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Developing human capital for successful implementation of international marine scientific research projects

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Developing human capital for successful implementation of international marine scientific research projects

Abstract
The oceans play a crucial role in the global environment and the sustainability of human populations, because of their involvement in climate regulation and provision of living and non-living resources to humans. Maintenance of healthy oceans in an era of increasing human pressure requires a high-level understanding of the processes occurring in the marine environment and the impacts of anthropogenic activities. Effective protection and sustainable resource management must be based, in part, on knowledge derived from successful research. Current marine research activities are being limited by a need for high-quality researchers capable of addressing critical issues in broad multidisciplinary research activities. This is particularly true for developing countries which will require the building of capacity for marine scientific research. This paper reviews the current activities aimed at increasing marine research capacity in developing and emerging countries and analyses the challenges faced, including: appropriate alignment of the research goals and societal and policy-relevant needs; training in multidisciplinary research; increasing capacity for overall synthesis of scientific data; building the capacity of technical staff; keeping highly qualified personnel in marine scientific research roles; cross-cultural issues in training; minimising duplication in training activities; improving linkages among human capital, project resources and infrastructure. Potential solutions to these challenges are provided, along with some priorities for action aimed at improving the overall research effort.

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Developing Human Capital for Successful Implementation of International Marine Scientific Research Projects

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Abstract

The oceans play a crucial role in the global environment and the sustainability of human populations, because of their involvement in climate regulation and provision of living and non-living resources to humans. Maintenance of healthy oceans in an era of increasing human pressure requires a high-level understanding of the processes occurring in the marine environment and the impacts of anthropogenic activities. Effective protection and sustainable resource management must be based, in part, on knowledge derived from successful research. Current marine research activities are being limited by a need for high-quality researchers capable of addressing critical issues in broad multidisciplinary research activities. This is particularly true for developing countries which will require the building of capacity for marine scientific research. This paper reviews the current activities aimed at increasing marine research capacity in developing and emerging countries and analyses the challenges faced, including: appropriate alignment of the research goals and societal and policy-relevant needs; training in multidisciplinary research; increasing capacity for overall synthesis of scientific data; building the capacity of technical staff; keeping highly qualified personnel in marine scientific research roles; cross-cultural issues in training; minimising duplication in training activities; improving linkages among human capital, project resources and infrastructure. Potential solutions to these challenges are provided, along with some priorities for action aimed at improving the overall research effort.

1. Introduction

The oceans are a critical component of the Earth's environment, covering more than 70% of the surface to an average depth of about 4000 m, and containing more than 97% of the water on our planet's surface. The wide surface coverage and great depth of the oceans lead to a wide variety of conditions in temperature, density and light, and demarcations between different zones are often difficult to delineate. The continuous exposure of the oceans to sunlight causes them to be the main energy store in the Earth's climate system and a major regulator of climate. In addition, the interaction between the oceans and the atmosphere plays a major role in controlling the composition of the atmosphere. This includes the production and transport of water vapour, as well as major processes in the global biogeochemical cycles. In addition to these important physical roles, the oceans play a vital role in biological productivity and diversity, and in geochemical cycling. Millions of species inhabit the oceans, ranging in size from blue whales (*Baleonopteramusculus*) to krill

(Euphausiasuperba), from giant kelp (*Macrocystis pyrifera*) to microphytoplankton (e.g., *Thalassionema* sp.). The total oceanic biomass is difficult to estimate, but figures of up to 10^9 tonnes of carbon (C) have been suggested (Groombridge and Jenkins, 2000). Humans harvest about 160-179 million tonnes of biomass annually from the oceans (FAO, 2013). The oceans receive the waters flowing from most of the world's major rivers (about $37x10^{15}$ kg/yr) containing varying loads of suspended and dissolved materials (Baumgartner and Reichel, 1975), while submarine groundwater discharges and volcanic hydrothermal systems add another 10^{15} kg/yr (Chester, 1990; Slomp and van Cappellan, 2004). The oceans thus represent the largest possible mixing vessel on Earth, facilitating a massive movement of materials and energy around the globe.

