolitan University	Oceanographic Research Institute

Country	Government research institutions and Universities	Non-governmental organizations
Tanzania	University of Dar es Salaam Department of Aquatic Sciences and Fisheries (Aquatic Environmental Sciences and Conservation and Fisheries and Aquaculture and MSc in Fisheries and Aquaculture and PhD) Institute of Marine Sciences (MSc in Marine Science and PhD) Tanzania Fisheries Research Institute (TAFIRI)	Sea Sense
Regional NGOs	Wildlife Conservation Society CORDIO WWF CI IUCN WIOMSA	

involved in the fishing of grouper spawning aggregations) to agree to stop the practise after being presented with the project's results (Robinson and others, 2007).

Finally, projects that involve high degrees of collaboration between scientists, managers and resource users at all stages of the work are more likely to result in outputs that have a probability of being used by managers, decision- and policy-makers. Through another MASMA-funded project, *"Developing a model for strategic adaptive management of MPAs in the Western Indian Ocean"*, project members working with the staff and stakeholders of the Mombasa Marine Park and using their research results as the basis assisted the Park to set new management objectives with measurable targets. They have also used their research results to evaluate progress and determine necessary management actions, and evaluated effectiveness of actions (O'Leary and Tuda 2015).

The main barriers between scientific and policy-making/management communities in the region include:

• A paucity of relevant and timely research, coupled with a willingness and concomitant capacity of decision-makers to use it are important factors. An inadequate knowledge-base and the lack of an evidence-based management culture, technical capacity and funding are also important barriers ensuing from this.

• Several countries lack mechanisms and institutions to promote science-based management and decision-making. Such mechanisms and institutions are developing, often as part of the growing implementation of ICZM, or they may be project-based. Examples include working groups, forums and roundtables, where decision-makers and key stakeholders are engaged collectively. However, many of these mechanisms or institutions are short-lived if not supported by long-term commitment by stakeholders, or government institutions, and backed up by sufficient resources.

• Overall levels of funding for research and knowledge generation remain inadequate. This may be related to a continued lack of recognition of the socio-economic significance of marine and coastal issues in national systems of science and innovation, including research councils or their equivalent.

• Research in the countries in the WIO region for long periods has been dependent on donor funding. Donor funding, while valuable, does not promote an overall national research portfolio geared towards addressing national research priorities. Accordingly, whilst providing critical support and often strong catalytic inputs, donor-funded research contributions often do not fill research gaps since they are driven by donor priorities rather than specific national goals and needs.

• Local management authorities face many capacity challenges, which result from inadequate funding, a lack of suitably skilled staff, management tools and technical knowledge. The use of science and its products are particularly weak under these conditions.

• Many researchers and scientists do not understand nor engage with policy-making processes, which contribute to a disconnection between the scientific and policy-making communities. Scientists often conceive the link between science and policy as a one-way flow of information in which scientists convey scientific 'truth' to drive the

development of policy. Scientist often fail to appreciate the fact that research products, no matter how well-developed and tested, can often not be incorporated directly into decision-making without the inclusion of political, economic or social realities. Similarly, the outputs provided by scientists are often in a form that is not readily assimilated by decision-makers.

• Conversely, policy-makers expect science to provide definite answers and a full cost-benefit analysis of the implications of decisions. They also often assume that scientists fully understand and describe complex problems. These may be outdated ways of thinking about science and policy but they remain common.

• A greater emphasis on co-design of trans-disciplinary projects by stakeholder including scientists, managers and civil society, and the growing importance of the contribution of all stakeholders to the scientific process (co-production of knowledge) is not fully realised or practised in the region.

RESEARCH PRIORITIES AND CAPACITY NEEDS

The Africa Progress Panel recently proclaimed that "*the time has come to unleash Africa's green and blue revolutions*", and, also that "*Africa's farmers and fishers are equal to the challenge, but they need the opportunity. They need their governments to demonstrate more ambition on their behalf. African governments must now scale up the appropriate infrastructure and ensure that financial systems are accessible for all*" (APP 2014). This State of the Coast Report has argued throughout that access to, and the use of defensible scientific data, information and knowledge is integral to management options, decisions, and policies, that the region requires to attain sustainability, as defined in the Scenario chapter (no. 32). Research funding in the region is scarce and should be optimised to achieve the most effective and longest-term outcomes possible. Regional coordination of research agendas could manage the necessary overlap of research activities in trans-boundary areas. Common priorities and coordinated research efforts could also attract funding from outside the region, especially where synergistic partnerships can be developed and co-investment can be leveraged. The sections below briefly consider some current global and regional research priorities. In most cases, these are embraced in reports or programmes that identify priority themes which are then translated into action.

Global and regional research priorities

On a global scale, the Global Biodiversity Outlook (CBD 2014) reported on progress in meeting the Aichi Biodiversity Targets; achieving the 2050 Vision on 'Living in Harmony with Nature'; and on the importance of biodiversity in meeting broader goals for sustainable human development during this century. The Outlook identified a number of strategic goals aimed to achieve the objectives stated above. Most of the goals can be further refined for the global coastal and marine environment. The strategic goals were to:

• Address the underlying causes of biodiversity loss by mainstreaming biodiversity issues in governance processes; Reduce the direct pressures on biodiversity and promote sustainable use;

• Improve the protection of biodiversity by safeguarding ecosystems, species and genetic diversity;

• Enhance the benefits of biodiversity and ecosystem services to all; and

• Enhance implementation of biodiversity protection through participatory planning, knowledge management and capacity-building.

Similarly, the WWF published a Living Planet Report (WWF International 2014) which identified priorities to achieve sustainable use of the planet's resources. These priorities were:

• Equitable Resource Governance - Share the available resources, make fair and ecologically informed choices, measure success beyond GDP.

• Redirect Financial Flows - Value nature, account for environmental and social costs, support and reward conservation, sustainable resource management and innovation.

• Consume More Wisely - Through low-footprint lifestyles, sustainable energy use and healthier food consumption patterns.

• Produce Better - Reduce inputs and waste, manage resources sustainably, scale-up renewable energy production.

• Preserve Natural Capital - Restore damaged ecosystems, halt the loss of priority habitats, and significantly expand protected areas.

When placed in the context of global climate change, the Programme of Research on Climate Change Vulnerability, Impacts and Adaptation (PROVIA) has proposed a number of specific objectives towards our future on the changing planet. PROVIA is a global scientific initiative of the UNEP, the UNESCO and the WMO that seeks to har-

monise, mobilise and communicate the growing knowledge base on vulnerability, impacts and adaptation (UNEP 2013). A PROVIA report (UNEP 2013) emphasises the understanding of climate change vulnerability through mapping and measurement; development and strengthening of indicator and monitoring systems; an understanding of the risks of extreme climate events, non-linear impacts and tipping points. It also promotes:

- Advancing vulnerability reduction and adaptation solutions;
- Developing more inclusive cost estimates and prioritization criteria; and,
- Enhancing communication and stakeholder/public participation.

PROVIA has also identified key systems that need attention namely: food, water, ecosystems, energy, infrastructure and the built environment. Some of the emerging topics identified by the report include impacts of geo-engineering; legal principles and the role of law; food-water-energy-security; participatory processes for climate change mitigation and adaptation scenarios; decision theory; risk perception, climate knowledge and behaviour; governance, collaborative frameworks and networks; and long-term planning and design.

Coastal and marine research priorities

In recognition of threats to global sustainability of human activities in the ocean and coastal environment, IOC/UNESCO, IMO, FAO, UNDP (2011) has identified the following problems as being the priority concerns:

- Unsustainable fishing;
- Climate change and ocean acidification;
- Pollution and waste; and
- Loss of habitats and biodiversity, in some cases because of invasive species.

Many international programmes have either been developed on climate change and variability, social needs and ecosystems, or have recently changed emphasis to focus on these issues. Examples include the International Geosphere-Biosphere Programme (IGBP), Intergovernmental Platform for Biodiversity and Ecosystem Services (IPBES), Scientific Committee on Oceanic Research (SCOR), Global Ocean Observing System (GOOS) together with its regional alliances, DIVERSITAS, the International Human Dimensions Programme (IHDP), the World Climate Research Programme (WCRP), Science Partnership for the Assessment of Complex Earth System Processes (SPACES), Ecosystem Services and Poverty Alleviation (ESPA), Global Ocean Ecosystem Dynamics (GLOBEC) and the Global Change, Biodiversity, Ecosystems and Society in Africa (GCBESA) programme.

A recent WWF International report on the development of the Ocean Economy (Hoegh-Guldberg and others, 2015) is of direct interest to the coastal and marine environment. In this, it is contended that assets that rely on a healthy ocean environment generate more than two thirds of the annual base economic value of the ocean. As a result of a decline in the state of these assets, the associated economic activities are faltering and not delivering to their full potential. There is, however, a growing need for food and resources from the ocean. The report identified eight actions to secure our ocean assets and restore the ocean economy:

- Ensure that ocean recovery features strongly in the UN Post-2015 Agenda, including the Sustainable Development Goals;
- Take global action to avoid dangerous climate change and further damage to the ocean;
- Conserve and effectively manage 10 per cent of representative coastal and marine areas by 2020, increasing coverage to 30 per cent by 2030;
- Rebuild fish stocks to ecologically sustainable harvest levels;
- Drive new global cooperation and investment in the ocean;
- Reinvent public/private partnerships;
- Build transparent accounting of the value of ocean assets to improve decision-making; and
- Share knowledge more effectively and drive institutional collaboration.

Finally, the UNEP Coastal and Marine Strategy (2011) provided some clear directives on coastal and marine actions (UNEP 2011) relevant to the need for scientific products in support of management, decision- and policy-making:

- Land-Ocean Connections: to integrate the management of coastal watersheds, the coastal area (including cities) and the marine environment to optimise the ecosystem services and resilience of marine and coastal systems. Meeting this objective will address the issue of degraded water quality in coastal water due to land-based activities.
- Ecosystems for Human Well-being: to identify, assess and value the status and key drivers of change in marine and coastal ecosystems, their services and their link to

human well-being. The need for a better understanding of ecosystem services and their value will be addressed to meet this objective.

• Reconciling Use and Conservation: to ensure that appropriate governance frameworks, management tools, capacity and options are available for regions, countries, communities and the private sector, to effectively engage in the sustainable management of marine and coastal ecosystems, including reconciling competing uses.

• Vulnerable People and Places: to strengthen the ecological, economic and social security of vulnerable communities and places, including SIDS, to adapt and respond to natural disasters and climate change, by enhancing the resilience of marine and coastal ecosystems and social capital, and improving access and benefit sharing. Meeting this objective will help to address issues specific to SIDS, coral reefs, seamounts and other sensitive marine ecosystems.

DEVELOPMENT OF CAPACITY FOR RESEARCH

The National Research Council (NRC) of the National Academy of Science (NAS) (NRC-NAS 2008) describes capacity building as "*programs designed to strengthen the knowledge, abilities, relationships and values that enable organizations, groups and individuals to reach their goals for sustainable use of ocean and coastal resources. It includes strengthening the institutions, processes, systems and rules that influence collective and individual behaviour and performance in all related endeavours. Capacity building also enhances people's ability to make informed choices and fosters their willingness to play new developmental roles and adapt to new challenge.*" This holistic definition of the capacity building encompasses much more than training but also includes **different levels** (individual, institutional, enabling environment) and all **phases of the knowledge generation and knowledge translation cycle** (from setting the research agenda and research design to research use and communication). This is an important distinction as it reflects the reality of variable capacities across countries and regions, and also recognises that there are strong needs at all phases from research data collection through to the assimilation and mainstreaming of the knowledge gained into decision-making.

Though most of the countries in the region achieved independence between the early 1960s and mid-1970s, it was not until the 1970 that a noticeable increase in the number of marine scientists occurred. During this period the first marine scientists were completing their postgraduate studies. They were initially few in number and mainly fisheries biologists by specialisation. During the 1980s and 2000s, more marine scientists from a spectrum of disciplines (both in natural and social science) were trained.

Capacity-building needs in resource management authorities

Different types of management authorities, from national ministries responsible for policy development to local governments and protected area management structures, are responsible for policy implementation and day-to-day management of coastal and marine resource use. These are vastly different in character and, as a result, have different capacity-building requirements.

Institutions responsible for development of policies, programmes and strategies at the national level include both politically-appointed officials as well as technical staff. The extent to which politically-appointed officials have adequate technical competence for marine and coastal management varies. However, these institutions also have technical personnel that are often highly qualified, in many cases in areas directly relevant to coastal and marine management, and with a good understanding of science. On the whole, at the national level in some countries, there is often requisite capacity (if not always the political will) to source and apply science to policies, legislation, plans and strategies.

At this level, and in view of the findings presented in previous sections of this chapter, some relevant capacity-building interventions are needed, aimed at management authorities. These include:

• **Reinforcing the capacity of decision-makers to formulate policy and associated research needs** through forward-looking methodologies such as envisioning future scenarios. These involve considering how emerging trends and developments might affect policy and practice. Policy-makers need to understand current and future drivers of change and plan accordingly, identifying and prioritizing research issues that will address emerging challenges.

• **Enhancing mutual understanding of how scientific and management communities operate** through specific training to address some prevailing misconceptions. Another way to enhance mutual understanding would be to promote secondment of managers to research institutions and scientists to management authorities for "job-shadowing".

Capacity-building strategies to overcome barriers to effective integration of science

Overcoming the barriers to effective integration of science into decision-making and management processes cannot be achieved through capacity building alone. There are, however, a number of additional strategies that would strengthen the link between science and marine and coastal management. These include:

• Support for knowledge brokerage in boundary organisations. These could identify, review and synthesise all available scientific information relevant for a particular policy or management issue and effectively interact with decision-makers.

• Compile project-level lessons-learned that link science and policy and management, highlighting successes.

• Support projects that combine research and demonstration or implementation activities. There are successful cases in the WIO that will yield useful lessons such as the Rodrigues octopus fisheries project (Yvergniaux, undated) and the MASMA-funded project "*Developing a model for strategic adaptive management of MPAs in the Western Indian Ocean*" (O'Leary and Tuda 2015).

Regional capacity-building initiatives

Capacity-building initiatives have taken different forms in the region, including capacity building of individuals, institutions and society in general. Such efforts have aimed at improving their understanding of processes in, and the value of, coastal and marine environments. Capacity-building initiatives have also targeted institutions to improve their decision-making processes and build their technical skills to better fulfil their mandates. Some capacity-building initiatives have also targeted civil society with the aim of building their capacity to empower people to understand, engage in, and resolve issues associated with the better use and management of resources to maximize their opportunities for livelihood improvement.

In this context, several mechanisms have been used to deliver these different forms of capacity-building, including:

• **Technical short-term courses.** These types of courses have covered different types of specialised technical subjects that often represent enabling knowledge or skill sets such as nutrient analysis, coral reef monitoring, algal physiology, coastal erosion and leadership. The Nairobi Convention, in collaboration with the IOC-UNESCO and WIOMSA, organized a number of leadership courses targeting senior scientists and heads of research and academic institutions. Such short-term courses have been instrumental in laying the foundation for collaboration between national and regional institutions. They have promoted of the use of the same or comparable techniques in fieldwork and laboratory studies, as well as raised awareness and information dissemination and promoted leadership for marine related research and management at the highest levels of governance.

• **Writing workshops.** WIOMSA, through its MASMA Programme, has been providing grants for writing workshops. Specifically, these workshops seek to assist participants to attain a level of scientific and grant writing that can compete on a global scale for grants and publications. In these workshops, participants are asked to bring their own data with the aim of synthesizing information from multidisciplinary projects as well as information from relevant projects supported by other partners, leading to publications in peer-reviewed journals or books or policy briefs. Writing workshops have become a common feature of most of the MASMA-funded projects. They have provided opportunities to brainstorm on key research results, as well as for capacity building amongst emerging scientists in terms of approaches to data analysis, information synthesis and access, and the best methods for the dissemination of information and results.

• **Practitioner Short Courses.** These include broad-based training on marine protected area or natural resource management and ICZM that combine learning in a workshop setting with field visits and opportunities for the exchange of experience. Courses of this kind aim to address the need to rapidly develop a general understanding of emerging issues where there is limited capacity. Introduction level and general courses are then superseded by more specialised technical courses and /or integration into vocational and masters training courses.

• **Multi-Stage Courses.** Multi-stage courses combine on-the-job-learning and assignments with one or more intensive training sessions, often involving exposure to projects or other real-life management situations that provide the experience participants need to build their own capabilities. Participants then complete assignments and projects based on their workplace (or volunteer) experience (Coley and others, 2002).

• **Certification of professionals.** WIOMSA recognised the importance of the marine conservation and compliance sector when it instituted WIO-COMPAS (Box

BOX 35.1. THE AGULHAS AND SOMALI CURRENT LARGE MARINE ECOSYSTEM PROJECT (ASCLME) – ACHIEVEMENTS IN RESEARCH AND CAPACITY BUILDING by David Vousden



R/V Dr. Fridtjof Nansen, one of the vessels used during the ASCLME-coordinated cruises. © EAF-Nansen project.

This Project ran from 2007 until 2014 and supported nine countries in the western Indian Ocean region to undertake an environmental baseline assessment of the Agulhas and Somali Current Large Marine Ecosystems, to fill the information gaps needed to develop a Transboundary Diagnostic Analysis (TDA) and to support improved management decision-making through development and adoption of a Strategic Action Programme (SAP).

The main achievements from the Project included the development of National MEDAs (Marine Ecosystem Diagnostic Analyses) as 'state of the marine environment' reports for each country; integration of the MEDAs into a single, regional Transboundary Diagnostic Analysis; a draft Strategic Action Programme for Management of the LMEs; and a Western Indian Ocean Sustainable Ecosystem Alliance of partners that agreed to support scientific research, monitoring, capacity building and training.

More specifically in the context of actual scientific research as well as capacity building and training, the project has listed the following deliveries and successes in collaboration with its many partners:

Scientific Studies and Research

- 50 individual cruises 'legs' around the western Indian Ocean
- Deployment of permanent ocean-atmosphere monitoring mooring systems
- Use of satellite imagery to track productivity hotspots and identify upwelling incidents
- Study of ocean kinetics, particularly in relation to eddies associated with the Mozambique channel
- Substantial data collected on primary and secondary productivity as well as fish biodiversity and genetics (including comprehensive fish collections)
- Fisheries data reconstructions to demonstrate significance of small-scale fisheries
- Studies on marine-based pollutants and extent of land-based pollution impacts offshore
- Mapping of invasive species distributions
- Mapping of critical habitats and vulnerable/endangered species along with proposed management measures
- National and regional policy and governance baseline assessments completed with recommendations for strengthening and harmonising across the region
- Regional 'Cost-Benefit of the Ecosystem Approach' assessment completed

Individual national demonstration on community engagement and evolution of local economic development plans)

Capacity Building and Training

- Nearshore and coastal monitoring programmes developed

and agreed with each country in support of the ecosystem-based management approach

• Training of more than 100 new scientists on ecosystem monitoring and assessment techniques

• A 3-week intensive study and filed-work course providing a grounding in theoretical oceanography follow by 'hands-on' training at sea in data collection, analysis and survey planning

• Co-development and co-delivery (with the International Ocean Institute and University of Cape Town) of a 4-week Ocean Governance Training Course for managers

• Numerous workshops on such topics as the use of GIS and remote sensing; marine pollution; invasive species, port control, taxonomy, etc.

• A regional Capacity Building and Training Needs road-map developed for the countries

Cooperative agreements with various 'Alliance' partners for long-term delivery of CB&T needs repatriation of data, where possible from previous scientific activities.

35.2), the Western Indian Ocean Certification of Marine Protected Area Professionals (WIO-COMPAS 2012). This is a joint initiative of WIOMSA and the Coastal Resources Center (CRC) at the University of Rhode Island (URI). The initiative was further refined in liaison with leading conservation professionals in a number of African countries. Entrants to the programme are assessed by leading professionals and are certified at three levels: Level 1 – Marine Field Operations; Level 2 – Site Management; and Level 3 – Policy and Planning. All of these levels of certification are of relevance to the management situation under consideration and the WIO-COMPAS initiative thus merits its support as it offers redress to what appears to be the most burning gap in the capacity-building needs of the region.

• **Tertiary education leading to BSc, MSc and Phds** has been accomplished by course work (for BSc) and via other mechanisms such as training abroad through scholarships programmes offered by various international organizations such as Sida, CIDA, NORAD, AusAid, Commonwealth, GTZ, Belgium and JICA, and 'sandwich' programmes, whereby students spend the majority of their time in their home countries working on a locally relevant research problem. There are two modes of training under such arrangements. In the first, candidates are registered at overseas universities and attend courses, undertake data analysis and thesis write-up at that university, while in the second mode, the candidate is registered at a regional university and part of the data analysis and thesis write-up takes place at an overseas university.

• Increasing accessibility of research results through organisation of the **conferences and scientific symposia.**

• The development of training materials and guides such as the *WIO MPA Toolkit* (IUCN 2004). This type of initiative aims to produce appropriately designed and relevant technical information, methodologies, guidelines and training to underpin best practise in one or more natural resource management areas.

CONCLUSION

The WIO region has, over the years, built capacity for coastal and marine research and it is reasonable to state that increasing the pool of coastal and marine data, information and knowledge (scientific evidence) has resulted in an improvement of management of the coastal and marine environments. As indicated earlier, scientific research commissioned within the context of national growth and development is more likely to directly impact on resource management and the development of policy compared to research solely driven by external support. Where there is a clear expression of need for data, information and knowledge by managers and policy-makers in context of a national, regional or sub-national vision, the research is much more likely to be applied to solve real-world problems that then directly improve the situation locally, nationally, and, regionally. This does not, however, reduce the relevance of the global coastal and marine research agenda as expressed by the United Nations agencies and international NGOs such as WWF for the WIO, and these agendas can contribute to the basis for developing regional research priorities.

Most of the experiences of scientists and managers in the WIO region indicate a persistent perception that science to policy is predominantly a one-way affair, from producer to user. Whilst there is clearly a much stronger role for policy-makers and their advisers in developing research questions and agendas, it is also true that managers and decision-makers often do not understand the limits of scientific data, and their inherent risks and the issues of tem-

poral and spatial applicability. Concomitantly, in a space as complex as the coastal and marine environment, scientific data is not the only informant of decision-making and this perspective warrants development among researchers and research organisations alike. The task of connecting or co-producing scientific knowledge with users is not an automatic process and there needs to be a concerted effort to own the problem of producing usable science in the WIO.

The WIO encompasses a wealth of research and management institutions and agencies and yet, the overall human capacity in the region is still not consummate to the needs of addressing the complex and multidisciplinary issues in the coastal and marine environments it is comprised of. This is a result of amongst others, inadequate financial and human resources resulting from the low percentage funding for R&D in relation to GDPs of most countries, and insufficient investment in education and training, inadequate knowledge and awareness arising from factors such as lack of or inadequate regulations, and a lack of legal expertise. Generally speaking, the interactions between science, policy and management in the WIO take place in a context of limited, and often inadequate human capacity, including inadequate governance capacity, research capacity and capacity for fulfilling financial, operational and human resource functions. Investment and innovative approaches to building human capacity development remains a top priority for countries in the WIO.

