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Intertidal and Nearshore Rocky Reefs

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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).

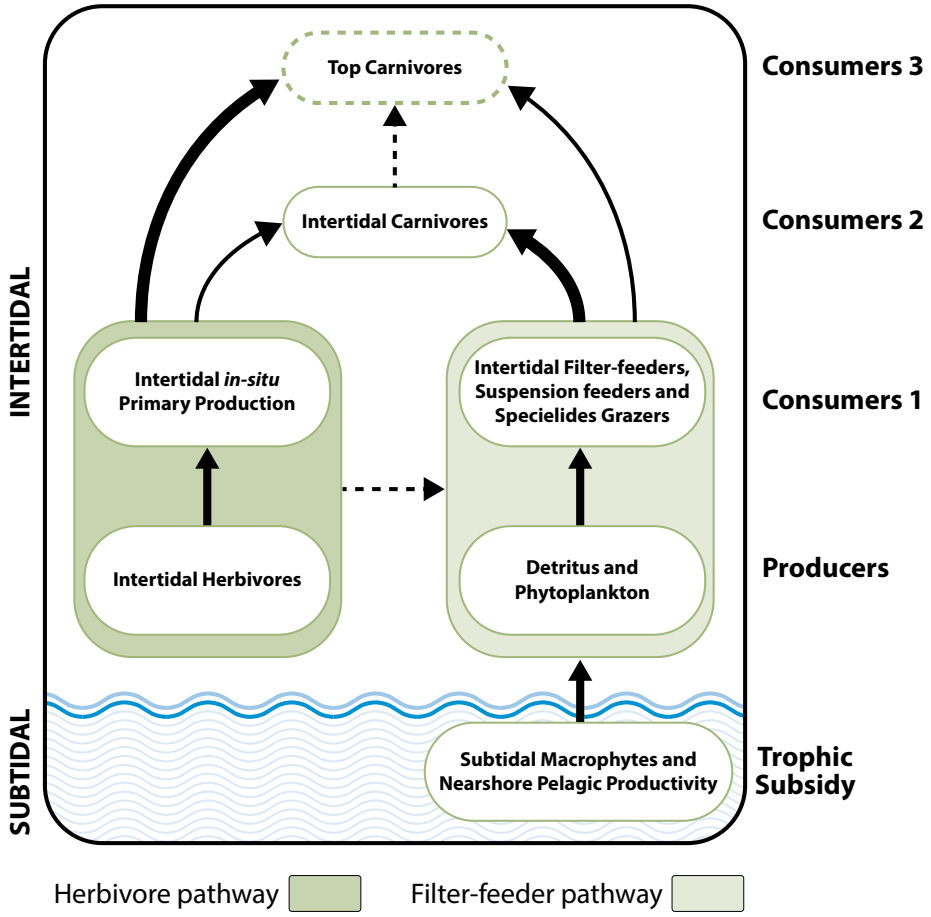


Figure 7.1. Schematic representation of the main pathways of energy-biomass transfer in a typical rocky reef food web. NB: Arrow thickness and pattern indicate the relative importance of the transfer between the different trophic compartments. Source: Steffani 2000.

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