Despite these vital contributions to global environmental systems and human existence, our scientific knowledge of the oceans is far from complete (UNEP, 2007; Banse, 2013). Over the last 60 years, researchers have significantly expanded our knowledge base, but many unknowns still remain, especially for areas distant from the coast. In addition, much of the research carried out has focussed on single disciplinary studies of the ocean (i.e., biology, chemistry, geology, and physics, etc.) and does not provide the information necessary to achieve a sufficient understanding of oceanic processes and the interactions between biological activity and the physical, chemical and geological processes that significantly affect ocean biology. Several international marine scientific research projects have been developed over the past three decades to examine ocean processes in an interdisciplinary manner, including the Joint Global Ocean Flux Studies (JGOFS), Global Ocean Ecosystem Dynamics (GLOBEC), Global Ecology and Oceanography of Harmful Algal Blooms (GEOHAB), the Surface Ocean-Lower Atmosphere Study (SOLAS), the International Study of the Marine Biogeochemical Cycles of Trace Elements and their Isotopes (GEOTRACES) and the Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) projects; these international initiatives have well-defined objectives to study one or several specific key global ocean scientific issues. For example, the IMBER project of the International Geosphere-Biosphere Programme (IGBP) and the Scientific Committee on Oceanic Research (SCOR) has a mission ***"to provide a comprehensive understanding of, and accurate predictive capacity for, ocean responses to accelerating global change and the consequent effects on the Earth System and human society"*** (cf. www.imber.info).

Ocean researchers are increasingly being asked to provide an improved understanding of processes essential for better management and more sustainable use of the oceans (Millennium Assessment, 2005; UN World Ocean Assessment, 2009). Issues of particular

interest and complexity include transformation of organic matter in marine food webs, transfers of matter across ocean interfaces, changing supplies of nutrients and the impacts of marine harvesting. Understanding and predicting how marine biogeochemical cycles and ecosystems will respond to a variety of global changes (e.g., ocean warming, oxygen depletion and acidification) is critical for examination of the feedbacks between the ocean and other Earth surface components. In addition, the multiple feedback mechanisms between humans and ocean systems need to be better understood to clarify what human institutions can do, either to mitigate anthropogenic perturbations of the ocean system or to adapt to such changes.

Marine scientific research is constrained by insufficient and aging infrastructure for sea-going observations and limited funding sources, particularly in developing countries (NRC, 2008); there are also related problems in the education of marine researchers with regard to adopting multi-disciplinary/inter-disciplinary approaches. To fully address the range of complex ocean issues requires researchers with a strong multi-disciplinary/inter-disciplinary background (e.g., physics, chemistry, ecology and geology, plus statistics, computational and spatial science, and social science) and preferably with a wide range of laboratory and field skills, including experience on ocean-going vessels. There is also a complementary need for skilled and experienced technical staff to support these global marine research activities. The number of researchers/technicians with such backgrounds is limited, especially in developing countries. There is, therefore, clearly a need for research capacity building to support this field (Zhang et al, 2013).

As a minimum, all countries with an ocean coastline must develop and maintain a pool of marine scientists large enough to protect and manage their marine resources, from the coastline to the outer limit of the national exclusive economic zone (EEZ). In order to keep this pool of scientists, several different social mechanisms are needed to attract and retain talented individuals and recruit young researchers. This is particularly important in developing and emerging countries, where resources for research may be limited. To overcome the lack of resources, developing countries may share facilities through bilateral and/or regional cooperation. and developed countries can and do provide assistance to developing nations.

Current international marine research initiatives require integrated multi-disciplinary approaches with strong support for equipment and observations funded at the country level. Involvement in open ocean research across the globe is relatively uneven in terms of country and institution participation, with a distinct lack of researchers based in developing or

emerging countries. The reasons for this include, but are not limited to, the following factors:

- The capacity of a national marine scientific research community may be limited; for example, the community may lack expertise in certain disciplines, owing to the nature of the existing education systems in the country;
- Sea-going equipment and facilities for research and observations are limited, especially for open ocean studies, which means that most developing countries focus their research on the coastal environment, and hence find it difficult to participate in international research initiatives with an open ocean focus and also to develop the expertise to characterize and manage their wider EEZ environments;
- The limited financial resources to support sea-going observations mean that developing countries tend to depend on bilateral collaboration, rather than international research projects that require more infrastructure. Also, the scarcity of national funding for ocean research may lead to an emphasis on short-term investment in equipment purchases as opposed to a long-term strategy for research and maintenance of facilities; and,
- In some countries, government support for research is somewhat erratic, and developing country scientists are not able to make longer-term commitments to international collaborations and other cooperative opportunities that could assist in the development of scientific capacity.