BOX 35.2. WESTERN INDIAN OCEAN CERTIFICATION OF MARINE PROTECTED AREAS PROFESSIONALS (WIO-COMPAS) by Michael H. Schleyer

WIO COMPAS
Western Indian Ocean • Certification of Marine Protected Area Professionals

The overall goal of WIO-COMPAS is to establish a professional association that provides a framework to promote competence, professionalism, leadership, innovation and ethical conduct amongst Marine Protected Area (MPA) managers. It recognizes and accredits individuals working in MPAs whose knowledge and skills meet a clearly defined professional standard. It then further enhances their knowledge and skills through networking with other professionals, sharing new ideas and thinking about MPA management and coastal governance.

The WIO-COMPAS programme is structured around the four elements of Experience, Examination, Education and Ethics. While it does not provide training, it does provide candidates professional development sessions during the certification assessment. Applicants are selected on merit and undergo a rigorous assessment during which they are scored in their competence in multiple areas. A code of ethics binds together individuals who become certified - known as MPA PROs - to uphold the high standards of the programme and their profession. A total of 68 MPA PROs have been accredited since the launch of WIO-COMPAS in 2012.



Participants of the Western Indian Ocean Training on Understanding and Communication Climate Change on a field trip in Algoa Bay, South Africa. © Yoon Kim.

Source: Coastal Resources Center and WIOMSA (2012)

References

References - Chapter 35 – Coastal and marine research and capacity building

APP (2014). *Grain, Fish, Money - Financing Africa's Green and Blue Revolutions*. Africa Progress Panel. Africa Progress

Report 2014

CBD (2014). *Global Biodiversity Outlook 4*. A mid-term assessment of progress towards the implementation of the Strategic Plan for Biodiversity 2011-2020. Secretariat of the Convention on Biological Diversity. Montréal

Coley, C., Squillante, L., Hale, L., Kiambo, R., Francis, J. and Mbarouk, F. (2002). *Learning and Performing: developing Skills for Coastal Management Practitioners*. Final Report on the First Course on building Capacity for Sustainable Integrated Coastal Management in the Western Indian Ocean Region. WIOMSA/CRC

COSTECH (undated). *Tanzania Commission for Science and Technology*. Available at http://www.costech.or.tz/

Davis, C. and Carden, F. (1998). Research effectiveness and R and D evaluation in developing countries. *Knowledge and Policy* 10(4), 7-30

EAMFRO (1965). *Annual Report*. East African Marine Fisheries Research Organization. East African Common Services Organization

Hoegh-Guldberg, O. (Lead Author) (2015). *Reviving the Ocean Economy: the case for action - 2015*. WWF International. Gland, Switzerland, Geneva

HRDC (2006). *Transforming Mauritius into a Knowledge Hub*. Human Resources Development Council. Ministry of Education and Human Resources Sectoral Committee Report

IOC/UNESCO, IMO, FAO, UNDP (2011). *A Blueprint for Ocean and Coastal Sustainability*. An inter-agency paper towards the preparation of the UN Conference on Sustainable Development (Rio+20). IOC/UNESCO. Paris, France

IUCN (2004). *Managing Marine Protected Areas: A Toolkit for the Western Indian Ocean*. IUCN Eastern African Regional Programme. Nairobi, Kenya, 172 pp. http://www.wiomsa.org/mpatoolkit/

Morcos, S. (2002). The Education Mission of Marine Sciences: A case study of East Africa, the early initiatives, 1930-1980. In *Oceanography History: The Pacific and Beyond* (eds. K.R. Benson and P.F. Rehbock) pp. 215-223. University of Washington Press

NACOSTI (undated). *National Commission for Science, Technology and Innovation*. Available at http://www.ncst.go.ke/

NRC-NAS (2008). *Increasing Capacity for Stewardship of Oceans and Coasts: A Priority for the 21st Century*. Committee on International Capacity Building for the Protection and Sustainable Use of Oceans and Coasts of the Ocean Studies Board. National Research Council of the National Academies of Science. National Academies Press, Washington, D.C.

O'Leary, J. and Tuda, A. (2015). *Using Science to Empower Communities and Improve Marine Protected Areas in East Africa*. Available at http://voices.nationalgeographic.com/2015/02/24/using-science-to-empower-communities-and-improve-marine-protected-areas-in-east-africa/

Rao, T.S.S. and Griffiths, R.C. (1998). *Understanding Indian Ocean: Perspective on Oceanography*. UNESCO. Paris, France

Richmond, M.D. (ed.) (2011). *A field guide to the seashores of Eastern Africa and Western Indian Ocean Islands*. Sida/WIOMSA

Robinson, J., Marguerite, M., Payet, R. and Isidore, M. (2007). *Investigation of the Importance of the Reef Fish Spawning Aggregations for Sustainable Management of Artisanal Fisheries Resources in Seychelles*. MASMA Final Technical Report. WIOMSA Book Series No 6

RoK (2008). *Science, Technology and Innovation Policy and Strategy*. Republic of Kenya. Ministry Of Science and Technology. Nairobi, Republic of Kenya

RoMZ (2006). *Estratégia de Ciência, Tecnologia e Inovação de Moçambique (ECTIM)*. Republic of Mozambique, Conselho de Ministros.

RSA (2002). *South Africa's National Research and Development Strategy*. Republic of South Africa.Department of Science and Technology, Government of the Republic of South Africa, Pretoria

The World Bank (undated). *Research and development expenditure (% of GDP)*. Available at *http://data.worldbank.org/indicator/GB.XPD.RSDV.GD.ZS*

UDC (2013). Politique Nationale de l'Enseignement Superieur et de la Recherche a l'Horizon 2020, Mars 2013. Union de Comores. Ministère de L'education Nationale de la Recherche de la Culture et des Arts Charge de la Jeunesse et des Sports. 25 pp

UIS (2010). MEASURING R&D: Challenges Faced by Developing Countries. UNESCO Institute for Statistics. Quebec, Canada. 40pp. www.uis.unesco.org/template/pdf/S&T/TechPaper5_EN.pdf

UNEP (2011). *Marine and Coastal Strategy: The Other 70% - Executive Summary*. UNEP. Kenya

UNEP (2013). *Research Priorities on Vulnerability, Impacts and Adaptation - Responding To The Climate Change Chal-*

lenge: Priorities on Impacts and Adaptation to the Climate Change Challenge. United Nations Environment Programme. Nairobi

URT (2010). The National Research and Development Policy. United Republic of Tanzania. Ministry of Communication, Science and Technology. United Republic of Tanzania

WIO-COMPAS (2012). W*estern Indian Ocean – Certification of Marine Protected Areas Professionals Program Handbook: Overview, Processes, Competences and Rules*. Coastal Resources Center and WIOMSA

WWF International (2014). *Living Planet Report 2014 - Species and spaces, people and places*. WWF International. Switzerland, Geneva

Yvergniaux, Y. (undated). *Management of the octopus fishery in Rodrigues*. Smart Fiche 12, SMARTFISH Programme

Part VIII
Overall Assessment

José Paula

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Overall Assessment of the State of the Coast in the Western Indian Ocean

José Paula

Opposite page: Will the marine resources these girls collect in the tidal flats near Ulo village, north Mozambique, be available in the future for food security or will they benefit from economic development and depend on modern amenities instead? © José Paula.

INTRODUCTION

This chapter offers an overall view of the state of the coast in the western Indian Ocean (WIO), by integrating the four sectorial assessments and following the Drivers – Pressures – State – Impact – Response (DPSIR) methodology. It analyses the current condition of ecosystems, resources, services and human activities and their expected evolution (*state and trends*) in response to root causes that drive change (*drivers*), further highlighting the ways these factors act on the environment and human related dependencies (*pressures*) and their expected outcome on the environment and livelihoods (*impacts*). Human societies adapt by acting on the drivers and pressures (*responses*) to mitigate impacts, aiming to maintain state of the environment or reverse negative trends. This chapter further condenses and provides sectorial recommendations.

The WIO region main features

The WIO spans a large latitudinal range, from the Somalia region, influenced by the strong monsoon regime of the northern Indian Ocean, to the sub-tropical regime of the Kwa-Zulu Natal Province in South Africa. It thus encompasses tropical and subtropical regions of diverse nature, rich stretches of coast along the mainland countries of Somalia, Kenya, Tanzania, Mozambique and South Africa, and vast oceanic areas with the island states of Madagascar, Seychelles, Comoros, Mauritius and French Territories. The WIO region is essentially within the Western Indo-Pacific biogeographic realm, but its southwest limit enters the Temperate Southern Africa biogeographic realm (Spalding and others, 2007). The WIO region presents such uniqueness of features that render it a structural and functional unity within the world global ocean (Obura and others, 2012). The main portion of WIO region is also referred to as the Eastern African Marine Ecoregion (WWF 2001).

Geomorphological and oceanographic features define the character of the WIO (see detailed description in Chapter 1). The bathymetric structure influences water flows (Parson and Evans 2005), modulating the ecosystems' large-scale mosaics and associated biodiversity (Obura and others, 2012). The main oceanographic features are the monsoonal regime in the northern WIO and the equatorial current that diverges close to the mainland and produces the southern moving complex eddy system of Mozambique Channel, the south-flowing East Madagascar Current, meeting the mainland south of Mozambique and merging with the Agulhas Current that transports heat to the south before retroflecting eastwards at the southern end of the African continent (Lutjeharms 2006, see Figure 36.1).

The social fabric of the WIO, where much of the population lives at the coast, is an amalgam of diverse populations with different origins, a product of the rich and varied political history, where networks of trade interactions generated a high ethnic and cultural diversity (see Chapter 1). The cultural heritage is important and matches the natural richness. Most countries in the WIO have high population

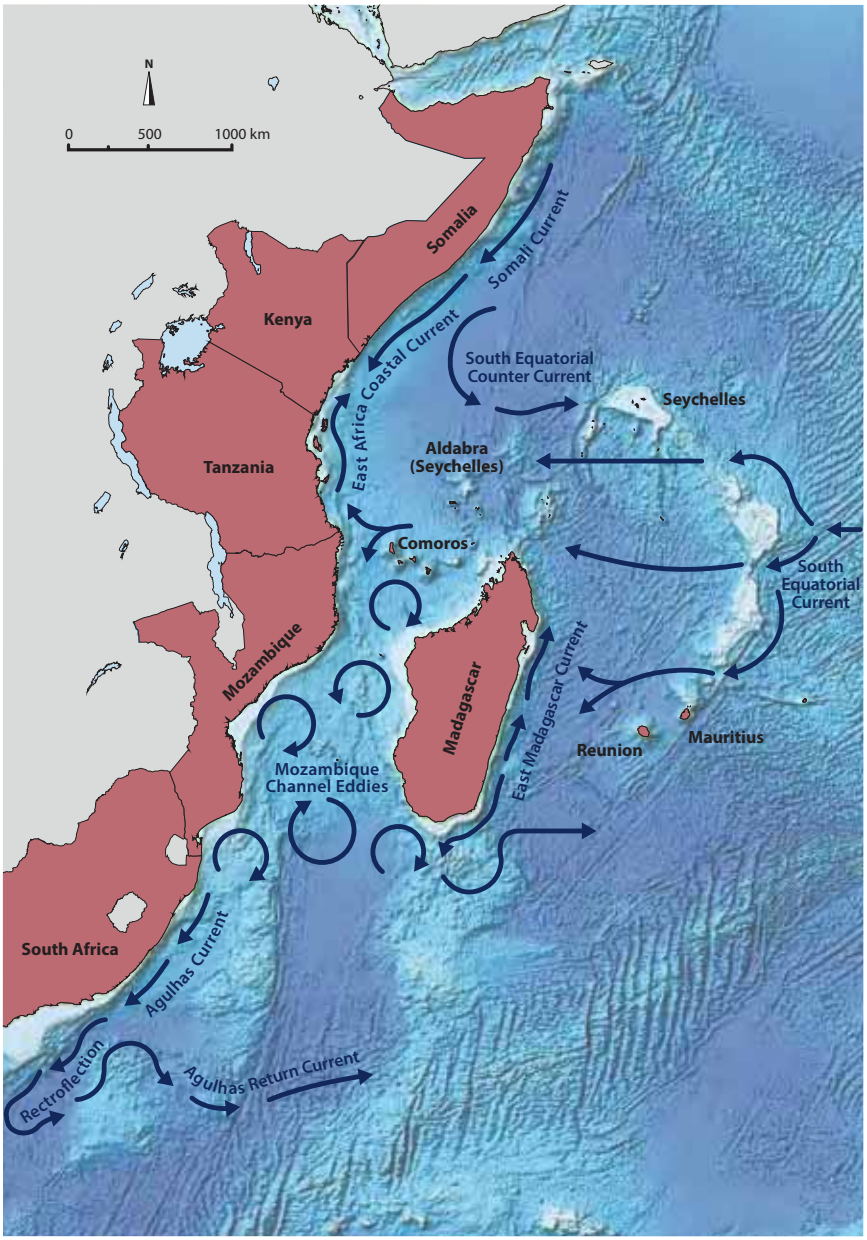


Figure 36.1. The WIO region, showing the countries, the bathymetric profile (adapted from Amante and Eakins 2009) and main current patterns (adapted from Lutjeharms and Bornman 2010).

growth rates (UNFPA 2002, UN 2012), and coastal development is expected to grow accordingly (UN-Habitat 2014).

The main drivers of growth rely on the extractive, construction and services sectors, and the latter also including the tourist industry. Foreign direct investments (FDIs) have supported growth but focus particularly on the extractive industry. However, for most WIO countries, GDP is low with widespread financial constraints and poverty. Economic development and poverty alleviation are therefore main targets within the policies of most WIO governments.

The vast resources of the region are driving economic development, with many countries presenting annual economic growth rates over 7 per cent. With the Blue Economy adoption (see Box 36.1), defensive precautionary policies give rise to sustainable exploitation of resources for economic development and poverty alleviation. For a few countries in the region, the oil and gas industry has the potential to take a leading role in driving national economies. Other emerging industries, such as those derived from the exploration of genetic resources and bio-prospecting, are developing. Although economies of most WIO countries are essentially still extraction-dominated, most have enormous potential for development, especially if they increase their capacity by moving into product transformation through adding value.

The mandate and methodology of the RSOCR for the WIO

The RSOCR derives from requirements of the Nairobi Convention and contributes towards the United Nations-led production of the World Ocean Assessment (WOA) reports, and to other global and regional processes, such as the Environment Outlooks, coordinated by UNEP. The background methodology is based on the Opportunities Framework and the DPSIR approach (see Chapter 2), adopting and adapting the WOA framework. While the political agenda included the Contracting Parties and National Focal Points of the Nairobi Convention, the RSOCR technical process was guided by WIOMSA (Western Indian Ocean Marine Science Association) and involved a representative set of scientists with broad experience in the region.

The general aim of the RSOCR is to integrate the socio-economic and ecological knowledge of the WIO region. Its main objectives are to: i) provide a comprehensive baseline, ii) highlight main opportunities, iii) describe successes and challenges, iv) identify capacity building needs, v) identify knowledge gaps, and vi) propose policy options.

ASSESSMENT OF BIODIVERSITY

The WIO countries have, in general, low income, and consequently a large portion of the population is dependent on coastal and marine resources and ecosystem services. The biodiversity of these systems is thus under direct and indirect pressures from resource exploitation and anthropogenically-driven habitat degradation. The effects and impacts of global climate change add further pressures to local-acting sources of disturbance.

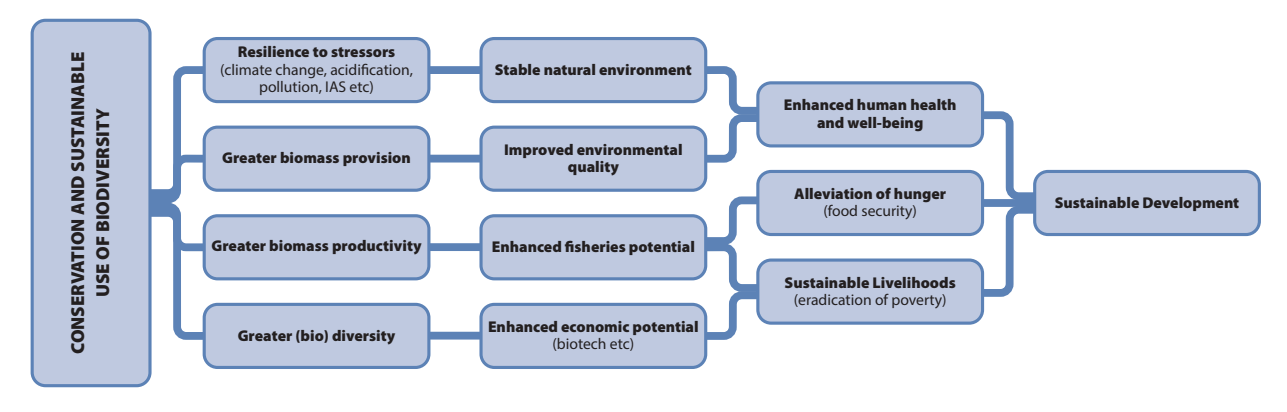
The assessment of biodiversity addressed the main ecosystems that constitute the major support for biodiversity and living resources, such as the nearshore habitats (see Chapter 4), mangroves, salt marshes and seagrass beds (see Chapter 5), coral reefs (see Chapter 6), rocky reefs (see Chapter 7), sediments (see Chapter 8) and pelagic and deep sea environments (see Chapter 9). The assessment further included a summary of threatened marine species (see Chapter 10), as well as the significant social and economic aspects of biodiversity conservation (see Chapter 11). For detailed descriptions, refer to these chapters and references therein. The overall assessment merges the biodiversity components (ecosystems, threatened species and socioeconomic aspects) into a single analysis. Figure 36.2 attempts to provide a summary of the RSOCR biodiversity assessments under a framework of DPSIR methodology. The term ''biodiversity" is used here in its holistic scientific meaning, ie, including all levels of organization of life, from genes and populations to species, habitats, ecosystems and ecoregions.

Drivers of change

Drivers of change include those that affect oceans at a planetary scale, namely global change driven by climatic alterations due mainly anthropogenic forcing, but also local drivers related to human development and emerging activities. Global change main effects include (see Chapters 14, 15 and 17):

- **Increased extreme events,** such as storms and cyclones, affecting physically the coastal zone by erosion, sedimentation and destruction of habitats, but also through alteration of precipitation patterns leading to flood and drought events. Behaviour of river catchments in relation to these pressures will produce changes in sediment loads and estuarine discharges to the ocean.
- **Sea level rise** is considered to affect the WIO region in the mid term, with consequences to habitats by submersion and erosion, especially in low lying intertidal areas like tidal flats, mangrove forests and salt marshes. Additionally, sea level puts at risk the integrity of human settlements at the coast.
- **Temperature rise,** mainly SST, affects directly the biology of key organisms such as corals that are prone to bleaching. On the longer term, ocean warming will alter the distribution of organisms and will impact of species local extinctions and replacement, with unforeseen consequences for ecological patterns and resource availability.
- **Ocean circulation** may be altered, namely patterns of currents at mesoscales. This will affect dispersal of organisms and distribution of primary productivity, affecting biomass and biological communities. These shifts may not necessarily decrease productivity and biodiversity at a WIO region scale, but will certainly displace resources and affect the geography of traditional living resource extraction activities.
- **Changes in sediment dynamics** can occur via extreme events, as well as changes to coastal currents and sediment loads from river basins, affecting patterns of sedimentation and erosion in the coastal zone.
- **Acidification** is a consequence of the increasing

BOX 36.1. THE OCEAN OR BLUE ECONOMY by Louis Celliers



Integrated holist approach underlining ecosystem approaches for developing countries with economies directly related to environmental exploitation, Source: UNEP Blue Economy Concept Paper.

UNEP defines a green economy as one that results in "improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities" (UNEP 2010b). In its simplest expression, a green economy is low-carbon, resource efficient, and socially inclusive. In a green economy, growth in income and employment are driven by public and private investments that reduce carbon emissions and pollution, enhance energy and resource efficiency, and prevent the loss of biodiversity and ecosystem services (UNEP 2011).

In providing food, oxygen and livelihoods, the world's oceans and coasts have the potential to perform a critical role in the move towards a green economy. In this coastal context, what can be called the 'Blue-Green Economy', results in a reduction in ecological impacts, while promoting the economic and social sustainability of traditional and emerging ocean-oriented economies (UNEP and others, 2012). The blue-green economy is related to a number of interrelated sectors, including, for example fisheries, tourism, maritime transport, energy generation, aquaculture, mining and nutrient Economy.

More recently, WWF International estimated the economic value of the oceans, measured as "gross marine product" (GMP) – equivalent to a country's annual gross domestic product, to be at least US$ 2.5 trillion. They estimated the total "asset" base of the ocean to be at least US$ 24 trillion (Hoegh-Guldberg and others, 2015). These values are underpinned by direct outputs (fishing, aquaculture), services enabled (tourism, education), trade and transportation (coastal and oceanic shipping) and adjacent benefits (carbon sequestration, biotechnology).

load of CO_2 in the oceans, albeit their effects more pronounced in cold and deep waters. It affects the calcification processes of organisms such as corals and certain phytoplankton. Scenarios predict that by 2100 all coral reefs will live in marginal conditions for survival under this threat.

At the WIO region level, demography, including population growth, is a major driver of change. The major components of human development drivers are (see Chapters 29 and 32-34):

- **Population growth** within the coastal zone, by either migration or high growth rates, impacts on urbanization and land reclamation, but also on pollution discharges and pressure over natural resources.
- **Poverty and inequality**, leading to widespread uncontrolled resource extraction.
- **Inadequate governance**, such as limited efforts for regulating and especially enforcing measures to avoid and mitigate impacts from human activities.
- **Lack of education and awareness** on coastal and marine issues is a widespread problem in the region, leading to a low appreciation of the natural environment, as well as low levels of community participatory actions and weak demand for civil rights.

Land based activities are a major source of pressure on species and ecosystems, and affect in particular the

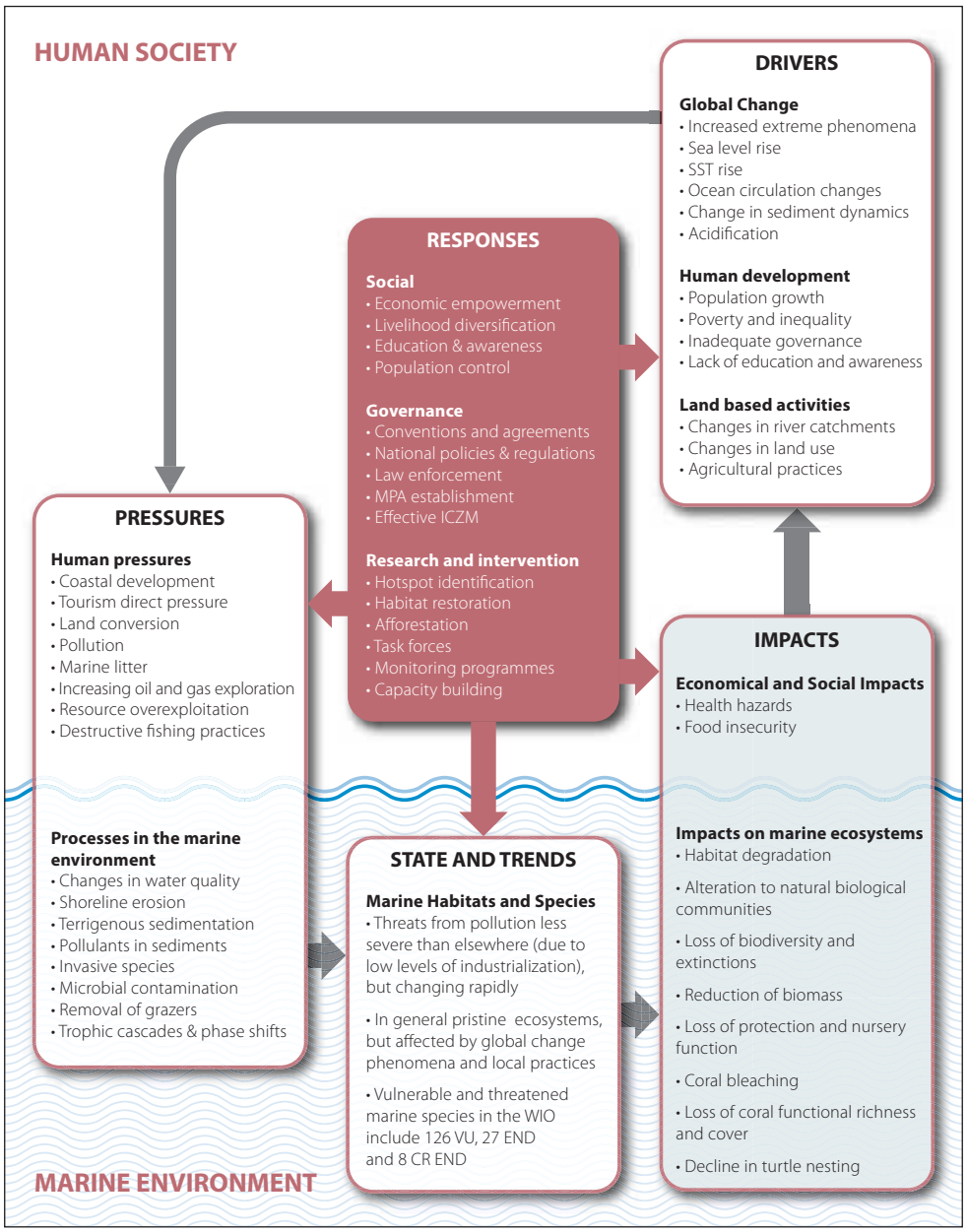


Fig 36.2. Diagrammatic summary of DPSIR analysis for marine biodiversity in the WIO.

aquatic interfaces of estuarine and lagoon character that are dependent on river basins. In particular (see Chapter 29):

• **Changes in river catchments** are increasing with economic development, namely damming for clean energy source and water subtraction for consumption and agriculture, with consequences for normal flood regimes and sediment transport, and potentially leading to salt intrusion processes near the coast.

• **Changes in land use,** namely reclamation of large portions of ecosystems such as mangroves and salt marshes for construction, aquaculture and salt ponds.

• **Agricultural practices** enhance nutrient load in rivers and estuaries, and provoke increased soil erosion.

Pressures on marine ecosystems and species

Direct pressures on marine ecosystems and species arise from human activities and include a wide range of sources that affect the environment in multiple and synergistic ways. These include:

• **Land conversion** diminishes the available ecosystem cover and associated biodiversity and resources (see Chapters 27-29).

• **Coastal development** leading to land reclamation and increasing overall impacts (see Chapter 29).

• **Pollution** arises from multiple sources and can be derived from industrialization, domestic load and other sources, such as aquaculture and agriculture, affecting biological and ecological processes (see chapters 25-29).

• **Marine litter** poses additional problems to many species by clogging feeding and respiratory biological systems, and by secondarily contaminating water (see Chapter 25).

• **Tourism pressure**, dependent on pristine ecosystems, has frequently a negative feedback by decreasing conditions that lead to tourism development in the first place (see Chapter 28).

• **Increasing oil and gas exploration** constitutes a developing threat to marine ecosystems. While creating significant economic opportunities it poses high risks for environmental contamination during both regular operations and in case of accidental spills (see Chapter 26).

• **Resource overexploitation** is evident for some resources in the WIO region (see Chapters 20 and 21).

• **Destructive fishing practices** impact on species and ecosystems, such as beach seining with destruction of seagrass beds, small-mesh seine nets affecting juvenile stages of resources, poison and dynamite used in coral reefs, and by-catch and incidental catches in semi-industrial and industrial fisheries (see Chapters 20 and 21).

The drivers of change will give rise to structural and functional anomalies within natural systems, creating situations that increase stress on the quality of ecosystems and bio-ecological patterns. In particular, the following processes may occur:

• **Changes in water quality**, affecting natural biogeochemical processes, primary productivity and tolerance of species.

• **Shoreline erosion** and sedimentation will alter natural patterns, creating artificial dynamics of sedimentary ecological processes.

• **Terrigenous sedimentation** affects different types of organisms, especially corals and filter-feeding species.

• **Pollutants** are trapped in seabed sediments, such as organic pesticides from agriculture and heavy metals from industrial waste, and can be released and contaminate trophic networks.

• **Invasive species**, via transport in ballast water or via immigration due to global climate change, pose additional threats to local species and ecological processes.

• **Microbial contamination** is a further threat to the health of ecosystems and their species, but also a risk to human health.

• **Removal of grazers** can provoke ecological disruptions and induce the overgrowth of opportunistic species.

• **Trophic cascades** are processes that affect whole trophic networks, reaching their top organisms, frequently those that represent food security resources. An example being nutrient enhancement leading to red tides that impact filter-feeders consumed by humans.

• **Phase shifts** are states of ecosystems in which the dominant structuring species change, with long-term effects, such as the case of substitution of corals by opportunistic algae following extreme bleaching, with concomitant erosion and decrease of habitat complexity that supports high biodiversity levels.

State and trends of the marine environment

In general, the WIO region has relatively pristine coastal and marine ecosystems, mainly due to the current low levels of industrialization and economic development. However, these conditions may be rapidly changing, as GDP is increasing and emergent activities will likely induce the much-needed economic development for the region. The benefits of development and adoption of Blue Economies will pose additional threats to ecosystems and species, and risk negative feedbacks on environmental quality and traditional living resources. It can be summarized that:

• Threats from pollution and other direct anthropogenic pressures are less severe than in other parts of the world, but this current state is changing rapidly with development trends.

• Overall the marine ecosystems present high levels of quality and associated biodiversity.

• Nevertheless the WIO region has several species listed as vulnerable and threatened by CITES, namely 126 Vulnerable, 27 Endangered and 8 Critically Endangered.

Impacts on the marine environment and related livelihoods

Impacts on the marine environment in the WIO region can be categorized as environmental impacts (affecting species and ecosystems) and human impacts (affecting economic and social features). The main environmental impacts may be summarized as follows:

• A degree of **habitat degradation** is evident at the global scale, the best example being the bleaching phenomena in coral reefs, albeit of worldwide character. At local scales, severe habitat degradation is mainly found in peri-urban ecosystems and affecting their highly utilized natural resources.

• **Alteration of natural biological community** structure is expected from multiple impacts that affect abundance and diversity.

• **Loss of biodiversity** results from multiple causes, global and local, and **extinctions** can be related to climate change or local degradation pressures.

• **Loss of protection** is evident at the coastal zone, where ecosystems like mangrove forests protect coastal land from storm surges or tsunamis, and contribute to coastal stability. Seagrass beds and dune vegetation also contribute to the latter. The loss of habitats such as mangroves and seagrasses reduces **nursery function** areas for resources like fish and shrimp.

• Degradation will ultimately lead to **reduction of resource biomass**, and, together with overexploitation, can disrupt traditional artisanal and industrial fisheries.

• In particular **coral bleaching** is a strong impact that puts at risk the highly diverse and productive reef ecosystems.

• Degradation of coral reefs, also driven by other non-global pressures such as trampling and overexploitation, leads to **loss of coral functional richness and cover**.

• Pressures on the neritic waters (from marine litter and incidental fishing) and coastal urbanization provoke **decline in turtle nesting** on sandy shores, putting at risk these vulnerable animals.

Society responses

Adaptation to global change and mitigation of its effects is of major importance for the years to come. The effects of the global drivers act synergistically with the local drivers of change, which society must minimize and mitigate. Responses to these increasing challenges must be addressed in multiple actions that cross sectors and specific activities. First, social approaches must be targeted through society responses. Secondly, governance structures must fulfil their role and develop adequate political and regulatory mechanisms. Thirdly, research must be strengthened and adequate communication with interested parties established, to transmit messages in the appropriate formats for each group of stakeholders. Civil society must be engaged in actions that will promote awareness. Regarding social responses, expected targets are:

• **Economic empowerment** of society at all levels that leads to human well-being, as a fundamental step for awareness and positive environmental attitudes.

• The alleviation of pressure on resources and the ecosystems where they thrive are related to **livelihood diversification**.

• **Education and awareness** are the basic frameworks for civil engagement on environmental issues, namely conservation and sustainable exploitation of resources.

• **Population control** is also considered as a target for sustainable development, by better regulation of human migrations and social interventions.

Managing environmental issues involves strong governance at all levels, from policies to enforcement. The following actions are necessary:

• Ratification of **global conventions and regional agreements**, to engage in worldwide efforts and promote transboundary management mechanisms.

• Establishment of strong national **environmental policies and sectorial regulations** to tackle marine issues.

• Create appropriate and effective **law enforcement** for regulations and practices.

• Establish adequate **networks of conservation** that comply with the targets of CBD by 2020 (10 per cent of protection), and this way protect sensitive systems and establish potential spill over areas.

• Strengthen **Integrated Coastal Zone Management**.

There is a consistent view that research in the coastal and marine environment has to be increased in the WIO region. Fundamental research creates the basis for the development of applied knowledge, that can address current challenges but also build up new opportunities in the framework of Blue Economy. Some of the actions that could be promoted include:

• Identification of sensitive and ecologically important areas that should be viewed and protected as **hotspots** for biodiversity at all levels.

• Promote knowledge for the **restoration of degraded habitats** to enhance ecological functions and maintain or decrease trends of biodiversity loss.

• **Afforestation** is a good example where community engagement in conservation efforts is producing promising results, such as mangrove forest plantations.

• Establishment of **task forces** within the scientific and civil society to address specific challenges, such as the existing Coral Reef Task Force and the WIO Mangrove Network.

• Create and maintain **monitoring programmes** for observing trends and link to research and management.

• Increase efficiency by making **capacity building** in necessary fields such as research, management, law enforcement and awareness promotion.

General recommendations regarding biodiversity (these recommendations derive from the assessment under Part III, and are detailed in the summary Chapter 12).

- Promote **awareness** at various levels (resource users and managers, the public, politicians and authorities) regarding the value and vulnerability of the WIO's natural marine capital.
- Increase **funding for research**, to create the knowledge needed for a greater understanding of WIO coastal and marine ecosystems and resources and consequently their improved management.
- Increase investigation of **shelf sediments and deep sea phenomena**, the major gaps in the WIO region.
- Increased funding for **marine resource management**.
- Increase **capacity building** to promote regional skills and expertise on threatened species and their protection.
- Establish **WIO Threatened Species Task Forces** as a means to mobilise capacity to deal with threatened or declining marine species and habitats, or those in need of special attention or protection.
- Promote **National and Regional integration** and **cross-sectorial linkages** to facilitate and provide a more coherent approach to the management of transboundary resources.
- Promote **alternative livelihoods**.
- Search for **alternative food sources/equivalents** to alleviate overfishing.
- Promote **value-adding** and **technological transfer** regarding new products.
- **Monitor the harvest** of vulnerable species.
- **Establish MPAs and closure mechanisms**, promoting community participation.
- Prioritize **areas for protection**, in terms of suitability, size and spacing.
- Identification of **areas of resilience**, where special protection should be granted.
- Promote community-based **habitat restoration and rehabilitation**.
- Promote **sustainable use** of coastal and marine resources.
- Strive for compliance with CBD biodiversity protection **targets by 2020**.

ASSESSMENT OF SERVICES FROM THE MARINE ENVIRONMENT OTHER THAN PROVISIONING

An assessment of services from the marine environment, other than provisioning, is developed under Part IV of the RSOCR. The concept of services provided by the WIO is presented in Chapter 13, and these may be categorized into regulating, supporting and cultural services. The assessment included the role of oceans in the hydrological cycle (see Chapter 14), sea/air interaction (see Chapter 15), phytoplankton primary production (see Chapter 16), ocean-sourced carbonate production (see Chapter 17) and cultural and derived services from the marine environment (see Chapter 18). Figure 36.3 provides a summary of the RSOCR assessment of services from the marine environment, other than provisioning, under the DPSIR methodology framework.

Climate regulation in the WIO

The exchange of mass and energy at the interface between the sea surface and the atmosphere results in a complex coupling (see Chapters 14 and 15 for details on biogeochemical processes, weather and climate regulation in the WIO region). The WIO region shows strong inter-annual climatic variability, due phenomena such as El Niño Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD), as well as seasonal climatic variability derived from the monsoon circulation (Manyilizu and others, 2014). Main climatic *pressures* are:

- Increase in sea surface temperature (SST) (Roxy and others, 2014),
- Increase in surface air temperature (Vincent and others, 2011), and
- Increase in wind speed (eg Mahongo and others, 2012).

Evidence shows that basin-scale decadal warming trends in the upper ocean heat content, for the period 1955 to 2008 may lead to rising sea levels and significant stress to some coastal and marine ecosystems (Levitus and others, 2009). Zinke and others (2005) reported evidence of strengthening of the South Equatorial Current (SEC). This ocean current affects biological productivity and the capacity of the ocean to store heat and carbon. In the upper thermocline, subtropical, subsurface waters of the Indian

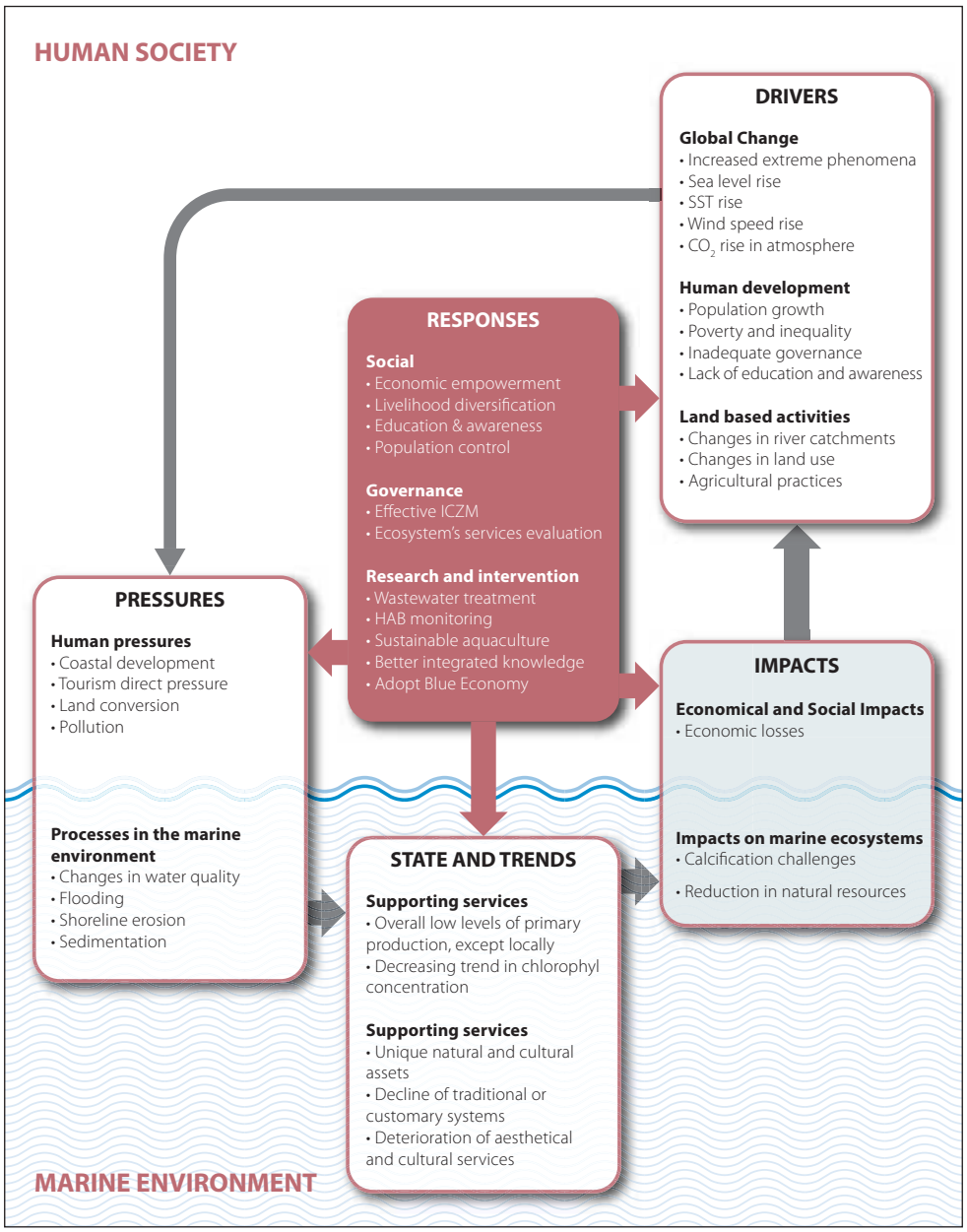


Fig 36.3. Diagrammatic summary of DPSIR analysis for services from the WIO marine environment other than provisioning.

Ocean along 20°S (which includes the southwestern Indian Ocean), anthropogenic CO_2 storage over an 8-year period (between 1995–2003/2004) is reported to have increased at an average rate of 7.1 mol m^{-2} (Murata and others, 2010), almost two times higher than that reported during the previous decade (Sabine and others, 1999).

Over the last three decades, both the mean and maximum speeds of the monsoon winds have generally strengthened in some parts of the region such as in Tanzania (Mahongo and others, 2012), however it is not excluded that these changes could be derived from natural climatic cycles. Webster and others (2005) observed an increase in the annual frequency of cyclones in the South Indian Ocean within the period 1970 and 2004. The number of intense tropical cyclones also increased from 36 during the 1980-1993 period, to 56 during 1994-2007, comparable to a simultaneous but smaller decrease in the number of tropical storms (Mavume and others, 2009). Globally however, there is no sound indication that tropical cyclone frequency has increased over the past century (Christensen and others, 2013). According to Christensen and others (2013), tropical cyclone numbers are unlikely to increase, but cyclone maximum intensity is likely to increase on the global average, meaning increased maximum precipitation and winds. Mauritius, Reunion, Madagascar and Mozambique are the regional countries that are more prone to

intense cyclone activity and landfall. Acidification is not well studied in the region, but is a global pressure affecting all oceans.

Impacts from extreme climatic events are flooding, coastal destructions by storm surges, wave action and erosion. An increase in ocean acidity will affect calcification processes in a wide range of organisms, as reported in next section.

Responses to the threats posed by climate trends cannot be addressed at local scales, and thus countries of the WIO region should join international efforts for decreasing drivers of change and adopt mitigation measures.

Support to primary production by the WIO

Status and trends: The general trend of chlorophyll-a concentration for the WIO region has been seen to decrease with time, although showing a significant inter-annual variability. The general decrease is in agreement with the global trend in primary production, which appears to be decreasing and impacting fisheries catches (Chassot and others, 2010). Although the general trend for primary production in the WIO region is a decrease, some exceptional areas have high productivity resulting from influence of nutrient input via land-based sources (eg Sofala Bank in Mozambique) and natural upwellings (off the Somalia coast).

Pressures and impacts: Ocean acidification derived from climate change *drivers* (Cooley and others, 2009) will impact phytoplankton, especially those with calcareous shells as well as calcareous macroalgae. Besides climate change, anthropogenic activities, such as increased coastal development to accommodate increased tourism (Sadally and others, in press), as well as destruction of habitats and damming of the rivers, increases sedimentation in coastal waters thereby reducing light availability for photosynthesis. So far in the WIO region, eutrophication at a large scale has not occurred. However, harmful (or nuisance) algal blooms (HABs) have been identified in pollution hotspots of the WIO countries (UNEP/Nairobi Convention Secretariat, CSIR and WIOMSA, 2009). HABs may reduce water clarity, effect aesthetics and biodiversity, increase pH, smother benthic communities, modify species composition and create anoxic conditions due to the decomposition of organic matter, resulting in mortalities of marine species from hypoxia (UNEP/Nairobi Convention Secretariat, CSIR and WIOMSA, 2009, ASCLME/ SWIOFP 2012, Chislock and others, 2013).

Responses:

- Reduction of inputs of raw domestic and industrial wastewater into the ocean, by treating the water at source to reduce contaminants and nutrients.
- Initiation of HAB monitoring programmes.
- Conduct sustainable aquaculture in which the effluent water is treated before being released.

Conduct research to understand better the impact of variation in primary production on the wellbeing of coastal communities. There is inadequate literature relating to the variation or trends of primary production to the environmental, social and economic implications to the societies of the WIO region.

Support to ocean-sourced carbonate production by the WIO

Drivers and pressures: The most significant pressure on carbonate producers is the increase in atmospheric carbon dioxide. Worldwide, it has been postulated that carbon dioxide levels are due to increase up to 450 ppm by 2040, if the current rate of increase persists, which is believed will cause rapid decline of coral reefs due to acidification, mass bleaching and other environmental impacts (Veron and others, 2009). The spatial variability of impact responses by coral reef habitats to climate warming have varied over geographical scales (Graham and others, 2008). For the WIO region it can be implied that similar variations may occur as a result of ocean acidification. In addition to this, some calcifying organisms may shift their distribution ranges to more carbonate rich environments (Doney and others, 2009).

There is an expanding pool of knowledge about carbonate producers in WIO waters and the few studies available provide a glimpse into the critical role that these organisms play in a world of increasing carbon (Kangwe and others, 2012, Semesi 2009). Inferences can be made from the experimental work by Doney and others (2009), that show that due to the highly diverse marine flora and fauna that characterizes the WIO region, the responses to increased acidification and eutrophication of the ocean will vary, with some species expected to be resilient to these changes.

Responses: Regional land-use management is frequently more important than mediating climate change (Maina and others, 2013). There is a need for focused studies that track impacts through food webs, to understand the specific responses of the carbonate producers. As described by

Doney and others (2009), programmes that provide for systematic, cost-effective monitoring of surface water chemistry and long-term laboratory manipulative experiments are critical in understanding the responses of carbonate producers in a fast changing world.