Among others, a key factor affecting investment in scientific research is the national appreciation of the importance of the marine sector to the country's economy and resources. Some countries (e.g., Chile, India, South Africa, and Malaysia) are highly aware of the relative importance of the marine sector and invest heavily in research and marine resource development and management. Others take a less tactical approach, investing less in marine-related research and development, as other sectors are seen as being of greater significance in terms of national economies, security and other factors. For example, some developing countries receive more than 10% of their gross domestic products (GDPs) from the marine sector (e.g., Thailand), similar to developed countries, while others may only get 1-5% of the GDPs from the marine sector (McIlgorm, 2009).

2. What Is Capacity Building in the Context of Marine Scientific Research?

The enhancement of the extent and quality of marine research in a country involves various institutional mechanisms, such as, attracting talented individuals, training them appropriately, investment in state-of-the-art facilities and provision of research funding (Figure 1).

Developing skills and infrastructure for any major activity is often referred to as capacity building (CB), but other terms such as capacity development (CD) or capacity enhancement (CE) are also used. 'Capacity Building' (hereafter referred to as CB) will be used in this paper. In this context, CB in marine scientific research is intended to enable individuals, groups, institutions/organisations and even entire countries to achieve a better understanding of oceanic processes so collectively they can fully contribute to the on-going sustainable use and management of the global oceanic system and their national part of it, in terms of resource extraction and ecosystem maintenance (for more detail see NRC, 2008). A key requirement for marine research CB is the growth in the numbers of young and mid-career marine researchers and technicians, with the requisite knowledge and skills, especially in developing countries, to make significant contributions to national, regional and international research. CB will not be effective unless built on a foundation of infrastructure provision and maintenance, and sustainable resources (e.g., funding), and an adequate research-policy dialogue.

The CB needs of individuals will be different for developing and developed countries simply because of prior opportunities made available for involvement in large-scale research projects. Also, researchers at different stages in their careers require different training. For example, early-career scientists may need to develop skills in experimentation and data collection, and progress to more skills in data analysis, modelling and interpretation of complex oceanic processes. Similarly, global marine research projects often require skills in data collection in the early phase, but later need abilities in data analysis and synthesis of results, and interpretation in the wider context as the project matures.

Over the last 20 years, there has been extensive CB in coastal zone management (CZM), marine protected areas (MPAs including locally managed marine areas – LMMAs), fisheries and aquaculture, coral reef ecology, ecosystem recovery, oil spill response, monitoring, sensor and gear development, etc. Many of these CB activities occur at the local, national or regional level in response to requests from national agencies to international aid and development agencies. Such efforts are extremely valuable because they tend to focus on issues related to immediate environmental issues experienced in a nation's coastal waters.

Recruitment of tertiary students to marine science is essential for maintaining a sustainable research endeavour and improving the research capacity of coastal nations. Although marine science, as a scientific career, has broad appeal to the young generation, several factors limit the attractiveness of marine science:

- Salaries for marine scientists are often lower than for other technical fields (e.g., medicine, biotechnology, mining and engineering) to which talented students might be attracted;
- Universities, government agencies and other employers of marine scientists do not offer enough positions for all qualified graduates. This creates a high level of competition for jobs and may discourage talented young scientists;
- Research funds through the employing university or agency, and through national funding agencies are often scarce; and,
- Working conditions may be difficult for marine scientists, with irregular hours, work in the field and at sea, significant time away from home, etc.

Figure 1 indicates the range of issues facing young scientists. In today's world, life is becoming even more difficult for the young researcher in light of increasing competition for positions and funding. Promotion and tenure decisions are often based on the number and quality of publications and the ability to attract external funding is decisive. More and more employment opportunities are provided by fixed-term contract positions (as opposed to tenured appointments).

INSERT FIGURE 1 ABOUT HERE

International Research Projects as CB Platforms - Involvement of national ocean science communities in global marine projects provides an opportunity to fulfil project CB needs and national CB needs; global projects can assist with personal skills enhancement, resources for dedicated activities and possible provision of limited infrastructure. The trained staff and allocated CB resources can then also be utilised in more locally focussed national or regional research and complement the existing capacity. At the same time, participation of researchers from developing countries can enhance international partnerships by bringing their local expertise into the program, and making the global programs truly global, not merely composed of participants from developed countries. This participation can be achieved in several ways including, for example, using regional meetings to facilitate a link with regional and national needs for information sharing and training. An example is provided by the GEOTRACES project that held regional meetings in Southeast Asia, South Asia, South America, Russia and the Mediterranean Sea region, and has used the meetings to involve developing country scientists and to include their research priorities in GEOTRACES implementation.