Cultural services of the WIO

The interaction between human culture and the coastal and marine environment in the WIO region has over time produced unique cultural products, practices and cultural influences (see Chapter 18 for detailed description). Landscapes have also attracted significant tourism due to their aesthetic and historical value. Equally important are traditional knowledge systems and institutions, which illustrate the existence of customary systems of resource management and local people's understanding as well as appreciation of ecosystem functioning (Cinner and Aswani 2007, Masalu and others, 2010). Marine resources are also part of the cultural heritage associated with the ecosystem, providing a range of benefits for the sustenance of coastal livelihoods. Certain historical sites and landscapes have however suffered from poor management (Duarte 2012), owing to factors that include changing value systems and physical intrusion, calling for concerted management efforts. At the same time, while some of the intangible heritage in the WIO region remains quite vibrant and dynamic, others are declining in cultural significance (Cinner 2007, Sunde 2013). Twenty-nine of 1 007 World Heritage Sites are found among the ten states of WIO region, with twelve of these located within the coastal zone (UNESCO 2014). The aesthetic and patrimonial value of some of these sites is a source of tourist attraction (Bakker and Odendaal 2008, Obura and others, 2012).

Pressures and trends: Traditional or customary systems are largely in decline, and their current effectiveness in coastal and marine resource management is complicated to establish without further careful ethnographic documentation. Modernization and intensification of the cash economy has led to fishing pressure both in terms of needs by the coastal populations, and (destructive) technologies. Meanwhile, market pressures have weakened or eroded customary management systems (Cinner and Aswani 2007, Masalu and others, 2010, Shalli 2011). The decline in these management systems has also partly resulted from the deterioration in quality of aesthetic and spiritual services offered by the coastal and marine environment. The WIO region is increasingly witnessing a decline in the quality of cultural heritage due to both natural and anthropogenic factors. The cultural value of many of the traditionally revered landscapes and seascapes, or customary practices, are deteriorating or eroding.

Responses: The role of science, in terms of providing a multi-disciplinary research approach (combining biological, sociological and cultural approaches) that will inform the policy making process on the value of cultural services in sustaining ecosystem health, needs to be emphasised (eg Tengberg and others, 2012). Management of coastal land- and seascapes should include customary systems into the evolving policy and legal frameworks for management. It is therefore important to identify and harmonise perceptions on cultural ecosystem services from different stakeholders for management. Likewise, it is recommended that the significance of various levels of practices, belief systems or faiths that are used to uphold ethical relationships with nature, need to be identified, for possible integration in ecosystem management (Cinner and Aswani 2007). It is also important to scale-up local capacity building for management planning and monitoring of natural and cultural heritage, among both heritage managers and local committees assigned to monitor the conservation of archaeological sites.

General recommendations regarding ecosystem services other then provisioning

(these recommendations derive from the assessment under Part IV, and are detailed in the summary Chapter 19).

- Promote holistic **ecosystem services valuation**, as these are often ignored in management planning.
- Adopt **Blue Economy** approach principles, to minimize environmental impacts of new developments.
- Adopt **knowledge integration**, namely traditional management systems with modern approaches, and its recognition in Law.
- Invest in research to address **knowledge gaps**, namely valuation of services, trends, status of traditional management, and drivers of change and vulnerability and mitigation.
- Promote **environmental awareness**.

ASSESSMENT OF FOOD SECURITY FROM MARINE RESOURCES

Around 60 million people inhabit the coastal zone in the wider WIO region (van der Elst and others, 2005), and many of them rely on the sea for their economic, social and cultural security (eg FAO 2010). The WIO region is characterised by high marine biodiversity, but contrastingly the biomass of individual species is generally low, with marine productivity depending more on nutrient input from rivers along the coasts of eastern Africa and Madagascar, than on upwelling systems (Caddy and Bakun 1994). The rapid population growth and global economic expansion over the past 50 years have exponentially increased the pressure on coastal resources (eg Jackson and others, 2001), and the resulting overfishing and demand from coastal development have increased pressure on both the abundance of fish stocks and coastal biodiversity. Compared to fishing, mariculture is a recent practice in the WIO region, where it appears to have positive future prospects, particularly in Madagascar, Mozambique, Tanzania and Kenya (Troell and others, 2011).

The assessment of food security from marine resources is dealt with in Part V of the RSOCR. Its most significant contributions are capture fisheries (see Chapter 21), the emergent and growing mariculture activities (see Chapter 22) and their socio-economic impacts (see Chapter 23). Figure 36.4 attempts to provide a summary of the RSOCR assessment of food security from marine resources under a framework of DPSIR methodology.

Capture fisheries

Status and trends: Artisanal fisheries comprise fishing households with small amounts of capital and access to simple gears, albeit diverse, that can be used from the shore or small boats. These are usually performed in inshore areas, and usually up to 3 nautical miles (around 5.5 km) from the coast and islands. Industrial fisheries of the WIO target migratory species such as tuna and tuna-like species (Cochrane and Japp 2015), penaeid prawns on shallow shelf sediments and mudbanks (Fennessy and Everett 2015) and deep-water mixed crustaceans (eg Everett and others, 2015). These industrial fisheries are dominated by fleets external to the WIO region countries.

Statistics on landings, that highlight contrasting figures, are considered as gross under-estimations, due widespread lack of reporting by the artisanal fisheries sector. Nevertheless, it is clear that landings have continued to increase over the past decade, showing growth of the fishing sector, as is the case of Mozambique and Madagascar (Benbow and Harris 2011). However, prawn landings have declined throughout the WIO. Seychelles experienced an increase in large pelagic fish landings after 1997 reflecting the development of its fishing port as a hub for the international tuna industry.

Pressures and impacts: The influence of environmental fluctuations on fish stocks and ecosystem functioning are weakly understood – a factor exacerbated by global climate change and predicted temperature, pH, sea level and acidity changes among other factors. Nevertheless, it is expected that distribution of species, including many that are important living resources, will suffer alterations and latitudinal shifts due to sea temperature changes and movements due to possible unpredictable changes in current patterns. The open access fisheries, in which the numbers of fishers, methods used, and harvest quantities are not controlled, inevitably lead to overexploitation and habitat degradation, particularly when the numbers of fishers and their needs continue to grow. Illegal, Unreported and Unregulated fishing is common in the SW Indian Ocean, where it is responsible for considerable economic, social and ecological losses in developing countries (MRAG 2005). To offset declining catches in nearshore fisheries, states are increasingly looking further offshore to increase catches. However, sustainable exploitation appears to be feasible for only very few deep-sea species under prevailing economic conditions and governance arrangements (Norse and others, 2012), mainly because these species are often slow-growing and have low productivity. Capture fisheries affect also the environment in which they operate in different ways. Apart from removals of the harvested resource, by-catches of non-targeted species can be substantial when non-selective gears, such as trawl nets, are used.

Responses: The lack of adequate infrastructure, trained manpower and scientific skills to fully assess marine resources, reflects a need for capacity building at various levels. Similarly, more information is required to describe bio-ecological processes, distribution patterns, fishing pressure and status of important fish stocks. Single-species approaches to fisheries management do not consider broader social, economic or ecological consequences. There is need of managing whole ecosystems, such as suggested by the 1992 Rio Declaration on Environment and Devel-

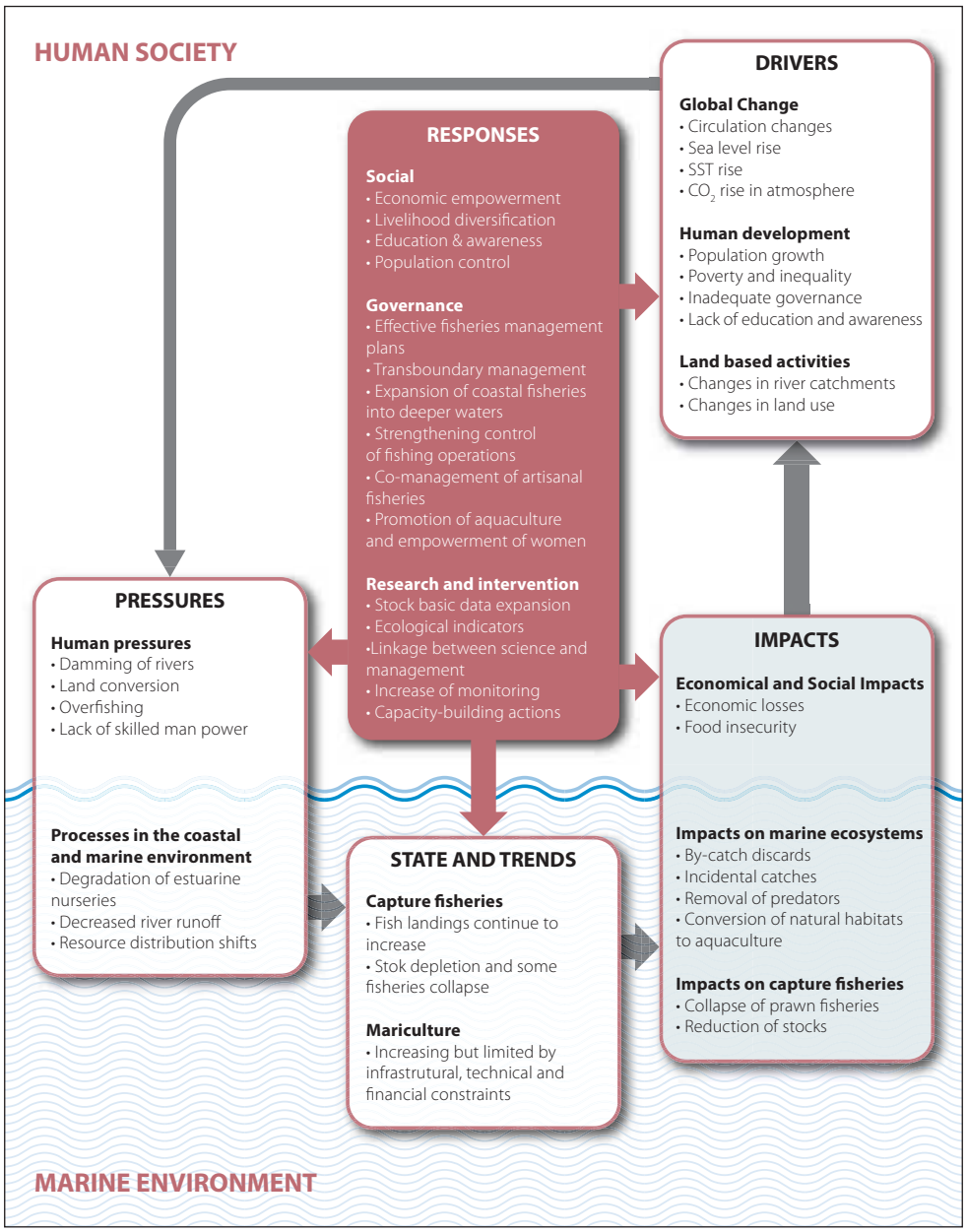


Fig 36.4. Diagrammatic summary of DPSIR analysis for food security from marine resources in the WIO.

opment (United Nations Code of Conduct for Responsible Fisheries; FAO 1995). Cooperative management of shared fish stocks among neighbouring countries may confer many ecological and economic advantages, but it is also a complex political process. New legislation in some countries (eg Kenya, Tanzania) allow for the establishment of Beach Management Units (BMUs) to co-manage fisheries jointly with officials of fisheries departments. BMU objectives are to strengthen the management of fish landing stations, involve all stakeholders in decisions, and prevent or reduce user conflicts.

Mariculture

Status and trends: Mariculture in the SW Indian Ocean is still in an early developmental phase, with the exception of seaweed culture in Tanzania (especially Zanzibar), where production and farming methods have grown substantially over the past two decades. Kenya has made some progress over the past decades, through development of simple innovative technologies, such as construction of inexpensive ponds, pens and cages. Culture species that need limited water management and feed low in the food chain (milkfish, mullets, mud crabs, penaeid prawns) have been studied (eg Mwaluma 2002). The Mozambique action plan for the Reduction of Absolute Poverty (2001-2005) promoted small-scale mariculture (or coastal aquaculture) as a means to contribute to food and nutritional security and socio-economic development. However, small-scale mari-

culture has not really been successful, and is presently limited to scattered prawn, fish and seaweed farming operations (Ribeiro 2007). Commercial prawn farming for *Penaeus monodon* commenced in the early 1990s, and has received regular financial, technical and infrastructure support from NGOs, especially Blue Ventures, plus foreign investors (Robinson 2011).

Pressures and impacts: Pond farming in Madagascar takes place behind mangrove areas along the northwest coasts where mangroves have come under threat through erosion, siltation and related effects from ponds constructed on salt flats. Limited success of mariculture is due economic isolation, insufficient training, and degraded road infrastructure, as is the case of Madagascar, but also Mozambique.

Responses: Mariculture is a good option for compensating for decreasing returns from capture fisheries, however it should be developed with adequate management plans, integrating governance vision, and co-management by private sector investment and NGO support, including the local communities.

General recommendations regarding food security from marine resources

(these recommendations derive from the assessment under Part V, and are detailed in the summary Chapter 24).

- Appropriate control should be acquired by authorities throughout the WIO region to address **overfishing of marine resources**; especially numbers of fishers, methods used, and harvest quantities.
- Governance and economic conditions should be developed to **expand coastal fisheries into deeper waters**, frequently tabled as an option to increase harvests from the sea.
- **Effective management plans** should be developed to include the majority of species and fisheries.
- **More basic data is required** to describe distribution patterns, biological characteristics and reference points, stock status, and the effects of fishing.
- **Strengthen the linkage between science and management** to pass messages from stock status, or to provide solutions to recent or longstanding management issues often not prioritized.
- **Increase monitoring, control and surveillance** (MCS) capacity, making enforcement of national and international laws and regulations more effective in most WIO countries.
- **Promote co-management of artisanal fisheries**, through Beach Management Units (BMUs) empowered to manage fisheries in specific areas on behalf of fisheries departments.
- Promote awareness and implementation of an **ecosystem approach to fisheries management** (EAF).
- Promote the use of **ecological indicators** for evaluating and comparing the status of exploited marine ecosystems.
- Promote cooperative **transboundary fish stock management** in the WIO.
- Promote **capacity-development initiatives** for the scarcity of skilled manpower (namely fisheries researchers, scientific observers, fisheries managers, surveillance technologists, hatchery and grow-out system operators) in the region.
- **Encourage mariculture** as an alternative activity to generate fish protein and wealth.
- A more **integrated approach** to mariculture is required.
- Promote **empowerment of women** in culture and business aspects of mariculture.

ASSESSMENT OF OTHER HUMAN ACTIVITIES

Assessment of other human activities in the marine environment is developed under Part VI of the RSOCR. It includes a number of important sectorial issues such as maritime activities (see Chapter 25), oil, gas and renewable energy (see Chapter 26), coastal mining and coastline stability (see Chapter 27), tourism and recreation (see Chapter 28), urbanization, coastal development and vulnerability and catchments (see Chapter 29) and marine genetic resources and bio-prospecting (see Chapter 30). The adoption of Blue Economy agenda should drive development of human activities that promote economic development and poverty alleviation, at the same time ensuring sustainable use of resources and environmental quality maintenance. Some of the analysed emergent activities can turn into opportunities for human development in the WIO region. Figure 36.5 provides a summary of the RSOCR assessment of other human activities in the coastal and marine environment under a framework of DPSIR methodology.

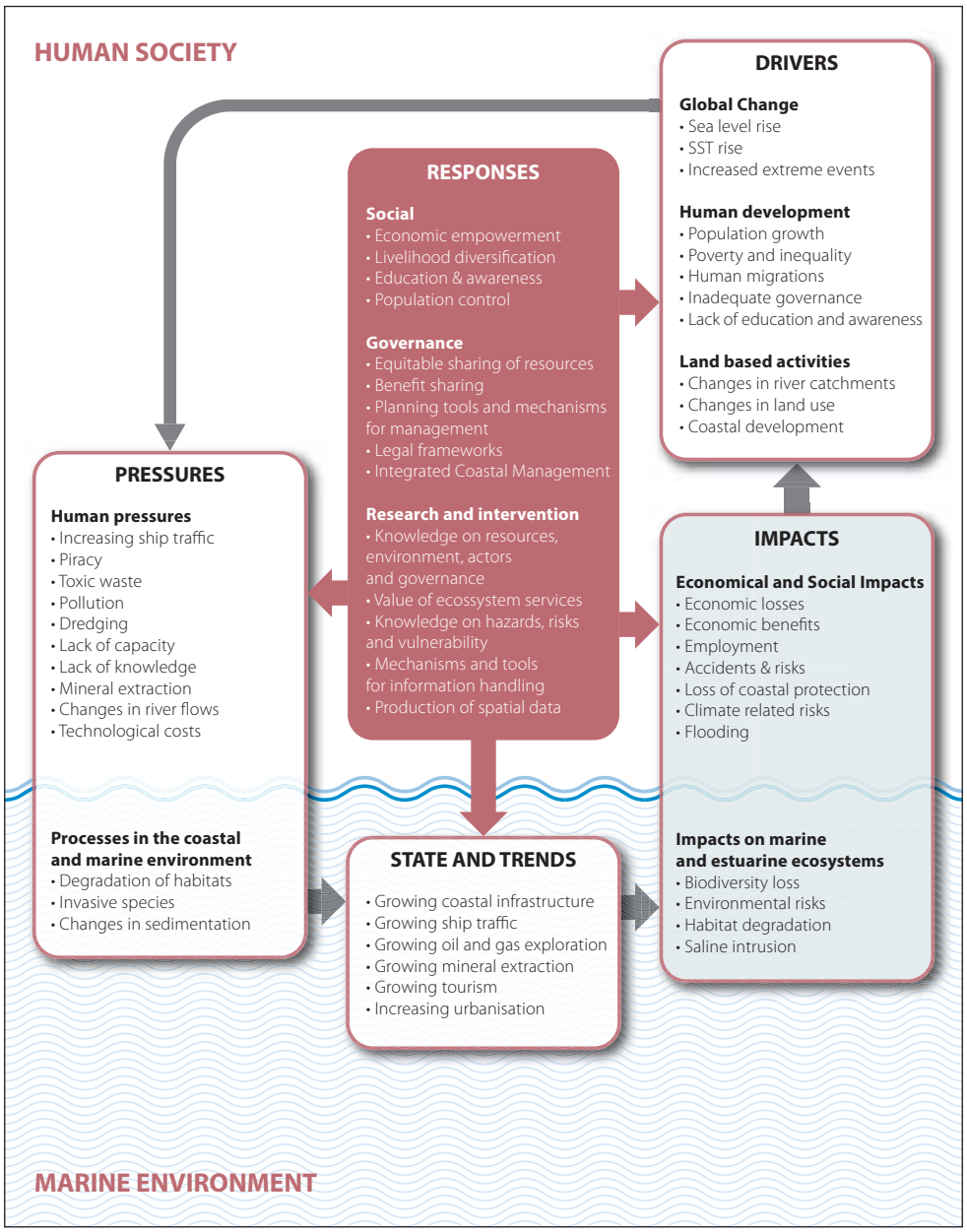


Figure 36.5. Diagrammatic summary of DPSIR analysis for other human activities in the coastal and marine environment in the WIO.

Status and trends: Oil tankers have now increased to represent 80 per cent of the WIO fleet, and around 6 per cent of the world trading fleet travels to ports in the Indian Ocean (UNCTAD 2006). Other *pressures* in the region include piracy, the illegal dumping of toxic waste and potential impacts of climate change as a result of more frequent storm events and rising sea levels. While ships are essential to the global economy, they have a variety of negative *environmental impacts*. These include pollution resulting from the ship's operations and as a result of accidents, and impacts related to ship recycling and translocation of invasive alien species primarily via ballast water and hull fouling.

Moreover, the growth of global maritime activities has led to congestion of shipping lanes, increasing the risks of accidents, in particular around ports. While there has been a general increase in both imports and exports over the years, the most significant change has been in the African export of crude oil since 2006, but mainly from West African countries, which are likely to grow due to the recent discovery of methane gas in some WIO countries. There are 13 existing commercial ports in the region with several others either in the planning phase or under construction. In addition, there are a number of smaller ports and harbours.

Impacts of operational pollution from ships: No data is available for operational pollution from ships in the region.

WIOLaB (De Mora 2006) reported that none of the countries in the region has a comprehensive national marine pollution monitoring programme. Similarly, there has been no specific assessment of litter discharged from vessels. UNEP and others (2008) concluded that marine-based sources of litter do not appear to be as significant as land-based sources. Apart from impacts on human health and tourism, marine litter affects biodiversity as a result of ingestion, entanglement (especially of turtles, seabirds and mammals) and smothering.

Regarding *impacts from shipping accidents*, databases on shipping casualties are very limited for the WIO countries. The majority of invasive alien species (IAS) that have been recorded in the WIO region are thought to have been introduced either via bio-fouling on ships, or as deliberate introductions for mariculture purposes. Their *impacts* are presently difficult to quantify. Assessment of environmental *impacts of port activities* is limited, but the majority of the pollution hotspots identified were in or adjacent to ports. Dredging for both port construction and operational phases and concomitant disposal of the dredged material are pressures on the adjacent marine environment. Examples are evident from Mombasa, Port Louis, Maputo, Matola, Beira and Nacala.

In addition to potential *environmental impacts*, there are a number of other challenges, including piracy, the illegal dumping of toxic waste and potential impacts of climate change on shipping and port infrastructure. Climate change *drivers* and *pressures* may impact increasingly maritime activities, for example, increased frequency of storm events and rising sea level. *Impacts* may include more frequent shipping accidents, increased costs of port maintenance and disruption of port operations from both the seaward-side and hinterland supply chains. Plans to maintain and expand maritime activities in the WIO region should take these concerns into account, as responses to these *impacts*.

Improved capacities are needed to address fundamental issues in maritime activities, such as port and Flag State control, surveillance of shipping lanes and provision of navigational aids. These include surveys of shipping routes, updated nautical charts, training on hydrography, marine cartography and electronic navigational charting, repairs, and training on aids to navigation and maintenance. Another challenge is responses to oil and other spills, namely compliance to the protocol of the Nairobi Convention.

Responses to these challenges can include the implementation of Flag and Port state controls, regional co-operation around maritime surveillance, scientific monitoring and reporting of pollution levels and incidents, prevention and control of alien and invasive species introduced by ships, provision of adequate waste reception facilities at ports, increasing awareness of the impacts of marine litter, inclusion of climate change concerns into risk assessments and the development of Climate Adaptation Plans for ports and financial mechanisms to provide for the required management activities.

Oil, gas and renewable energy

Status and trends: The countries in the WIO region rely on the importation of oil to fuel power stations to generate electricity, although countries like Mozambique have a significant generation of energy from hydropower. The main driving force for generating energy is to supply electricity to industry, commerce and citizens, which is further required to account for population growth and need to reduce the dependence on imported fuel. Off the coasts of Tanzania and Mozambique, combined estimates indicate the presence of at least 150 trillion cubic feet (tcf) of natural gas (Wood Mackenzie 2014). Four main geological provinces in the WIO region are prone to discover technically recoverable conventional oil and gas resources, and estimates show potential for more gas (and oil) to be found in the WIO such as in mainland Africa, western Madagascar and the Seychelles Plateau (Brownfield and others, 2012). The East Africa discoveries have fuelled interest in the EEZs of neighbouring islands in the Mozambique Channel, and seismic surveys are starting soon (Spectrum 2014). For most countries in the WIO region, local investors are unable to match the costs of exploration and unprepared to take the risks, hence the need for participation of the large independent and major companies in the oil and gas industry. But most countries in the WIO region assume that energy diversification is fundamental to address the growing needs of the expanding populations and industries, and alternative energy sources can be deep ocean cold water, tidal energy, ocean currents and wave energy. So far only Mauritius has started the production of energy with deep ocean cold water.

Pressures and impacts: The impacts from exploration, development and production of energy from the sea include those associated to the placement of structures in the marine environment, fossil fuel exploration and production. Structures including seismic survey and drillships,

floating LNG plants, offshore oil and gas production platforms and seabed feed pipelines can physical obstruct and interfere with access for navigation or fishing activities, similarly affecting the movement of marine mammals and fish. Regarding fossil fuel exploration, the noise levels that impacts on migrating species such as whales, turtles, tuna and whale sharks, the amounts of discharged drilling muds and fluids at the well locations, on the seabed and into the water column, and the resulting degraded seawater quality around drilling platforms constitute pressures that are *state indicators*. *Impact indicators* include any reduction in migrating marine species because of the disturbance. Impacts from fossil fuel production include those derived from transportation, which is vulnerable to poor maintenance, infrastructures and accidents that result in threats to the coastal and marine environment. Social impacts can be positive (employment, benefits from corporate social obligations, skilled training) or negative (incidents due lack of adequate communication and awareness, inflation). Pollution is a concern in fossil fuel production.

Responses can include raise awareness and capacity building including the environmental regulators and negotiators with energy sector; promotion of effective management and governance of the extractive sector, encouraging participation of civil society organisations; protect the marine environment and ensure oil pollution preparedness and insurance for compensation for eventual loss of livelihoods; sign and ratify all International Maritime Organisation (IMO) conventions relevant to oil and gas exploration; review legal mandates to ensure compensation for damages caused by marine-based energy companies; adhere to the conditions of the Nairobi Convention; develop and promote renewable energy alternatives; promote regional coordination on planning of transboundary issues such as oil spill contingency, piracy and security, as well as cross-border developments to minimize negative impacts and maximize benefits from marine based energy sources.

Coastal mining and stability

Status and trends: The coastal regions of Sub-Saharan Africa are witnessing increasing non-renewable mineral resources extraction (UNEP/ Nairobi Convention Secretariat 2009a). Human development results in heavy dependence on natural resources, namely as building materials such as cement, sand and coarse aggregate (stones) for concrete and mortar, and clay for bricks (eg ASCLME 2012). The major types of materials and environments used are coral rock and limestone for cement manufacturing and course aggregates for concrete and road building by quarrying, artisanal sand mining from catchments, flood plains, river banks, estuaries and lagoons, informal removal of sand from beaches and fore dunes, and production of sea salt from saltpans located on estuary flood plains.

Pressures and impacts: Overexploitation, modification and loss of habitats and uncontrolled development or encroachment have resulted in environmental degradation including a reduction of the natural protection effect against sea surges during storms (Roger 2002). These factors have a negative impact on coastal communities and often on the countries at large (Masalu 2002). Impacts include catchment degradation due to uncontrolled mining activities such as sand excavation from rivers and the destruction of riverine habitat for salt production (DHI and Samaki 2014). This can result in increased sediment and silt load in rivers, causing coastal accretion and in places and smothering of sensitive marine communities such as coral reefs. On the other hand, coastal erosion is enhanced due the decrease of sources of sand. Activities acting synergistically include the construction of dams in rivers courses (which trap sediments) and mining (Tinley 1985). The construction of harbours including breakwaters and/or the dredging of shipping entrance channels changes the natural alongshore sand transport, erosion and deposition patterns. According to DHI and Samaki (2014) sand and stone quarrying along beaches, coastal water-courses and other areas are important livelihood activities, in places developing into significant local industries. These informal activities create a range of jobs and local income with resultant socio-economic opportunities and challenges (Masalu 2002). Negative feedbacks however can lead to decreased economic activities, job losses and extensive long-term costs to the local economies.

Responses: Policies that relate to coastal mining activities do exist in most of the WIO countries and should be strengthened, as should local capacity regarding control of mining activities, especially where informal mining prevails. Research should be increased and a higher degree of awareness promoted, related to the importance of coastal stability and role in protecting the coast from climate change enhanced hazards from the sea. Policies to ensure the direct participation of current artisanal (informal) sand miners in the whole value chain of this activity would also enhance socio-economic benefits, whilst ensuring the integrity of the coastal sedimentary system.

Tourism and recreation

Coastal areas display high aesthetical value and offer numerous opportunities for generalised tourism and recreation (Beatley and others, 1994), while the open ocean also offers many opportunities for more specialised tourism and recreational activities (sports fishing, whale and dolphin watching and cruises). Tourism also pressures the natural marine environment, nevertheless, the economic benefits of tourism and recreation in generating employment, local income and foreign exchange is of major importance to economies, specially for those with restricted export goods or low sources of income. The WIO region has a variety of high quality physical, environmental and cultural features that serve to attract the tourism industry which should be a viable option for contributing to socio-economic development. The development of this sector is, however, directly and indirectly linked to the state of the coast and the marine environment, in myriad ways.

State and trends: The WIO countries are increasingly attracting international tourists, and the growth rate, measured as tourism income for all the countries, has been showing an encouraging trend. Coastal tourism is very popular among local populations, particularly in the Small Island Developing States (SIDS) and coastal region of the mainland states of the WIO region. Sport fishing clubs and services attracting tourists exist in all WIO countries, lead by South Africa, where recreational fishing attracts increasingly activities focused on sustainability. The expansion of cruise tourism is also on many national growth and development agendas (eg Government of Mauritius 2013), and is increasing in many South Africa and East African ports.

Impacts and pressures: The tourism and recreation sector is a major driver for socio-economic development, promotion of economic growth and alleviation of poverty (eg Richardson 2010) with direct and indirect economic impacts, promoting infrastructure development such as roads, airports and amenities in the coastal zone (eg Seetanah and others, 2011). The tourism industry is an important source of direct and indirect employment, creating multiple opportunities. Tourism often supports conservation through the promotion of private, communal and public conservation (Buckley 2008). Ecotourism is becoming popular among environmentally-conscious tourists, presenting opportunities for sustainable tourism development. Although tourism has great potential to contribute to socioeconomic development and to environmental rehabilitation, it also has a wide range of negative social and environmental impacts (Gössling 2006). The health status of the marine environment in the WIO is increasingly under threat and the additional pressure of tourism and recreation is a growing environmental concern.

Responses: In order to promote sustainable coastal development, there is a need to adopt long-term planning and management (eg May 1991), in order to maintain environmental and cultural integrity (Puppim de Oliveira 2005). This will help generate income, employment and conserve the local ecosystems and cultural heritage (UNEP 2003). Specific responses can include promotion of mutually beneficial tourism and conservation, whale and dolphin watching, cruise tourism, research and monitoring. Also relevant are the establishment of Marine Protected Areas, addressing piracy menaces, coastal and shoreline management, beach awards systems and efforts to increase domestic tourism.

Coastal development and vulnerability

The growth of coastal cities places an increasing demand on coastal extractive and non-extractive resources. As elsewhere, coastal cities of the WIO region attract populations that migrate from rural areas, thereby increasing pressure on the coastal zone. Urbanisation reflects the share of the national population in towns and the extent to which this change is accompanied by shifts in the economy and employment (UN-Habitat 2014).

Status and trends: Eastern Africa is a relatively low urbanized region, but this is changing rapidly. The region continues to experience massive urban poverty and other social problems (UN-Habitat 2014). The recent urban growth and projections for the short- up to long-term are cause for concern (UN-Habitat 2014), especially given the existing unemployment levels amongst the urban population and the extent and condition of degraded urban areas. Although urban growth shows a decelerating trend, the absolute urban population is projected to increase and will remain an enormous challenge. Small island states like Seychelles, Mauritius and, to some extent French Reunion, are exceptions to this generalisation since urban population growth is small, in absolute terms, or even declining (UN-Habitat 2014).

Pressures and impacts: The expansion of the built environment is among the most irreversible human impacts on the global biosphere and urban land-use

change remains one of the primary drivers of habitat loss and species extinction (Hahs and others, 2009). The transboundary diagnostic analysis by UNEP/Nairobi Convention Secretariat and WIOMSA (2009b) identified several direct causal links between urbanisation and water quality degradation, habitat modification and a decline in living marine resources. Furthermore, coastal urban areas on the mainland countries of the WIO are mostly located in the vicinity of critical habitats such as estuaries, mangrove swamps and coastal lagoons. The coastal WIO cities are mostly located in low-lying coastal and estuarine and deltaic areas, and as such prone to natural disasters derived from climate factors. In addition, the high incidence of poverty, low capacity to build and maintain infrastructural defences and soft erodible coasts contribute to the risks. A number of regional assessments have identified East Africa as one of the most threatened coastal regions in Africa and globally (eg Boko and others, 2007). Climate change drivers pose numerous threats to coastal zones where major cities are located: sea level rise, storm swells and risk of coastal flooding. Other climate change impacts, such as flooding of river catchments will also continue to affect coastal zones (IPCC 2014). Socio-economic vulnerability is expected to increase over the next decades.

Responses: Policy responses to mitigate negative environmental, social and economic consequences can include disaster risk reduction and climate change adaptation, promotion of research devoted to exploring ways to address climate issues, robust urban planning processes, reduction of the high levels of vulnerability and low adaptive capacity in local governments. Response may also address better land-use plans, establishing environmental baselines, mainstreaming adaptation options into integrated coastal management and sustainable development plans, socio-political reforms and changes for improving planning regimes, improvement of the capacity of municipal and central governments to govern urban areas, and development of effective adaptation strategies for port cities of the WIO region.

Catchments

River catchments, which connect terrestrial and freshwater ecosystems to oceans, enable and modulate essential ecological processes in coastal and marine environments. Rivers transport freshwater, sediments, nutrients, biota and chemicals, which, along with oceanic forces, shape the coast and establish the availability of natural resources in estuaries and coastal environments (UNEP/Nairobi Convention Secretariat and WIOMSA 2009a)

Status and trends: The WIO region has twelve major river catchments and a myriad of smaller river basins. Three of these catchments, namely the Juba-Shabelle, Limpopo River and Zambezi River Catchments, are among Africa's major transboundary river catchments (UNEP 2010a). The central Mozambican coast is called the 'swamp coast', due its many estuaries and extensive mangrove swamps; the combined discharge of these estuaries and the wide shelf make this area highly productive and important for fisheries. Many of the catchment systems in the WIO region are still in relatively good conditions, however increasing human pressures pose a variety of challenges and these ultimately impact the lower basins and their associated resources and livelihoods.

Pressures and impacts: Several major issues concerning river-coast interaction in the WIO region arise from both direct anthropogenic pressure and global climate change. These include the modification of river flows (water quantity), water quality and sediment loads (primarily because of abstraction and damming) and inappropriate land-use practices. Most large river catchments experience pressures that generate high water stress in the lower basins, due to dams constructed for hydropower and water abstraction for agriculture and consumption. The abstraction and regulation of water flows decrease the frequency of natural floods on which coastal resources like shrimp depend, and in some lower catchments like the Zambezi delta, salt intrusion is evident. Other impacts emanate from industries, poor sanitation and bad agricultural practices that contaminate freshwater bodies. In some instances, sediment transport is altered, and the pressure on lower systems is further aggravated by river sand harvesting.

Responses: Some suggestions for regional policy interventions include development of coordinated legal frameworks for the management of transboundary catchments, effective implementation of inter-governmental management instruments for river catchment management, development of protocols for inter-sectorial water governance, improvement in the collection of data and information, monitoring and assessment, improved financial investment in the development of human capital, and the development of integrated holistic regional policies for water resource management.

Genetic resources and bio-prospecting

There is global interest in exploring the commercial potential of marine genetic and associated natural product resources. Potential applications exist in a wide range of industries including pharmaceuticals, food and beverage, cosmetics, agriculture and industrial biotechnology (eg Arrieta and others, 2010, Global Ocean Commission 2013). Scientific and technological developments in various fields, such as molecular biology, genomics, and bioinformatics, together with technological advances for the exploration of the deep ocean have raised capacities for bio-prospecting the oceans (Global Ocean Commission 2013).

Status and trends: The countries of the WIO region have limited scientific and technical capabilities and consequently most research, development and commercialisation of marine genetic resources and their property rights are conducted outside the region. South Africa and, to a lesser extent, Kenya, are the only WIO countries engaged actively in international collaborative projects. Several areas in the WIO are however of major interest for the exploration of natural products. There is an increased interest in the WIO islands and East African coastline, and the presence of biodiversity hotspots in the region also suggests that the area is likely to be of increasing interest for marine natural products. Only a small fraction of this biodiversity has been explored for its commercial potential (Davies-Coleman and Sunassee 2012).

Pressures and impacts: Currently the impacts of bio-prospecting are negligible, and the main limitations for the development of these activities are the costs of research and technologies that remains prohibitively high, the low scientific capacity, and the significant gaps in regional taxonomic and ecological knowledge.

Responses: Promotion of the exploration of marine genetic resources and bio-prospecting implies strengthening of national and regional laws relating to access and benefit sharing (ABS) from marine biodiversity in the EEZ. Promotion of research that contributes to the conservation and sustainable use of biodiversity, the building of scientific capacity and transfer of appropriate technology and access to technology from developed countries and institutions, thus improving scientific knowledge about the marine biodiversity of the WIO region are priority responses. Developing a regional ABS approach for marine genetic resources, and supporting improved disclosure of the origin of material in patent applications to ensure greater transparency and improved tracking of the source of the material.

General recommendations regarding other human activities

(these recommendations derive from the assessment under Part VI, and are detailed in the integrative Chapter 31).

- Increase the **knowledge** about the resources, the environment, the people using and exploiting such resources, and the way in which they are governed.
- Understanding the **value of ecosystem services** and how it is influenced by environmental change.
- Promote **equitable access** to and **benefit sharing** of coastal and marine resources, preferably entrenched in all national policy and legislation.
- Promote the understanding and management of **hazards, vulnerability and risk**.
- Develop **mechanisms and tools** for the capture, exploration and archiving of data, information and knowledge.
- Develop **planning tools and mechanisms** for the management of coastal land-use and conversion at all scales (regional, national and sub-national) and human activities and their usage and exploitation of resources.
- Emphasize the production of **spatial data** that enables usage of scientific products for marine planning and other similar mechanisms.
- Establish relevant **legal frameworks** that enable rather than frustrate efforts to develop environmental management solutions for sustainable development.
- Prioritize **integrated coastal management** (ICM) for the management of coastal areas and associated human activities.

SCENARIOS, POLICIES AND CAPACITY BUILDING NEEDS

Future scenarios for the WIO region

Scenarios are fundamental tools for understanding the use of natural goods and services with respect to sustainable development. Addressing gaps and policy failures in the governance of the ocean and coasts requires holistic approaches to manage the complexity of the natural environment. Long-range planning, informed by scenarios,

enables decision-makers to predict and explore a range of possible alternative futures in order to identify possible adaptation of governance and its effects on change trends. This way, scenario analysis can be effective in supporting policies for resource-use management and conservation. Scenario analysis goes beyond simple contingency planning, sensitivity analysis and computer simulations by presenting comprehensive exploration of alternative futures.

The scenario approach adopted the DPSIR framework (see Chapter 32) and was integrated based on variables, links, and feedbacks relevant to dynamic modelling of marine social–ecological systems, including drivers that influence human behavioural change, such as society, knowledge systems, political and institutional setting and the economy (UNEP, IOC-UNESCO 2009). The assessment used two main scenarios (or opposite worlds): the Conventional World Scenario (CWS) representing a business as usual pathway (BAU), and the Challenge Scenario or Sustainable World Scenario (SWS) representing the Western Indian Ocean Strategic Action Programme (WIO-SAP) aspirations (UNEP/Nairobi Convention Secretariat 2009b) and the Sustainable Development Goals (SDGs).

The CWS scenario

Under this scenario, governance frameworks remain neglected due to inadequate action, and, consequently, degradation trends related to the coastal and marine environment of the WIO remain. Inevitably, the decline in capture fish production and biodiversity loss is expected to continue. Damage to habitats such as coral reefs will extend to fish resources, and further affect ecotourism and associated livelihoods, while the reduction in critical coastal habitats may reduce coastal protection from storms with potential associated erosion and coastal damage risks. The diversity of nearshore habitats (including beaches, rocky shores, muddy shores and mangroves, coral reefs and seagrass beds) will continue to diminish due to impacts from climate change, alteration of nearshore geomorphology and unsustainable coastal land-use. Non-compliance with regulations and inappropriate fisheries methods continue to be major causes of habitat degradation accompanied by the decrease in stocks of living resources. In addition to other human activities, such as continued mining and exploration, sand harvesting, trawl fishing and infrastructure developments, such as cities, ports and oil rigs, the projected exponential increase in population will challenge biodiversity conservation from species to ecosystem levels. Concomitantly, the risks of pollution, resulting from operational activities and accidents, as well as translocation of invasive alien species through ballast water and hull-fouling, will remain.

The SWS scenario

The value of healthy, critical, coastal and marine habitats is secured through the development of tools and methodologies to support their sustainable management, and restoration of critical coastal and marine habitats is achieved. Adequate development and implementation of management plans, scheduled for completion by 2025, such as National Plans of Action (NPAs), Integrated Coastal Zone Management (ICZM) plans or National Environmental Management (NEM) plans should be developed throughout the WIO region. The development of tools and capacity-building actions for sectorial skills will contribute as mechanisms towards management improvement, as will transboundary collaboration and integrated regional management, addressing maritime and industrial risks. Further efforts should target the development of regional approaches to the management of alien and invasive species, as well as mainstreaming climate change adaptation.

The way forward

The use of the scenario framework must be adaptive and respond accordingly to new challenges, opportunities or threats that undoubtedly will emerge. The Nairobi Convention, through its management and policy platforms, can promote the scenario frameworks for engagement between actors, as a basis for decision-making and as tools for planning and environmental monitoring. Scenarios can be used for the creation of options for policy and management, for effectively managing the coasts and oceans, for promoting adaptive management, but also for monitoring programmes to assist in refining scenarios to respond to observed change in trends.

Governance and policy options

The governments of the WIO region are Parties to the Nairobi Convention, which offers a regional legal platform for the protection, management and development of the marine and coastal environment, constituting a framework of governance in the WIO region. There are national, regional and global institutions that deal with environmental issues. Legal and institutional frameworks for addressing the marine and coastal environment include

constitutional provisions, framework environmental laws and sector-based laws. Chapters 33 and 34 provide detailed analyses of governance and policies concerning the marine and coastal environment in the WIO region.

Major governance weaknesses related to oceans and the coastal environment of the WIO region have been identified, and include policy and legislative inadequacies, limited institutional capacities, inadequate awareness, inadequate financial resources and mechanisms, as well as poor knowledge management (UNEP/Nairobi Convention Secretariat 2009a). There is also inadequate translation of relevant international commitments and obligations into national laws, and an apparent lack of mechanisms for effective coordination and inter-sectorial governance among institutions involved in the management of coastal and marine environment. A root cause is the limited capacity of human and technical resources. Governance challenges include inadequate technical capacity, lack of sufficient financial resources, overlapping or uncoordinated institutional mandates, multiple sectors affecting coastal and marine issues, lack of political will and prioritization, language and legal system constraints, multiple regional affiliations and political instability.

Governance responses and interventions are constrained by overlapping mandates of different level institutions, giving rise to inefficient use of governance instruments and resources. Nevertheless, legal, institutional and policy responses appear to converge, acknowledging that anthropogenic activities do create pressure on coastal and marine zones with resulting environmental impacts that need to be regulated. All WIO countries apply environmental impact assessment (EIA) regulations and further develop ICZM laws and policies.

There are contrasting policy options that are open to the countries of the WIO region concerning the sustainability of the coastal and marine environment, both at the national and regional level. These include: i) overarching policy instruments with sector players taking primary responsibility, ii) maintenance of sectorial policies and providing a coordinating mechanism, and iii) maintenance of sector policies as well as sectorial implementation of the policies without having a coordinating mechanism.

Research and capacity-building

Coastal and marine research in the WIO is limited when compared to more developed regions of the world, however the past twenty years have witnessed a significant increase in regional capacities and scientific output. This has created not only more, but also better, knowledge that progressively improves management of the coastal and marine environment. Data generated by local capacity is more likely to provide adequate data for adapted management to regional and local socio-ecological needs. Nevertheless, research agendas from United Nations agencies and international NGOs (such as WWF) are contributing to the establishment of regional research targets and promoting capacity-building in key sectors and disciplines that are relevant for a sound understanding of the marine and coastal environment in the region.

Among the many socioeconomic and institutional factors that constrain capacity in the WIO region are limited financial and human resources, low investment in education and training, inadequate knowledge and awareness and lack of legal expertise. Investment and innovative approaches to building human capacity development remains a top priority for countries in the WIO. Communicating scientific results to government remains a challenge. There is a widespread perception that decision-makers often do not understand the limits of scientific data, nor how to use it to address practical applicability for management and governance framework agendas.

OVERALL CONCLUSIONS

The WIO region has unique characteristics of high biodiversity, both in terms of species and ecosystems, which place it as one of the most rich and interesting ocean regions of the world. Its geomorphological features and the complex current patterns, together with its location in relation to global biogeographic units and centres of endemism, modulate the complex distribution and richness of ecosystem mosaics. Overall biological productivity is not high but with significant production in estuarine dominated mainland coasts and upwelling systems. Most countries in the WIO are developing countries with strong socioeconomic limitations and their economies, at least in the coastal zone where most of the population is concentrated, is highly dependent on marine and coastal resources. The biodiversity of these systems is thus under direct and indirect pressures from resource exploitation and anthropogenically-driven habitat degradation. The effects and impacts of global climate change add further pressures to local-acting sources of disturbance.

The Regional State of the Coast Report for the West-

ern Indian Ocean has used a DPSIR framework for the assessment of the relevant components pertaining to the marine and coastal environment. The analysis has highlighted the main drivers of change and the consequential pressures that are exerted on the environment and human livelihoods, described current status and trends of natural and societal processes, and identified impacts. Responses to these challenges were summarized and further translated into recommendations under main sectors, providing linkages and integrative mechanisms for addressing them.

Regarding biodiversity assessment, it is apparent that marine ecosystems in the WIO region are in a fairly good condition, but the pressures from global climate change acting synergistically with the local anthropogenically-induced drivers are increasingly challenging the natural processes. Ecosystems service assessments, both related to food security from marine resources as well as those other than provisioning, also revealed similar challenges and increasing pressures from a variety of human activities on the marine and coastal environment.

Other human activities are increasing in the region, such as maritime trade and mineral extraction from the coast, oil and gas exploration, coastal tourism and bio-prospecting. While these sectors present enormous potential opportunities to contribute towards economic development, the potential impacts associated with each may challenge sustainability. Their development should be addressed and monitored with integrated sound management strategies.