3. What Is Being Done To Address These Issues?

The challenges to CB described above are being addressed by various international projects and organizations involved in marine science (SCOR, 2010). Table 1 presents examples of CB approaches used and which organizations are involved in CB for ocean science on regional and international levels (see www.scor-int.org/Capacity_Building/Meeting_Report-Bremen.pdf). The information presented covers the majority of CB for ocean research worldwide (minus the 'normal' academic curricula), although may not include every activity/organisation. The table does not include activities relating to marine policy, governance and management. The information in Table 1 focuses on CB activities that are especially important to help international marine research projects achieve their scientific goals, which is a subset of activities that might be pursued by permanent organizations, as research projects are time-limited.

3.1 Grants to attend meetings

One of the most common CB approaches is to provide support for early-career scientists and individuals from developing countries to attend scientific meetings. This mode can create opportunities for networking, knowledge transfer and mentoring (Urban and Boscolo, 2013). IAEA, IFS, IOC, PICES, SCOR, START in particular, provide international travel support by different mechanisms. Individuals supported through travel grants can help publicize science that may not be well known outside the recipients' countries, through poster and oral presentations. Projects can use travel grants strategically to bring new scientists into international projects and to establish new collaborations on topics or in regions that are particularly important to meet the scientific goals of the project. IFS provides small research grants to developing country scientists and then supplies travel grants to make it possible for recipients of the research grants to present their results at scientific meetings.

3.2 Training in data and information management

Data and information management is an often-neglected aspect of oceanographic research, but is increasingly gaining appropriate attention. International research projects usually ask their scientists to submit their data to national data centres and/or project-related data centres. Most ocean data managers were originally trained as ocean researchers and later moved into data management. The International Oceanographic Data and Information Exchange (IODE) of UNESCO's Intergovernmental Oceanographic Commission (IOC) provides grants for training in data and information management, making it possible for individuals to participate in courses in developing regions, and also at the IOC Project Office for IODE in Oostende, Belgium. In an interdisciplinary context, IODE also provides instruction to early-career scientists in the value of sharing information among themselves in the interest of science.

Such training could be especially important to projects that do not employ professional data managers. IMBER has held data management workshops in conjunction with each of its IMBIZO ('imbizo' is a Zulu word that means 'gathering') open science meetings, to familiarize participants with the need for careful data management (Box 1) and has developed a 'cookbook' for data management that is available to all researchers (Pollard et al, 2011).

INSERT BOX 1 ABOUT HERE

3.3 Summer Schools

Summer schools bring together graduate students and early-career scientists for 1-2 weeks to focus on specific topics or areas of study, with classroom lectures and often with hands-on laboratory sessions, shipboard time, modelling experience, etc. For example, research projects sponsored by SCOR have used this approach effectively to bring students together to cross the boundaries of atmospheric and ocean science (SOLAS), and the boundaries of ocean biogeochemistry and ecosystem research (IMBER). PICES member nations host summer schools developed by PICES Committees and Expert Groups for early-career scientists. IODE has developed a portal to ocean summer schools (see http://www.oceansummerschools.org/). Summer schools have the benefit of focusing student attention on a specific topic in an intensive setting. Summer schools are often interdisciplinary and can be used to develop a community of young scientists working across traditional disciplinary boundaries. Summer schools can also be used for focused training on laboratory analysis techniques, such as those related to ocean carbon cycles. The networking achieved through summer schools can be important in career development for participating young scientists and to develop future research collaborations and networks. Continuity and tracking of summer school graduates is important, to determine the impact of the program on the field of research, and maintain support and funding for the schools. Funding can be a challenge, particularly for regularly repeated schools. Usually funding is derived from a student's own institution, national programs, or funding from external sources (or a combination of sources). SOLAS (Surface Ocean-Lower Atmosphere Study) Summer Schools often have used funding from dozens of sources (Box 2), and this can be a challenge for summer school organizers to obtain and manage.