Long-term planning enables decision-makers to evaluate predictions and explore a range of possible alternative futures in order to identify possible options for policy and management. The WIO governance frameworks are in place and the continued development of efficient institutions and regulatory mechanisms will provide the region with mechanisms for progress towards a sustainable use of the enormous potential of marine and coastal resources. But while capacities are limited in the WIO region, both economic and human, investment and innovative approaches to developing human capacity should remain at the top of priorities for all the countries in the region, at all levels.

The adoption of a Blue Economy and the will to address socioeconomic development in the region, with emphasis on poverty alleviation, gives hope for the future of the marine and coastal environment of the WIO region and the associated human wellbeing and livelihoods.

References

Amante, C. and Eakins, B.W. (2009). ETOPO1 1 Arc-Minute Global Relief Model: Procedures, Data Sources and Analysis. NOAA Technical Memorandum NESDIS NGDC-24. National Geophysical Data Center, NOAA. doi:10.7289/V5C8276M

Arrieta, J.M., Arnaud-Haond, S. and Duarte, C.M. (2010). What lies underneath: conserving the oceans' genetic resources. *PNAS* 107(43), 18318-18324

ASCLME (2012). National Marine Ecosystem Diagnostic Analysis. Tanzania. Contribution to the Agulhas and Somali Current Large Marine Ecosystems Project (supported by UNDP with GEF grant financing)

ASCLME/SWIOFP (2012). Transboundary Diagnostic Analysis for the Western Indian Ocean. vol. 1: Baseline. South Africa

Bakker, K.A. and Odendaal, F. (2008). Managing heritage in a contested space: the case of Le Morne Cultural Landscape in Mauritius. *South African Journal of Art History* 23(1), 225-244

Beatley, T., Brower, D.J. and Schwab, A.K. (1994). *An introduction to coastal zone management*. Island Press, Washington, D.C.

Benbow, S. and Harris, A. (2011). *Managing Madagascar's octopus fisheries*. Proceedings of the workshop on *Octopus cyanea* fisheries. BlueVentures. Aberdeen Centre, London

Boko, M, Niang, I., Nyong, A., Vogel, C., Githeko, A., Medany, M., Osman-Elasha, B., Tabo, R. and Yanda, P. (2007). Africa. In *Climate Change Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (eds. Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J. and Hanson, C.E.) pp. 433–467. Cambridge University Press. Cambridge,UK

Brownfield, M.E., Schenk, C.J., Charpentier, R.R., Klett,

T.R., Cook, T.A., Pollastro, R.M. and Tennyson, M.E. (2012). Assessment of Undiscovered Oil and Gas Resources of Four East Africa Geologic Provinces . No 2012-3039. U.S. Geological Survey's (USGS). World Petroleum Resources Project

Buckley, R.C. (2008). Testing take-up of academic concepts in an influential commercial tourism publication. *Tour. Manag.* 29(4), 721–729

Caddy, J.F. and Bakun, A. (1994). A tentative classification of coastal marine ecosystems based on dominant processes of nutrient supply. *Ocean Coast. Manage.* 23(3), 201-211

Chassot, E., Bonhommeau, S., Dulvy, N.K., Melin, F., Watson, R., Gascuel, D. and Le Pape, O. (2010). Global marine primary production constrains fisheries catches. *Ecol. Lett.* 13, 495–505

Chislock, M.F., Doster, E., Zitomer, R.A. and Wilson, A.E. (2013). Eutrophication: causes, consequences, and controls in aquatic ecosystems. *Nat. Educ. Knowl.* 4(4), 10

Christensen, J.H., Krishna Kumar, K., Aldrian, E., An, S.-I., Cavalcanti, I.F.A., de Castro, M., Dong, W., Goswami, P., Hall, A., Kanyanga, J.K., Kitoh, A., Kossin, J., Lau, N.-C., Renwick, J., Stephenson, D.B., Xie, S.-P. and Zhou, T. (2013). Climate Phenomena and their Relevance for Future Regional Climate Change. In *Climate Change 2013: The Physical Science Basis*. Contribution of Working Group I to the Fifth Assessment Report of the IPCC . (eds. Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley) pp. 1217-1308 Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Cinner, J.E (2007). The role of taboos in conserving coastal resources in Madagascar. *SPC Traditional Marine Resource Management and Knowledge Information Bulletin* 22, 15-23

Cinner, J.E. and Aswani, S. (2007). Integrating customary management into marine conservation. *Biol. Conserv.* 140(3), 201-216

Cochrane, K.L. and Japp, D. (2015). Pelagic fisheries: A retrospective analysis of their status in the Southwest Indian Ocean. In *Offshore fisheries of the Southwest Indian Ocean: their status and the impact on vulnerable species* (eds. R.P. van der Elst and B.I. Everett) Special Publication No 10. Durban: South African Association for Marine Biological Research

Cooley, S.R., Kite-Powell, H.L. and Doney, S.C. (2009). Ocean acidification's potential to alter global marine ecosystem services. *Oceanography* 22, 172-181

Davies-Coleman, M.T and Sunassee, S.N. (2012). Marine bioprospecting in southern Africa. In *Drug discovery in Africa – impacts of geneomics, natural products, traditional medicines, insights into medicinal chemistry, and technology platforms in pursuit of new drugs* (eds. K. Chibale, M. Davies-Coleman, and C. Masimirembwa) pp. 193-209. Springer-Verlag, Berlim

De Mora, S. (2006). *An Assessment of the National Capabilities for Marine Pollution Monitoring in the Western Indian Ocean Region and Recommendations for Regional Capacity Building and Training Needs*. Report to UNEP and WIO-Lab by the International Atomic Energy Agency: Marine Environmental Laboratory. Monaco

DHI and Samaki (2014). Coastal Profile for Mainland Tanzania 2014 Thematic Volume – Draft 0. Investment Prioritization for Resilient Livelihoods and Ecosystems in Coastal Zones of Tanzania DHI and Samaki Consultants

Doney, S., Fabry, V., Feely, R. and Kleypas, J. (2009). Ocean Acidification: The other CO_2 problem. *Annu. Rev. Mar. Sci.* 1, 69–92

Duarte, R.T (2012). Maritime History in Mozambique and East Africa: The Urgent Need for the Proper Study and Preservation of Endangered Underwater Cultural Heritage. *Journal of Maritime Archaeology* 7(1), 63–86

Everett, B.I., Groeneveld, J.C., Fennessy, S.T., Dias, N., Filipe, O., Zacarias, L., Igulu, M., Kuguru, B., Kimani, E., Munga, C.N., Rabarison, G.A., Razafindrakoto, H. and Yemane, D. (2015). Composition and abundance of deep-water crustaceans in the Southwest Indian Ocean: Enough to support trawl fisheries? *Ocean Coast. Manage.* 111, 50-61

FAO (1995). Code of Conduct for Responsible Fisheries. Food and Agriculture Organization. http://www.fao.org/docrep/005/v9878e/v9878e00.htm

FAO (2010). *The state of world fisheries and aquaculture*. Food and Agriculture Organization of the United Nations, Rome

Fennessy, S.T. and Everett, B.I. (2015). Crustacean shallow-water trawl fisheries: A retrospective analysis of their status in the Southwest Indian Ocean. In *Offshore fisheries of the Southwest Indian Ocean: their status and the impact on vulnerable species* (eds. R.P. van der Elst and B.I. Everett) Special Publication No 10. Durban: South African Association for Marine Biological Research

Global Ocean Commission (2013). Policy Options Paper No. 4: Bioprospecting and marine genetic resources in the high seas. A series of papers on policy options, prepared for the third meeting of the Global Ocean Commission. November 2013. Available at http://www.globaloceancommission.org/wp-content/uploads/GOC-paper04-bioprospecting.pdf

Gössling, S. (2006). Towards sustainable Tourism in the Western Indian Ocean. *Western Indian Ocean J. Mar. Sci.* 5(1), 55-70

Government of Mauritius (2013). The Ocean Economy. A Roadmap for Mauritius. Prime Minister's Office

Graham, N. McClanahan, T., MacNeil, M., Wilson, S., Polunin, N., Jennings, S., Chabanet, P., Clark, S., Spalding, M., Letourneur, Y., Bigot, L., Galzin, R., Ohman, M., Garpe, K., Edwards, A. and Sheppard, C. (2008). Climate Warming, Marine Protected Areas and the Ocean-Scale Integrity of Coral Reef Ecosystems. *PLoS ONE* 3(8): e3039

Hahs, A., McDonnell, M., McCarthy, M., Vesk, P., Corlett, R., Norton, B., Clemants, S.E., Duncan, R.P., Thompson, K., Schwartz, M.W. and Williams, N.S.G. (2009). A global synthesis of plant extinction rates in urban areas. *Ecol. Lett.* 12(11), 1165–1173

Hoegh-Guldberg, O. (Lead Author) (2015). Reviving the Ocean Economy: the case for action - 2015. WWF International, Gland, Switzerland, Geneva, 60 pp

IPCC (2014). *Climate Change 2014: Impacts, Adaptation, and Vulnerability*. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (eds. V.R. Barros, C.B. Field, D.J. Dokken, M.D. Mastran drea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White) Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Jackson, J.B., Kirby, M.X., Berger, W.H., Bjorndal, K.A., Botsford, L.W., Bourque, B.J., Bradbury, R.H., Cooke, R., Erlandson, J. and Estes, J.A. (2001). Historical overfishing and the recent collapse of coastal ecosystems. *Science* 293(5530), 629-637

Kangwe, J., Semesi, S., Beer, S., Mtolera, M. and Bjork, M. (2012). Carbonate production by calcareous algae in a seagrass dominated system: The example of Chwaka Bay. In *People, Nature and Research in Chwaka Bay, Zanzibar, Tanzania* (eds. De la Torre Castro, M. and Lyimo, T.) pp. 143–156

Levitus, S., Antonov, J.I., Boyer, T.P., Locarnini, R.A., Garcia, H.E. and Mishonov, A.V. (2009). Global ocean heat content 1955-2008 in light of recently revealed instrumentation problems. *Geophy. Res. Lett.* 36(7), L07608

Lutjeharms, J.R.E. (2006). *The Agulhas current*. Springer-Verlag, Heidelberg

Lutjeharms, J.R.E. and Bornman, T.G. (2010). The importance of the greater Agulhas Current is increasingly being recognised. *S. Afr. J. Sci.* (online) 106(3/4), 4 pp. DOI: 10.4102/sajs.v106i3/4.160

Mahongo, S.B., Francis, J. and Osima, S.E. (2012). Wind Patterns of Coastal Tanzania: Their Variability and Trends. *Western Indian Ocean J. Mar. Sci.* 10, 107-120

Maina, J., Moel, H., Zinke, J., Madin, J., McClanahan, T. and Vermaat, J. (2013). Human deforestation outweighs future climate change impacts of sedimentation on coral reefs. *Nat. Commun*. 4, 1986

Manyilizu, M., Dufois, F., Penven, P. and Reason, C. (2014). Interannual variability of sea surface temperature and circulation in the tropical western Indian Ocean. *Afri. J. Mar. Sci.* 36(2), 233-252

Masalu, D.C.P. (2002). Coastal Erosion and Its Social and Environmental Aspects in Tanzania: A Case Study in Illegal Sand Mining. *J. Coast. Manage*. 30 (4), 347-359

Masalu, D.C.P., Shalli, M. and Kitula, R. (2010). Customs and taboos: The role of indigenous knowledge in the management of fish stocks and coral reefs in Tanzania. Coral reef, targeted research and capacity building for Management Program, 2010. Currie Communications, Melbourne, Australia

Mavume, A.F., Rydberg, L., Rouault, M. and Lutjeharms, J.R.E. (2009). Climatology and landfall of tropical cyclones in the south-west Indian Ocean. *Western Indian Ocean J. Mar. Sci.* 8(1), 15-36

May, V. (1991). Tourism, environment and development. Values, sustainability and stewardship. *Tour. Manag.* 12(2), 112-118

MRAG (2005). Review of Impacts of Illegal, Unreported and Unregulated Fishing on Developing Countries. Final Report, Department for International Development (DFID, UK), and Norwegian Agency for Development Cooperation (NORAD)

Murata, A., Kumamoto, Y., Sasaki, K., Watanabe, S. and Fukasawa, M. (2010). Decadal increases in anthropogenic CO_2 along 20°S in the South Indian Ocean. *J. Geophy. Res., Oceans* 115(C12)

Mwaluma, J. (2002). Pen culture of the mud crab *Scylla serrata* in Mtwapa mangrove system, Kenya. *Western Indian Ocean J. Mar. Sci.* 1(2), 127-133

Norse, E.A., Brooke, S., Cheung, W.W., Clark, M.R., Ekeland, I., Froese, R., Gjerde, K.M., Haedrich, R.L., Heppell, S.S., Morato, T., Morgan, L.E., Pauli, D., Sumaila, R. and Watson, R. (2012). Sustainability of deep-sea fisheries. *Marine Policy* 36 (2), 307-320

Obura, D.O., Church, J.E. and Gabrié, C. (2012). *Assessing Marine World Heritage from an Ecosystem Perspective: The Western Indian Ocean*. World Heritage Centre, United Nations Education, Science and Cultural Organization (UNESCO)

Parson, L.M. and Evans, A.J. (2005). Seafloor topography and tectonic elements of the Western Indian Ocean. *Phil. Trans. R. Soc. A* 363(1826), 15-24

Puppim de Oliveira, J.A. (2005). Tourism as a Force for Establishing Protected Areas: The Case of Bahia, Brazil. *J. Sustainable Tour*. 13(1), 24-49

Ribeiro, F. (2007). Inventory of Small-Scale Mariculture in Mozambique . WIOMSA SUCCESS Programme

Richardson, B. (2010). The Contribution of Tourism to Economic Growth and Food Security. USAID Mali, Office of Economic Growth. Michigan State University, USA

Robinson, G. (2011). Community Based Sea CucumberAquaculture in Madagascar. In *Mariculture in the WIO Region "Challenges and Prospects"* (eds. Troell, M., Hetcht, T., Beveridge, M., Stead, S., Bryceson, I., Kautsky,N., Ollevier, F. and Mmochi, A.) No 11, pp. 47-52. WIOMSA Book Series

Roger, H.C. (2002). Impact on the Coastal Environment of Marine Aggregates Mining. *Int. J. Environ. Stud.* 59(3), 297-322

Roxy, M.K., Ritika, K., Terray, P. and Masson, S. (2014). The Curious Case of Indian Ocean Warming. *J. Clim.* 27(22), 8501-8509

Sabine, C.L., Key, R.M., Johnson, K.M., Millero, F.J., Poisson, A., Sarmiento, J.L., Wallace, D.W. R. and Winn, C.D. (1999). Anthropogenic CO_2 inventory of the Indian Ocean. *Glob. Biogeochem. Cycles* 13(1), 179-198

Sadally, S.B., Taleb-Hossenkhan, N. and Bhagooli, R. (in press). Spatial and temporal variations of micro-phytoplankton diversity and biomass in two tropical coral reefs. *Afr. J. Marine Sci*.

Seetanah, B., Juwaheer, T.D., Lamport, M,J., Rojid, S., Sannassee, R.V. and Subadar Agathee, U. (2011). Does Infrastructure Matter In Tourism Development? *University of Mauritius Research Journal* 17, 89-108

Semesi, I. (2009). Seawater pH as a controlling factor in macroalgal calcification and photosynthesis. PhD Thesis. Stockholm University

Shalli, M. (2011). Taditional Knowledge in the Management of Coastal and Marine Resources in Tanzania. PhD Thesis. Aquatic Sciences. University of Dar es Salaam

Spalding, M.D., Fox H.E., Allen, G.R., Davidson, N., Ferdana, Z.A., Finlayson, M., Halpern, B.S., Jorge, M.A., Lombana, A.L. and Lourie, S.A. (2007). Marine ecoregions of the world: a bioregionalization of coastal and shelf areas. *BioScience* 57, 573–583

Spectrum (2014). New seismic agreement with Madagascar's OMNIS. Press Release 3 October 2014. http://www.spectrumasa.com/press-release/new-seismic-agreement-with-madagascars-omnis Accessed at 19 November2014

Sunde, J. (2013). *Living customary law along the South African coast: securing the rights of small-scale fishing communities*. Environmental Evaluation Unit, University of Cape Town

Tengberg, A., Fredholm, S., Eliasson, I., Knez, I., Saltzman, K. and Wetterberg, O. (2012). Cultural Ecosystem Services provided by Landscapes: Assessment of heritage values and identity. *Ecosystem Services* 2, 14-26

Tinley, K.L. (1985). *Coastal dunes of South Africa*. South African National Science Programme report 109. Pretoria: FRD-CSIR. South Africa

Troell, M., Hecht, T., Beveridge, M., Stead, S., Bryceson, I., Kautsky, N., Ollevier, F. and Mmochi, A. (2011). Mariculture in the WIO region – Introduction and some perspectives. In *Mariculture in the WIO region "Challenges and Prospects"* (eds. M. Troell, T. Hecht, M. Beveridge, S. Stead, I. Bryceson, N. Kautsky, F. Ollevier and A. Mmochi) WIOMSA Book Series No 11, Pp. 1-5. Jamana Printers Limited, Tanzania

UN (2012). United Nations Department of Economic and Social Affairs/Population Division. World Population Prospects: The 2012 Revision, Highlights and Advance Tables. Paper No. ESA/P/WP.228.

UNCTAD (2006). Review of Maritime Transport 2006. United Nations publication. NY. Geneva

UNEP (2003). Tourism and Local Agenda 21: The Role of Local Authorities in Sustainable Tourism. United Nations Environment Programme. The International

Council for Local Environmental Initiatives

UNEP (2010a). Africa Water Atlas. Division of Early Warning and Assessment (DEWA). United Nations Environment Programme (UNEP). Nairobi, Kenya.

UNEP (2010b). Are you a green leader? Business and biodiversity: making the case for a lasting solution. Paris: United Nations Environment Programme.

UNEP (2011). Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication. http://www.unep.org/greeneconomy/Portals/88/documents/ger/ger_final_dec_2011/Green%20EconomyReport_Final_Dec2011.pdf [Accessed December 19, 2012].

UNEP, FAO, IMO, UNDP, IUCN, World Fish Center, GRID-Arendal (2012). Green Economy in a Blue World. www.unep.org/greeneconomy and www.unep.org/regionalseas

UNEP, IOC-UNESCO (2009). An Assessment of Assessments, findings of the Group of Experts. Start-up phase of the Regular Process for Global Reporting and Assessment of the State of the Marine Environment including Socio-economic Aspects. Summary for Decision Makers. United Nations Environment Programme and Intergovernmental Oceanographic Commission/ United Nations Educational Scientific and Cultural Organization. Malta

UNEP, Nairobi Convention Secretariat, WIOMSA (2008). Marine Litter in the Eastern Africa Region: An Overview Assessment. United Nations Environmental Programme

UNEP/Nairobi Convention Secretariat and WIOMSA (2009). An assessment of hydrological and land use characteristics affecting river-coast interactions in the Western Indian Ocean region. UNEP/Nairobi Convention Secretariat and WIOMSA. Nairobi, Kenya

UNEP/Nairobi Convention Secretariat (2009a). Transboundary Diagnostic Analysis of Land-based Sources and Activities Affecting the Western Indian Ocean Coastal and Marine Environment. UNEP Nairobi, Kenya

UNEP/Nairobi Convention Secretariat (2009b). Strategic Action Programme for the Protection of the Coastal and Marine Environment of the Western Indian Ocean from Land-based Sources and Activities. Nairobi, Kenya

UNEP/Nairobi Convention Secretariat, CSIR and WIOMSA (2009). Regional Synthesis Report on the Status of Pollution in the Western Indian Ocean Region. UNEP. Nairobi, Kenya

UNESCO (2014). World Heritage in Africa Region: UNESCO WORLD HERITAGE CENTRE. June 2011. http://Whc.unesco.org/en/sessions/35COM

UNFPA (2002). UNFPA at work 2001. United Nations Population Fund, New York

UN-Habitat (2014). The State of African Cities 2014: Reimagining sustainable urban transitions. UN-Habitat. Nairobi, Kenya

van der Elst, R., Everett, B., Jiddawi, N., Mwatha, G., Afonso, P. S. and Boulle, D. (2005). Fish, fishers and fisheries of the Western Indian Ocean: their diversity and status. A preliminary assessment. *Phil. Trans. R. Soc.* A 363(1826), 263-284

Veron, J.E.N., Hoegh-Guldberg, O., Lenton, T.M., Lough, J.M., Obura, D.O., Pearce-Kelly, P., Sheppard, C.R.C., Spalding, M., Stafford-Smith, M.G. and Rogers, A.D. (2009). The coral reef crisis: The critical importance of <350 ppm CO2. *Mar. Pollut. Bull.* 58, 1428–1436

Vincent, L.A., Aguilar, E., Saindou, M., Hassane, A.F., Jumaux, G., Roy, D., Booneeady, P., Virasami, R., Randriamarolaza, L.Y.A., Faniriantsoa, F.R., Amelie, V., Seeward, H. and Montfraix, B. (2011). Observed trends in indices of daily and extreme temperature and precipitation for the countries of the western Indian Ocean, 1961–2008. *J. Geophys. Res.-Atmos.* 116(D10)

Webster, P.J., Holland, G.J., Curry, J.A. and Chang, H.R. (2005). Changes in Tropical Cyclone Number, Duration, and Intensity in a Warming Environment. *Science* 309(5742), 1844-1846

WWF (2001). *Eastern African Marine Ecoregion*. Proceedings of the Vision Workshop. 23-27 April 2001. Mombasa, Kenya

Zinke, J., Pfeiffer, M., Timm, O., Dullo, W.C. and Davies, G.R. (2005). Atmosphere-ocean dynamics in the Western Indian Ocean recorded in corals. *Phil. Trans. R. Soc.* A 363(1826), 121-142

ABBREVIATIONS

ABNJ	Areas Beyond National Jurisdiction
ACLME	Agulhas Current Large Marine Ecosystem
AEO	Africa Environment Outlook
AMCEN	African Ministerial Conference on the Environment
AMCOW	African Ministerial Conference on Water
AQUAMAY	Mayotte Aquaculture Development Association
AR5	IPCC Fifth Assessment Report
ARDA	Association Réunionanaise de Développement de l'Aquaculture
ASCLME	Agulhas and Somali Current Large Marine Ecosystems
ASFIS	Aquatic Sciences and Fisheries Information System
BAU	Business As Usual pathway
BMU	Beach Management Unit
BP	Before Present
CBD	Convention on Biological Diversity
CBO	Community-Based Organization
CCA	Community Conservation Area
CCP	Community Fishing Council
CCSBT	Commission for the Conservation of Southern Bluefin Tuna
CDA	Coast Development Authority
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CMS	Convention on the Conservation of Migratory Species of Wild Animals (also known as Bonn Convention)
COMESA	Common Market for Eastern and Southern Africa
CONNEPP	Consultative National Environmental Policy Process
COP7	Seventh Meeting of the Contracting Parties
CORDIO	Coastal Oceans Research and Development in the Indian Ocean
CPUE	Catch per Unit Effort
CRP	Coordinated Research Project
CRTF	Coral Reef Task Force
CSIR	Council for Scientific and Industrial Research
CWS	Conventional World Scenario
DAFF	Department of Agriculture, Forestry and Fisheries
DDT	Dichloro-diphenyl-trichloroethane
DEA	Department of Environmental Affairs
DEAT	Department of Environmental Affairs and Tourism
DESA	Department of Economic and Social Affairs
DEWA	United Nations Environmental Programme's Division of Early Warning and Assessment
DGE	Direction General de l'Environment
DNV	Det Norske Veritas
DOE	Division of Environment
DoT	Department of Transport
DOWA	Deep Ocean Water Application
DPSIR	Driving forces, Pressures, States, Impacts, Responses
DWFN	Distant Waters Fishing Nations
EAA	Ecosystem Approach to Aquaculture

EAC	East Africa Community
EACC	East Africa Coastal Current
EAF	Ecosystem Approach to Fisheries
EARO	East African Regional Programme Office
EAWLS	East African Wildlife Society
EBM	Ecosystem-Based Management
EBSA	Ecologically or Biologically Significant Marine Areas
ECA	Environment Conservation Act
EEZ	Exclusive Economic Zone
EFA	Awareness of Environmental Flow Assessment
EMCA	Environmental Management and Coordination Act
EMPS	Environmental Management Plan of Seychelles
ENSO	El Niño Southern Oscillation
EOF	Empirical Orthogonal Function
EPA	Environment Protection Act
ESIA	Environmental and Social Impact Assessment
ESV	Ecosystem Services Valuation
ETP species	Endangered, Threatened or Protected species
EU	European Union
FAD	Fish Aggregation Device
FAO	Food and Agriculture Organization of the United Nations
FPA	Fisheries Partnership Agreement
GBIF	Global Biodiversity Information Facility
GCRMN	Global Coral Reef Monitoring Network
GDP	Gross Domestic Product
GEF	Global Environment Facility
GPA	Global Programme of Action
WIOMHD	Western Indian Ocean Marine Highway Development and Coastal and Marine Contamination Prevention Project
GEO	Global Environment Outlook
GNP	Gross National Product
GOBI	Global Oceans Biodiversity Initiative
GRID	Global Resource Information Database
HAB	Harmful Algal Bloom
HACCP	Hazard Analysis Critical Control Point
HDI	Human Development Index
IAEA	International Atomic Energy Agency
ICARM	Integrated Coastal Area and River Basin Management
ICZM	Integrated Coastal Zone Management
IFREMER	Institut Français de Recherche pour l'Exploitation de la Mer
IIOE	International Indian Ocean Expedition
IMO	International Maritime Organization
INFOPECHE	Intergovernmental Organization for Marketing Information and Cooperation Services for Fishery Products in Africa
IOC	Indian Ocean Commission
IOC-UNESCO	Inter-Governmental Oceanographic Commission
IOD	Indian Ocean Dipole

IOM	Integrated Ocean Management
IOSEA	Indian Ocean and South East Asia
IOTC	Indian Ocean Tuna Commission
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
IPOA	International Plan of Action
IISD	International Institute for Sustainable Development
ITCZ	Inter-Tropical Convergence Zone
ITF	Indonesian Through-Flow
IUCN	International Union for Conservation of Nature
IUU	Illegal, Unreported and Unregulated
JGOFS	Joint Global Ocean Flux Studies
JPOI	Johannesburg Plan of Implementation
KCDP	Kenya Coastal Development Programme
KCMCA	Kuruwitu Community Managed Conservation Area
KCWA	Kuruwitu Conservation and Welfare Association
KFS	Kenya Forest Service
KMA	Kenya Maritime Authority
KMFRI	Kenya Marine and Fisheries Research Institute
KPA	Kenya Ports Authority
KWS	Kenya Wildlife Services
LBSA	Land Based Sources and Activities
LDC	Least Developed Countries
LIP	Large Igneous Province
LME	Large Marine Ecosystem
LMMA	Locally-Managed Marine Area
LNG	Asian Liquefied Natural Gas
MADE	Mitigating Adverse Ecological impacts of open ocean fisheries
MARPOL	MARine POLlution
MASMA	Marine Science for Management programme
MCS	Monitoring, Control and Surveillance
MDG	Millennium Development Goals
MEA	Millennium Ecosystem Assessment
MEAs	Multilateral Environmental Agreements
MEDA	Marine Ecosystem Diagnostic Analysis
MEOW	Marine Ecoregions of the World
MICOA	Ministry for Coordination of Environmental Affairs
MLRA	Marine Living Resources Act
MMO	Marine Mammal Observer
MNP	Marine National Parks
MOE	Ministry of Environment and National Development Unit
MoET	Ministry of Environment and Transport
MPA	Marine Protected Areas
MTNRE	Ministry of Tourism, Natural Resources and Environment
NATO	North Atlantic Treaty Organization
NBSAP	National Biodiversity Strategy and Action Plan
NCEP	National Centres for Environmental Prediction

NDEIE	National Directorate of Environmental Impact Evaluation
NDS	National Development Strategy
NEAP	National Environmental Strategy and Action Plan
NEC	National Environment Council
NECC	North Equatorial Counter Current
NEM	National Environmental Management
NEMA	National Environmental and Management Authority
NEMA	National Environmental Management Act
NEMC	National Environment Management Council
NEP	National Environment Policy
NEPAD	New Partnership for Africa's Development
NGO	Non-Governmental Organization
NMEDA	National Marine Ecosystem Diagnostic Analysis
NPA	National Plans of Action
NSP	National Sewerage Program
NTA	Northern Trans-Boundary Section
OBIS	Ocean Biogeographic Information System
OBP	Oceans Beyond Piracy
ODINAFRICA	Africa Marine Atlas
OLR	Outgoing Longwave Radiation
OSS	Ocean Water Salinity
OTEC	Ocean Thermal Energy Conversion
PADH	Physical Alterations and Destruction of Habitats
PAR	Photosynthetically Active Radiation
PES	Payment for Ecosystem Services
PETM	Paleocene / Eocene thermal maximum
POPs	Persistent Organic Pollutants
PSSA	Particularly Sensitive Sea Area
RAC	Regional Activity Centre
RCC	Regional Coordination Centre
RCP	Representative Concentration Pathways
REDD	Reduction of Emissions from Deforestation and forest Degradation
RFMO	Regional Fisheries Management Organization
RSA	Republic of South Africa
RSOCR	Regional State of the Coast Report
RSP	Regional Seas Programme
SABBWWA	South African Boat–based Whale Watching Association
SADC	Southern African Development Community
SAEO	South Africa Environmental Outlook
SAMSA	South African Maritime Safety Authority
SAPO	South African Port Operations
SCLME	Somali Current Large Marine Ecosystem
SCUBA	Self-Contained Underwater Breathing Apparatus
SDG	Sustainable Development Goal
SEA	Strategic Environmental Assessment
SEC	South Equatorial Current
SIDS	Small Island Developing States

SIODFA	Southern Indian Ocean Deep-sea Fishers' Association
SMP	Sewerage Master Plan
SOSA	Subregional Office for Southern Africa
SRC	Service de la Réglementation et du Contrôle
SSH	Sea Surface Height
SSLA	Steric Sea Level Anomaly
SSM	Sub-Surface Chlorophyll Maximum
SSOP	Standard Sanitary Operation Processes
SST	Sea Surface Temperature
STA	Southern Trans-Boundary Area
SWIO	Southwest Indian Ocean
SWIOFC	Southwest Indian Ocean Fisheries Commission
SWIOFish	Southwest Indian Ocean Fisheries
SWIOFP	Southwest Indian Ocean Fisheries Project
SWS	Sustainable World Scenario
TARDA	Tana and Athi River Development Authority
TDA	Trans-boundary Diagnostic Analyses
TEV	Total Economic Value
TRANSMAP	Transboundary networks of Marine Protected areas for integrated conservation and sustainable development: biophysical, socio-economic and governance assessment in East Africa
UN/OLA/DOALOS	Division for Ocean Affairs and the Law of the Sea of the Office of Legal Affairs of the United Nations
UNCLOS	United Nations Convention on the Law of the Sea
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
UNWTO	United Nations World Tourism Organization
UVR	Ultra-Violet Radiation
VME	Vulnerable Marine Ecosystem
WCS	Wildlife Conservation Society
WEIO	Western Equatorial Indian Ocean
WIO	Western Indian Ocean
WIO-C	Consortium for Conservation of Coastal and Marine Ecosystems in Western Indian Ocean
WIOMSA	Western Indian Ocean Marine Science Association
WIO-SAP	Western Indian Ocean Strategic Action Programme
WMA	Waste Water Management Authority
WOA	World Ocean Assessment
WPEB	Working Party on Ecosystems and Bycatch
WSSD	World Summit on Sustainable Development
WTP	Willingness to Pay Principle
WWF	World Wide Fund for Nature
ZATI	Zanzibar Association of Tourism Investors
ZSL	Zoological Society of London

GLOSSARY

A

Abiotic Factor - non-living physical and chemical factors which affect the ability of organisms to survive and reproduce.

Abyss - the great depths of the oceans, usually considered to be depths of 2000 to 6000 m. It is a region of low temperatures, high pressure and an absence of sunlight.

Abyssal Plain - an extensive, flat, gently sloping region at abyssal depths.

Accretion - the process of coastal sediments returning to the visible portion of a beach following a submersion event.

Acidification - the change in environment's natural chemical balance caused by an increase in the concentration of acidic elements.

Aeolianite - a calcareous dune sand that has been cemented by percolating rainwater.

Agro-chemical - any substance used to help manage an agricultural ecosystem or the community of organisms in a farming area. Agrochemicals include fertilizers, liming and acidifying agents, soil conditioners, pesticides, and chemicals used in animal husbandry, such as antibiotics and hormones.

Albedo - the fraction of solar radiation reflected by a surface, often expressed as a percentage.

Algal Bloom - a rapid increase in the population of algae in an aquatic system. Algal blooms may occur in freshwater as well as marine environments.

Alien Species - species introduced outside its normal distribution. Also named non-native, non-indigenous, foreign or exotic.

Animal Husbandry - controlled cultivation, management and production of domestic animals, including improvement of the qualities considered desirable by humans by means of breeding. Animals are bred and raised for utility (eg, food, fur), sport, pleasure, and research.

Anthropogenic - created through human activities.

Anticlines - a fold (wave in the stratified rocks of the Earth's crust) that maintains an upwards convex shape, with the oldest beds found at its core.

Anticyclonic Eddy - a warm eddy, with a clockwise movement in the Northern Hemisphere, and a counter clockwise in the Southern Hemisphere.

Antifouling Paint - used to coat the bottoms of ships to prevent marine organisms' attachment in the hull.

Apiculture - the maintenance of honey bee colonies, commonly in hives, by humans.

Aquaculture - the farming of aquatic organisms in inland and coastal areas, involving intervention in the rearing process to enhance production and the individual or corporate ownership of the stock being cultivated.

Atmosphere - the layer of gases surrounding the planet Earth.

Atoll - an annular reef enclosing a lagoon in which there are no promontories other than reefs and islets, composed of reef material.

Autotroph - an organism that serves as a primary producer in a food chain, obtaining energy and nutrients through photosynthesis (photoautotrophs) or obtaining chemical energy through oxidation (chemoautotrophs) to make organic substances from inorganic ones.

B

Ballast Water - fresh or salt water, sometimes containing sediments, held in tanks and cargo holds of ships to increase stability and manoeuvrability during transit.

Bank - elevation over which the depth of water is relatively shallow but normally sufficient for safe surface navigation.

Baroclinity - in fluid dynamics, the baroclinity of a stratified fluid is a measure of how misaligned the gradient of pressure is from the gradient of density in a fluid.

Barrier Islands - offshore sandbanks that may, or may not, be exposed at low tide and which protect a coast from prevailing wave action.

Bathymetry - underwater topography defined by patterns in depth.

Bay - concavity of a coastline or re-entrant of the sea, usually smaller than a gulf.

Beach Nourishment - a process by which sediment (usually sand) lost through longshore drift or erosion is replaced from sources outside of the eroding beach. Beach nourishment does not stop erosion.

Beach Seining - fishing method usually carried out using a length of net and an additional length of rope. The net and rope are laid out from, and back to, the shore and retrieved by hauling on to the shore. Mullet, flatfish, snapper, trevally and crabs are caught this way. Also called drag netting.

Bedrock - a deposit of solid rock that is typically buried beneath soil and others broken or unconsolidated materials.

Benthic - associated with the seafloor, either sessile or moving close to the bottom.

Billfish - refers to a group of predatory fish characterised by a spear-like rostrum, or "bill", which is used for slashing and stunning preys. Billfish include sailfish, marlin and swordfish.

Bio-Capacity - shorthand for biological capacity, which is the ability of an ecosystem to produce useful biological materials and to absorb carbon dioxide emissions.

Bioclastic - skeletal fragments of marine or land organisms that are found in sedimentary rocks laid down in a marine environment.

Biodiversity - the variety of life found on Earth and all of the natural processes. This includes ecosystem, genetic and cultural diversity, and the connections within and between these and all species.

Biodiversity Hotspot - a biogeographic region with a significant reservoir of biodiversity that is under threat from humans.

Bio-fuel - a fuel derived from biological materials, such as plants and animals, or derived from organic matter (obtained directly from plants, or indirectly from agricultural, commercial, domestic, and/or industrial wastes). Since such feedstock material can be replenished readily, biofuel is considered to be a source of renewable energy.

Biomass - it can be considered the mass of organisms in a community, in a specified area or volume, measured as weight. Or as the organic material, both above ground and below ground, and both living and dead, such as trees, crops, grasses, tree litter and roots.

Biota - combined flora and fauna of a geographic region or a time period.

Biotic Factor - refers to organisms or their materials that directly or indirectly affect an organism in its environment. This would include organisms, their presence, parts, interaction, and wastes.

Biotope - a portion of a habitat characterized by uniformity in climate and distribution of biotic and abiotic components.

Bivalve - member of the invertebrate class Bivalvia, including the shellfish groups with two hinged shells.

Bleaching - when corals are stressed by alterations in environmental conditions, such as temperature, light or nutrients, they expel the symbiotic algae (zooxanthellae) living in their tissues, causing them to turn completely white.

Blue Economy - the marine-based economic development that leads to improved human well-being and social equity, while reducing environmental risks and ecological scarcities.

Bottom-trawling - an industrial fishing method where a large net with heavy weights is dragged across the seafloor. Bottom trawling is intended to catch fish and other target species found near the ocean floor, but also entraps countless bycatch, including sponges, corals and other non-target species.

Bottom-Up Effect - the effect that a particular level of the ecosystem's hierarchy has in its upper levels.

Boulder - a rock with no less than 30 centimetres diameter.

Boundary Layer - the air layer near the ground, affected by diurnal heat, moisture or momentum transfer to or from the surface.

Brackish - water that has more salinity than fresh water, but not as much as seawater.

Breakwater - offshore structure built to protect harbours and marinas from wave action.

Bycatch - the incidental harvesting of organisms of one species during pursuit of another.

C

Cape - a headland or a promontory of large size that narrowly extends into a body of water.

Carbon Cycle - term used to describe the flow of carbon through the atmosphere, ocean, terrestrial and marine biosphere and lithosphere.

Carbon Sequestration - long-term carbon storage in plants, soils, geologic formations and in the ocean.

Carbon Sink - natural systems that absorbs and store carbon dioxide from the atmosphere.

Carotenoids - the group of yellow, orange or red pigments that are almost universally distributed in living organisms.

Carrageenan - generic term for compounds extracted from species of red algae. Carrageenans are used in stabilizing and jellifying foods, cosmetics, pharmaceuticals and industrial products.

Cassava - a tuberous edible plant of the spurge family (Euphorbiaceae). It is also called manioc, mandioca or yucca.

Cenozoic Era - the most recent of the three major subdivisions of History, that began about 65.5 million years ago.

Cephalopod - molluscs (phylum Mollusca) of the Class Cephalopoda, which includes octopuses, squids, cuttlefishes and nautilus.

Channel - a narrow sea area, often with strong currents, between island and mainland, between two major islands, or created by currents in seafloor sediment.

Chlorophyll - green photosynthetic pigment virtually found in all photosynthetic organisms, including green plants, prokaryotic blue-green algae and eukaryotic algae.

Climate Change - any change in climate over time, whether due to natural variability or as a result of human activity.

Coastal Belt - the outline of a coast.

Cold Seep - area of the ocean floor where hydrogen sulphide, methane, and other hydrocarbon-rich fluid seepage occurs.

Community - natural, intermingled plant and animal populations which share a given space, compete for resources, and interact with one another in an ecosystem.

Competition - interaction that occurs between organisms, whenever two or more require the same limited resource, such as food, water, sexual partner or territory. Competitors reduce each other's growth, reproduction and/or survival.

Conservation - study of the Earth's biological diversity loss and how it can be prevented.

Continental Margin - the submarine edge of the continental crust distinguished by relatively light and isostatically high-floating material. It's the name for the collective area that encompasses the continental shelf, continental slope, and continental rise.

Continental Rise - the major depositional regime in oceans made of thick sequences of continental material accumulated between the continental slope and the abyssal plain.

Continental Shelf - a broad, relatively shallow submarine terrace of continental crust forming the edge of a continental landmass. Typically extends from the coast to depths of 100-200 metres.

Continental Slope - the sloping edge of the continent as it merges into the deep ocean basin.

Coral Reefs - marine ecosystem in which the principal organisms are corals that harbour algal symbionts (zooxanthellae) within their tissues. These ecosystems require fully marine waters, warm temperatures and ample sunlight. Therefore, they are restricted to shallow waters of tropical and subtropical regions.

Corallivore - animal that eats corals.

Coriolis Effect - is the force experienced by a moving body of water due to the fact that the planet is rotating. The Coriolis Effect causes the currents to be deflected northwards in the Northern Hemisphere and southwards in the Southern Hemisphere. The divergent flow of these surface waters from the Equator promotes nutrient rich water upwelling.

Cosmeceutical - cosmetic products with biologically active ingredients claiming to have medicinal or drug-like benefits.

Cosmopolitan Species - species that have a worldwide distribution.

Cretaceous Period - was the last and longest segment of the Mesozoic Era. It began 145 million years ago and ended 66 million years ago.

Critically Endangered - species facing an extremely high risk of extinction in the wild. It is the highest risk category assigned by the IUCN Red List for wild species.

Crustacean - member of the aquatic class Crustacea of the phylum Arthropoda.

Cryptogenic Species - species that are "not demonstrably native or introduced", ie, their actual origin is unknown.

Cyanophytes - photosynthetic microorganisms that live in water. Also called cyanobacteria.

Cyclogenesis - the development or strengthening of cyclonic circulation in the atmosphere.

Cyclones - low pressure systems which develop in the tropics, in the Southern Hemisphere. They are sufficiently

intense to produce winds of at least 63 km/h, in clockwise circulations. Depending on where they occur, severe tropical cyclones are also known as hurricanes (Atlantic and northern Pacific) and typhoons (North-western Pacific).

Cyclonic Eddy - a cold eddy, with a counter clockwise movement in the Northern Hemisphere, and a clockwise in the Southern Hemisphere.

D

DDT - stands for dichlorodiphenyltrichloroethane. It is a synthetic chemical compound once used widely throughout the world as a pesticide. Although remarkably effective in destroying harmful organisms to plants and animals, it can also be extremely dangerous to humans and the environment.

Deep Sea Environment - represents all the water or benthic habitats beneath the edge of the continental shelf, which is below 200 metres.

Deforestation - conversion of forested land to non-forest areas.

Demersal - just above the sediment of the bottom-sea.

Denudation - the long-term sum of processes that cause the wearing away of the Earth's surface, leading to a reduction in elevation and relief of landforms and landscapes. The three major denudation processes are weathering, mass wasting and erosion.

Depocentre - an area or site of maximum deposition, ie the thickest part of any specified stratigraphic unit in a depositional basin.

Dhow - traditional sailing vessels with one or more masts with lateen sails used in the Red Sea and Indian Ocean region.

Dominant Species - species that dominate a sample or area, by virtue of its abundance, biomass, size or conspicuousness.

Dredging - removal of sediments and debris from the bottom of lakes, rivers, harbours and other water bodies.

Drift Net - string of gillnets kept more or less vertical by floats on the upper line and weights on the lower line, drifting with the current, in general near the surface or in mid-water. (net)

Dugout Canoe - a boat made from a hollowed tree trunk.

Dyke - sheet of rock formed in a fracture in a pre-existing rock body.

E

Earmarked - a legislative (especially congressional) provision that directs approved funds to be spent on specific projects, or that directs specific exemptions from taxes or mandated fees.

Echinoderms - simple animals from the phylum Echinodermata, which includes sea stars, urchins, brittle stars and sea cucumbers.

Ecological Footprint - an index of the area of productive land and aquatic ecosystems required to produce the resources used and to assimilate the wastes produced by a defined population at a specified material standard of living, wherever on Earth that land may be located.

Ecosystem - a natural system that includes all living organisms, the non-living environment and its physical forces, and the relationships among these, including processes as predation, competition, energy flow, and nutrient cycling.

Ecosystem Diversity - variety of ecosystems in a given place.

Ecosystem Services - direct and indirect contributions of ecosystems to human survival and quality of life.

Eco-tourism - tourism supported by natural ecological attributes of an area.

Eddy - circular movement of water causing a whirlpool effect.

El Niño - warm ocean current that periodically flows along the coast of Ecuador and Peru. During an El Niño event, the prevailing trade winds weaken and the equatorial counter current strengthens. This event has great impact on the wind, sea surface temperature and precipitation patterns in the tropical Pacific. It has climatic effects throughout the Pacific region and in many other parts of the world.

Elasmobranchs - all cartilaginous fishes including sharks, rays and skates.

Endangered - species at risk of extinction because of a sudden rapid decrease in its population or a loss of its critical habitat.

Endemic / Endemism - species native or restricted to a particular geographical region.

Environmental Stress - pressure on the environment caused by human or by natural events.

Epibiont - organism that lives on the surface of another living organism.

Epifauna - animals living on the surface of the seabed or riverbed.

Epiphyte - plant that grows harmlessly upon another plant.

Erosion - the removal of surface material from the Earth's crust, primarily soil and rock debris, and the transportation of the eroded materials by water, wind and ice.

Essential Nutrient - nutrient that the organism cannot synthesize on its own, or not in an adequate amount, and must be provided by the diet.

Estuary - area at the mouth of a river where it broadens into the sea, forming a transition zone between river environments and maritime environments. Estuaries are subject both to marine influences - such as tides, waves, and the influx of saline water - and to riverine influences - such as flows of fresh water and sediment.

Euphotic zone - the upper part of the water column that receives sufficient light to allow plant growth. May extend to 50 metres depth.

Eustatic Change - when the sea level changes due to an alteration in the volume of water in the ocean, or due to a change in the shape of an ocean basin, hence a change in the amount of water which that basin can sustain. Eustatic change is always a global effect.

Eutrophication - the degradation of water quality due to enrichment by nutrients, which results in excessive plant (principally algae) growth and decay. Eutrophication of a lake normally contributes to its slow evolution into a bog or marsh and ultimately to dry land. Eutrophication may be accelerated by human activities that speed up the ageing process.

Evapotranspiration - the combined process of evaporation from the Earth's surface and transpiration from vegetation.

Exclusive Economic Zone (EEZ) - sea zone prescribed by the United Nations Convention on the Law of the Sea over which a state has special rights regarding the exploration and use of marine resources, including energy production from water and wind. It stretches from the baseline of the coast to 200 nautical miles.

Exoskeleton - external skeleton that supports and protects an animal's body.

Extinction - dying out or termination of a species.

Extremophile - an organism that is tolerant to environmental extremes and that has evolved to grow optimally under one or more of these extreme conditions.

Extremozymes - enzymes that are functional under extreme conditions.

F

Facies - characteristics of a rock or sediment unit that reflect its environment of deposition and allow it to be distinguished from rock or sediment deposited in an adjacent environment.

Fault Blocks - very large blocks of rock, sometimes with hundreds of kilometres in extent, created by tectonic and localized stresses in the Earth's crust.

Fauna - all the animals that live in a particular area, time period, or environment.

Fence Trap - fishing trap made of wooden sticks, and placed across narrow tidal inlets. The fence trap is raised at high tide and tied in place, trapping any fish which have entered the inlet. Trapped fish are harvested at low tide.

Filter-feeding - a form of food procurement in which food particles or small organisms are randomly strained from water. It is found primarily among the small- to medium-sized invertebrates but occurs in a few large vertebrates (eg, flamingos and baleen whales).

Fisherfolk - fishers themselves, their families and other people, who are dedicated to fishing as a primary source of income.

Flagellate - uninucleate organism that possess, at some time in the life cycle, one to many flagella (hairlike structure capable of whiplike lashing movements) for locomotion and sensation.

Floodplain - flat land area alongside a stream or river, composed of unconsolidated sedimentary deposits (alluvium), that is subject to periodic flooding. Also called alluvial plain.

Food Chain - linear sequence of links in a food web starting from "producer" and ending at apex predator species,

detrivores or decomposer species. It shows only the organisms that contribute to the diet of the top consumer.

Food Web - the natural interconnection of food chains.

Foraminifera - single-celled organisms (protists) with external or internal shells.

Fossil - preserved remains or traces organisms from the remote past.

Fossil Fuel - natural resources such as coal, oil (including gasoline and diesel fuel) and natural gas, formed from the remains of ancient plant and animal life. Fossil fuels are non-renewable energy.

Fracture Zone - long, narrow, and mountainous linear submarine feature that generally separates ocean-floor ridges.

Fringing Reef - reef that grows directly from a shore. While there may be areas of shallow intertidal or sub-tidal sand bottom lying between the beach and the inshore edge of coral growth, there is no lagoon between the reef and the shore.

G

Gastropod - snails and similar organisms with an asymmetrical, spirally-coiled shell, members of the class Gastropoda of the phylum Mollusca.

Geomorphology - the physical formation, alteration, and configuration of the Earth's landforms.

Geostrophic Current - current in balance with the horizontal pressure gradient and the Coriolis force, and thus is outside of the influence of friction. Thus, the current is directly parallel to isobars and its speed is proportional to the horizontal pressure gradient.

Geo-thermal Energy - thermal energy contained in rocks and fluids in the earth's crust.

Gillnet - wall of netting that hangs in the water column, kept more or less vertical by a floatline and a weighted groundline. Mesh sizes are designed to allow fish to get only their head through the netting, but not their body. The fish's gills then get caught in the mesh and, as the fish struggles to free itself, it becomes more and more entangled.

Glacial Maxima - periods of very low sea level coincident with glaciation phases.

Global Warming - increase of Earth's average surface temperature due to the effect of greenhouse gases, that trap heat that would otherwise escape from Earth.

Globalization - the increasing integration of economies and societies around the world, particularly through trade and financial flows, and the transfer of culture and technology.

Gondwana - ancient supercontinent that incorporated present-day South America, Africa, Arabia, Madagascar, India, Australia, and Antarctica, which divided about 180 million years ago.

Greenhouse Effect - warming of the Earth's surface and troposphere (the lowest layer of the atmosphere), caused by the presence of water vapour, carbon dioxide, methane and other gases in the air.

Greenhouse gas - any gaseous compound in the atmosphere that is capable of absorbing infrared radiation, thereby trapping and holding heat in the atmosphere.

Gross Tonnes - unitless index related to a ship's overall internal volume. Often abbreviated as GT, G.T. or gt.

Groyne - protective structure built across a beach, from the back of the beach down into the sea, that interrupts water flow and limits the movement of sediment.

Gully - landform created by running water, eroding sharply into soil, typically on a hillside.

Gyre - vast circular system of ocean currents that spiral about a central point. Gyres rotate clockwise direction in the Northern Hemisphere and counter-clockwise in the Southern Hemisphere.

H

Habitat - environment chosen by a species to live in, that provides life requisites such as food and shelter.

Hadley Cells - the low-latitude overturning circulations that have air rising at the Equator and air sinking at roughly 30° latitude. They are responsible for the trade winds in the Tropics and control low-latitude weather patterns.

Hard Coral - corals that produce a rigid skeleton made of calcium carbonate ($CaCO^3$) in crystal form called aragonite. Also known as scleractinian and stony coral.

Harmful Algal Bloom (HAB) - occur when colonies of algae grow out of control while producing toxic or harmful effects on fish, shellfish, marine mammals, birds and humans. The human illnesses caused by HABs, though rare, can be debilitating or even fatal.

Hatchery - place where eggs are incubated and hatched under artificial conditions.

Hatchling - young animal that has recently emerged from its egg.

Holocene - the current period of geologic time. Also known as the Anthropocene Epoch.

Host - an organism that harbours a parasite, or a mutual or commensal symbiont, typically providing nourishment and shelter.

Hotspot (geology) - area in the upper mantle from which heat rises from a plume, deep in the Earth, where magma rises through cracks to the surface and forms volcanoes. As the tectonic plate moves over the stationary hotspot, the volcanoes are rafted away and new ones form in their place. This results in a chain of volcanoes.

Hull-fouling - organisms that attach themselves to the hulls of ships, fouling them. These organisms then colonize the hull and "hitch a ride" from one port or bioregion to the next. Also called bio-fouling.

Hydraulic Fracturing - well-stimulation technique in which rock is fractured by a hydraulically pressurized liquid made of water, sand and chemicals. Also known as hydrofracturing, hydrofracking, fracking or fraccing.

Hydrocarbons - organic compounds that are only made of hydrogen and carbon atoms. Hydrocarbons are the principal components of petroleum and natural gas. They serve as fuels and lubricants as well as raw materials for the production of plastics, fibres, rubbers, solvents, explosives, and industrial chemicals.

Hydroid - member of the invertebrate order Hydroida (class Hydrozoa, phylum Cnidaria).

Hydrological Cycle - cycle that involves the continuous circulation of water in the Earth-atmosphere system.

Hydropower - power derived from the energy of falling or running water, which may be harnessed for useful purposes.

Hydrosphere - combined mass of water found on, under and over the Earth's surface. It includes all liquid and frozen surface waters, groundwater held in soil and rock, and atmospheric water vapour.

Hydrothermal Vent - the result of seawater percolating down through fissures in the ocean crust in the proximity of spreading centres or subduction zones. The cold seawater is heated by hot magma and re-emerges to form the vents.

I

Ichthyofauna - the group of fish of a particular region.

Ichthyoplankton - fish larvae

Indian Ocean Dipole (IOD) - difference in sea surface temperature between two areas - a western pole in the Arabian Sea and an eastern pole in south of Indonesia. The IOD affects the climate of countries that surround the Indian Ocean Basin, and is a significant contributor to rainfall variability in this region.

Infauna - small animals that live partially or completely buried.

Inland Water - water of the interior that does not border upon marginal or high seas or is above the rise and fall of the tides. Inland waters include rivers, lakes, floodplains, reservoirs, wetlands, and inland saline systems.

Intertidal Zone - area between the high-water mark and low-water mark that is submerged at high tide and exposed at low tide. Often used synonymous with seashore.

Invertebrate - animal without a backbone.

Irradiance - the power per area of the radiation received by a surface.

J

Jetty - a long, narrow structure that protects a coastline from the currents and tides.

Juvenile - organism that has not yet reached its adult form, sexual maturity or size.

K

Kelvin Wave - extremely long ocean wave that propagates eastward toward the coast of South America, where it causes the upper ocean layer of relatively warm water to thicken and sea level to rise. Kelvin waves occur toward the end of the year preceding an El Niño event.

Keystone Species - an organism that plays a unique and crucial role in the way an ecosystem functions. Without keystone species, the ecosystem would be dramatically different or cease to exist altogether.

L

Larvae - an early stage of development in the life cycle of the organism.

Life Cycle - the series of stages through which an organism passes from the beginning of its life until its death.

Lithosphere - the solid, outer part of the Earth. It includes the brittle upper portion of the mantle and the crust.

Littoral Zone - the area of shoreline influenced by the rise and fall of the tides.

Living Fossil - organism that has retained the same form over millions of years, similar to a species otherwise known only from fossils, and typically with no close living relatives.

Logbook - a record of important events in the management, operation, and navigation of a ship.

Longlining - a passive type of fishing technique making use of lines with baited hooks as fishing gear.

Longshore Current - ocean current that moves parallel to shore. It is caused by large swells sweeping into the shoreline at an angle and pushing water down the length of the beach in one direction.

M

Macrofauna - organisms which are at least one millimetre in length, visible but not usually identifiable to species level by eye.

Macrophyte - conspicuous plants that dominate wetlands, shallow lakes, and streams.

Mangrove - woody trees or shrubs that flourish at the sea-land interface in tropical estuaries and inlets.

Mariculture - production of marine organisms for food and other products in the open ocean, in an enclosed section of the ocean, or in tanks, ponds or raceways which are filled with seawater.

Marine Outfall - pipeline or tunnel that discharges municipal or industrial treated wastewater from land to sea.

Marine Protected Area (MPA) - a geographically defined marine area that is designated or regulated and managed to achieve specific conservation objectives.

Meander - winding curve or bend in a river. A meander forms when the water in a stream erodes the outer banks and widens its valley, and the inner part of the river has less energy and deposits silt.

Megafauna - large animals easily identified by eye without magnification.

Meiofauna - small, but not microscopic, animals, between 45 and 1000 µm.

Mesoscale - of intermediate size, or middle-scale.

Mesozooplankton - planktonic animals with size range within 0.2-20 mm.

Metabolism - term used to describe all chemical reactions involved in maintaining the living state of the cells and the organism.

Metagenomic Mining - technique that allows researchers to search directly within a sample for genes that produce enzymes with specific biocatalytic capabilities, rather than growing organisms in the laboratory as was previously necessary.

Metamorphosis - striking change of form or structure in an individual after hatching or birth. These physical changes are accompanied by alterations of the organism's physiology, biochemistry and behaviour.

Microfauna - animals with less than 45 µm.

Microphytobenthos - cyanobacteria, benthic diatoms, and flagellates that form a layer on shelf sediments in the euphotic zone and which can contribute substantially to continental shelf productivity.

Mid-ocean ridge - underwater mountain chain, formed by plate tectonics.

Migration - seasonal movement of animals in pursuit of food, suitable breeding sites or to escape non-favourable weather or other environmental conditions.

Mining - process of extracting useful minerals or other geological materials from the surface of the Earth, including the seas.

Mitigation - structural and non-structural measures undertaken to minimize, reduce or eliminate the adverse impact of natural hazards, environmental degradation and technological hazards.

Mollusc - soft-bodied invertebrate of the phylum *Mollusca*, usually wholly or partly enclosed in a calcium carbonate shell secreted by a soft mantle covering the body.

Monsoon - traditionally is defined as a seasonal reversing wind accompanied by corresponding changes in precipitation, but now is used to describe seasonal changes in atmospheric circulation and precipitation associated with the asymmetric heating of land and sea.

N

Near Shore - region of land extending between the shoreline and the beginning of the offshore zone. Water depth in this area is usually less than 10 metres.

Neritic Species - relating to or inhabiting the ocean waters between the low tide mark and a depth of about 200 meters.

Nitrification - process by which ammonia is converted to nitrites and then nitrates. This process naturally occurs in the environment, where it is carried out by specialized bacteria.

Non-renewable Resource - a resource that does not renew itself at a sufficient rate for sustainable economic extraction in meaningful human time-frame.

Nursery Habitat - a subset of all habitats where juveniles of a species occur, having a greater level of productivity per unit area than other juvenile habitats.

Nutricline - zone of rapid nutrient variation with depth in the water column, often as a result of entrainment of water from a lower depth that is higher in concentration of a particular nutrient.

O

Ocean Trenches - long, deep depression in the ocean floor. Ocean trenches are formed in a convergent boundary, ie, where one lithospheric plate sinks beneath another and returns to the mantle.

Oligotroph - organism that can live in an environment that offers very low levels of nutrients.

Otolith - hard, calcium carbonate structures located directly behind the brain of teleost (bony) fish. Otoliths help with balance, orientation, and sound detection.

Outcrop - visible exposure of bedrock or ancient superficial deposits on the surface of the Earth.

Overexploitation - the excessive use of raw materials without considering the long-term ecological impacts of such use.

Overfishing - a form of overexploitation, where fish stocks are reduced to below acceptable levels, ie, catching more fish than the ocean can produce.

P

Palimpsest Pavements - where the different landforms that make up the landscape have different ages, with some surface landforms being very young because they are being shaped at the present time, and other surface landforms being old, because they were shaped under climatic conditions or by processes that are no longer present in that region.

Passive Margin - transition between oceanic and continental lithosphere. There is no collision or subduction taking place, tectonic activity is minimal and the earth's weathering and erosional processes are dominant.

Pathogen - an agent causing disease or illness to its host.

Pelagic - plants and animals that live in the water column or in the open waters of the ocean.

Peninsula - piece of land that is almost entirely surrounded by water but is connected to the mainland on one side.

Perennial - plants that persist for many growing seasons.

Photosynthesis - chemical process through which plants, some bacteria and algae, produce glucose and oxygen from carbon dioxide and water, using only light as a source of energy.

Phylogenetic - study of evolutionary relationships among groups of organisms, which are discovered through molecular sequencing data and morphological data matrices.

Phylum - taxonomic rank of biological classification, below kingdom and above class, that groups together all classes of organisms that have the same body plan.

Phytoplankton - autotrophic components of the plankton community and a key factor of oceans, seas and freshwater basins ecosystems.

Plankton - marine and freshwater organisms, drifting or floating in water, consisting mainly of diatoms, protozoans, molluscs, small crustaceans and the eggs and larval stages of larger animals.

Pleistocene - geological epoch which lasted from about 2.588.000 to 11.700 years ago, during which a succession of glacial and interglacial climatic cycles occurred.

Pre-Cambrian - period of time that began about 4.6 billion years ago (the point at which Earth began to form) to the beginning of the Cambrian Period, 542 million years ago. It represents more than 80 percent of the total geologic record.

Precautionary principle - allows policy makers to make discretionary decisions in the absence of extensive scientific consensus or insufficient information for comprehensive assessment when there is a risk of causing harm to the public or environment.

Primary Producer - organisms in an ecosystem that produce biomass from inorganic compounds.

Productivity - the amount and rate of production which occur in a given ecosystem over a given time period. It may apply to a single organism, a population, or entire communities and ecosystems. Productivity can be expressed in terms of dry matter produced per area per time (net production), or in terms of energy produced per area per time (gross production = respiration + heat losses + net production).

Prokaryote - microscopic single-celled organism which has neither a distinct nucleus with a membrane nor other specialized organelles, including the bacteria and cyanobacteria.

Pteropods - free-swimming pelagic sea snails and sea slugs.

Purse-seining - fishing technique that involves setting a large circular 'wall' of net around fish, then 'pursing' the bottom together to capture them.

Q

Quarternary - unit of time within the Cenozoic Era, beginning 2.588.000 years ago and continuing to the present day.

R

Ramsar Site - wetland of international importance designated under the Ramsar Convention.

Recruitment - the addiction of new individuals to the harvested stock, for they are to be the next generation of breeders.

Reefs - a rock, sandbar or other feature lying beneath the surface of the water (80 meters or less beneath low water).

Renewable Resources - resources that are replenished by the environment over relatively short periods of time.

Rift - linear zone where the Earth's crust and lithosphere are being pulled apart and is an example of extensional tectonics.

River Delta - wetland that forms as rivers empty their water and sediment into another body of water, such as an ocean, lake, or another river. Deltas can also empty into land, although this is less common.

Runoff - the portion of rainfall, melted snow or irrigation water that flows across the ground's surface and is eventually returned to streams. Run-off can pick up pollutants from air or land and carry them to receiving waters.

S

Salt Marshes - coastal wetlands that are flooded and drained by salt water brought in by the tides.

Sand Mining - a practice that is used to extract sand, mainly through an open pit.

Sea pen - closed off area in the ocean where marine animal are held captive, either permanently or temporarily.

Seabed - the bottom of the ocean, also known as the seafloor, sea floor or ocean floor.

Seagrass - vascular flowering plants that live in coastal and estuarine areas. Usually they are totally submerged in the water.

Seamounts - undersea mountains, formed by volcanic activity, that do not break the water's surface.

Seascape - undersea landscapes.

Seawall - structure that is designed to protect a shoreline from flooding and erosion.

Sediment - solid material originated mostly from disintegrated rocks and is transported by, suspended in or deposited from water.

Sedimentation - strictly, is the process of depositing sediment from suspension in water. Broadly, it's all the processes whereby particles of rock material are accumulated to form sedimentary deposits. Sedimentation involves aqueous, glacial, aeolian and organic agents.

Seismic Survey - method of investigating subterranean structure, related to the exploration of petroleum, natural gas, and mineral deposits.

Sessile - organisms attached to the substratum.

Shelf Break - submerged offshore edge of a shallow continental shelf, where the seafloor transitions to continental slope. A shelf break is characterized by markedly increased slope gradients toward the deep ocean bottom.

Siltation - pollution of water by fine particulate terrestrial clastic material, with a particle size dominated by silt or clay.

Snorkelling - the practice of swimming on or through a body of water while equipped with a diving mask, a shaped tube called a snorkel, and usually fins.

Spawning - the release of gametes or eggs into the water.

Species - group of individuals that actually or potentially interbreed in nature.

Species Assemblage - species that constitute a co-occurring community of organisms in a given habitat. (net)

Species Diversity - measure of the diversity within an ecological community that incorporates both species richness (the number of species in a community) and the species evenness (relative abundance of species).

Stratum (plural strata) - layer of sedimentary rock or soil with internally consistent characteristics that distinguish it from other layers.

Submarine Canyons - major incisions into the continental slope and continental rise, eroded by sediment-laden gravity flows as they travel downslope, transporting sediments, organic carbon and other nutrients from the land to the deep ocean floor.

Substrate - substance used as a food source by organisms or enzymes.

Substratum (plural Substrata) - surface to which an organism grows on or amongst.

Subtidal Zone - area below the low tide water line, which means is always covered by water.

Succulent Species - plants that have thickened and fleshy parts, usually to retain water in arid climates or soil conditions.

Supratidal - uppermost part of the shore affected by wave splash but not regularly submerged by the sea water. Also called epilittoral, splashzone, spray zone, littoral fringe, and strandline.

Sustainability - state whereby the needs of the present population can be met without compromising the ability of future generations to meet their needs.

Symbiosis - interaction between two different organisms living in close association, with advantage for both organisms.

T

Taxon (plural Taxa) - category of organisms, any of the groups to which organisms are assigned according to the principles of taxonomy, including subspecies, species, genus, family, order, class, and phylum.

Tectonic Plate - massive, irregularly shaped slab of solid rock, generally composed of both continental and oceanic lithosphere. Plate size can vary greatly, from a few hundred to thousands of kilometres across.

Tectonics - scientific study of the deformation of the rocks that compose the Earth's crust and the forces that produce such deformation.

Teleosts - group of ray-finned fish (Actinopterygii). Their fins are supported by "rays" of bony spines. Ray-finned fishes form the largest group of vertebrates and include 25.000 species.

Thalassotherapy - medical use of seawater as a form of therapy.

Thermocline - boundary between dense cooler bottom water and warmer less dense surface water.

Thermohaline Ocean Circulation - a part of the large-scale ocean circulation that is driven by global density gradients created by surface heat and freshwater fluxes.

Threatened - any species that is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range.

Tide-gauge - device for measuring the change in sea level relative to a datum. Also known as mareograph or marigraph.

Titaniferous - containing or yielding titanium

Top-Down Effect - the effect that a particular level of the ecosystem's hierarchy has in its lower levels.

Topography - study and depiction (such as charts or maps) of the distribution, relative positions, and elevations of natural and man-made features of a particular landscape.

Trace Elements - an element in a sample that has an average concentration of less than 100 micrograms per gram.

Trans-Boundary - crossing a provincial, territorial or national boundary or border.

Trophic Structure - organization of organisms into groups based on their function within the ecosystem.

Tsunamis - giant waves initiated by an underwater disturbance, such as an earthquake, volcanic eruption or slumping. Out in the depths of the ocean, tsunamis do not dramatically increase in height. But as the waves travel inland, they

build up to higher heights as the depth of the ocean decreases. Also called seismic sea wave or tidal wave.

Turbidity - measure of the degree to which the water loses its transparency due to the presence of suspended particulates.

U

Upwelling - an oceanographic process by which water rises from the lower depths upwards into shallow surface waters.

V

Voucher specimen - representative specimen of the organism used in a study, such as a specimen collected as part of an ecological survey or a specimen which was the source of DNA for a molecular study. Voucher specimens confirm the identity of the species referred to in the study. They are a backup against misidentification, changing species concepts which mislead results.

Vulnerability - the extent to which a population or an ecosystem is liable to be affected by a hazard event.

Vulnerable - species of special concern because of characteristics that make it particularly sensitive to human activities or natural events.

W

Walker - conceptual model of the air flow in the tropics in the lower atmosphere.

Watershed - area of land that drains all the streams and rivers into a single larger body of water, such as a larger river, a lake or an ocean.

Wetland - area of marsh, fen, peat land or bog, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water to a depth at low tide that does not exceed 6 metres.

Whaling - hunting and killing of whales for commercial, recreational or scientific purposes.

World Heritage - designation for places on Earth that are of outstanding universal value to humanity and as such, have been inscribed on the World Heritage List to be protected for future generations to appreciate and enjoy.

Z

Zonation - the distribution of organisms in the intertidal zone, depending on their physical and physiological tolerance for environmental factors, such as wave exposure, temperature, salinity and tidal dynamics.

Zooplankton - animals that live in the plankton and which are unable to move against regional currents.

Zooxanthellae - symbiotic algae that live within the hard corals. The symbiotic relation is based on the corals' inability to generate sufficient amounts of food and the algae's photosynthesis ability. The coral in return provides protection and a nutrient rich environment for excellent algae growth. Corals are completely dependent on the symbiotic algae.