INSERT BOX 2 ABOUT HERE

3.4 Ship-board experience

One form of CB that can directly benefit project goals is ship-board training, in which trainees participate in ship-board science activities. This approach provides first-hand experience for trainees about what is involved in conducting ocean research from ships. Many international

research projects include research cruises to fulfil scientific goals. These cruises may be coastal or in the open ocean. They may be 'process studies' that focus on a process in a relatively small area or 'transects' that measure selected parameters on some predetermined pattern of stations in a given area or across an ocean basin. Developed country students often get training in conducting research at sea using ship resources from their own institution or cooperating institutions, but early-career scientists from developing countries may either not have any access to ships at their own institution or may not have locally based scientists who can provide the necessary training in relevant techniques. International research projects can develop capacity directly related to the project by providing training at-sea for developing country scientists on project related cruises. This approach can be particularly important in the early years of a project. SCOR occasionally provides support for travel of scientists from developing countries to and from research cruises that have offered empty berths for training, in relation to SCOR-supported projects. For example, the GEOTRACES project involves several national cruises each year and SCOR has supported individuals from several different countries to participate in GEOTRACES cruises (Box 3)

The POGO Visiting Fellowship Programme for on-board training on an Atlantic Meridional Transect Cruise (see http://ocean-partners.org/training-and-education/research-cruise-training) offers the opportunity for a scientist from a developing country to participate in cruise preparation and planning, to help make hydrological, biological, and ecological observations on board the ship, and to analyse and statistically interpret the results after the cruise. IOC has used a Training Through Research (TTR) approach to train early-career scientists, particularly using Ukrainian research vessels and training cruises on the Black Sea. Ideally, the trainee can spend some time at the host institution before and after the cruise for extended preparation and analysis of samples/data. For instance, the POGO AMT fellowship uses this approach, although it substantially increases the cost per trainee. It is especially important that trainees will be able to take advantage of their shipboard experience when they return home, that is, their institution/country has access to a research vessel on which the trainee's new skills can be used, and their job continuity is assured. The availability of berths on research cruises and ship-time for training cruises is a major barrier to using this approach. POGO maintains a cruise database that can be searched for cruises with berths available (http://www.pogo-oceancruises.org/content/content.asp?pageid=2) (Urban et al., 2009). Recently, the German funding agency BMBF has provided funding for training cruises on German ships as well, for example, as part of the German SPACES program.

INSERT BOX 3 ABOUT HERE

3.5 Visiting Professorships

The number of developing country scientists who benefit from CB can be increased by sending experienced scientists and technicians to a developing country to undertake teaching, mentoring, undertaking joint research and developing new research partnerships. POGO, SCOR, and START use this approach. It allows the training of a larger number of scientists and the training provided is relevant to the research questions of interest in the region. Such training also uses techniques and equipment that can be adapted in the region to answer regional and national research questions. This approach provides an opportunity for extended contact between the trainer and trainees over weeks to months, which when maintained are beneficial to the scientists' careers. In some cases, hosts and visiting professors will self-associate; in other cases, hosts and potential visiting professors will need help with matching. Local hosts are likely to have more 'buy in' to the visit if they are expected to provide some level of local support. Consideration should be given to either providing one-time professorships to developing country institutions, or to creating a sustained partnership with a few institutions, or to use a combination of both approaches. Projects should consider identifying participating scientists who can serve as visiting scientists at institutions in developing countries and whose visit could be particularly useful to meet project scientific goals.

3.6 Centres of Excellence in oceanography training

Actual or virtual centres of excellence may be developed to bring together teaching expertise with students from a region or globally. One approach, adopted by IOC, is to establish a series of Regional Training and Research Centres and UNESCO Chairs dedicated to marine science with a view to addressing the capacity-building needs of IOC Member States. One IOC Regional Training and Research Centre on Ocean Dynamics and Climate was established in the First Institute of Oceanography, State Oceanic Administration of China, with the main beneficiaries being from the Western Pacific and its adjacent regions, while the International Training Centre for Operational Oceanography (ITCOocean) was established in Hyderabad as a contribution to capacity development activities mainly in the Indian Ocean- rim countries. Seven UNESCO Chairs have been established in marine sciences, ranging from Integrated Coastal Management (in Mozambique) to Physical Oceanography (in Chile and Georgia) and Marine Geosciences (in Russia).

The POGO approach, funded by the Nippon Foundation, brought students to the Bermuda Institute of Ocean Sciences (BIOS) from 2008 to 2012 with a second phase to be hosted by the Alfred Wegener Institute for Polar and Marine Research. In Phase I, the COE (Centre of

Excellence) offered a 10-month program of study to 10 students each year. This approach enables students to be trained in a wide range of techniques for ocean science over an extended period, including data collection, analysis and communication. It also provides advantages in terms of networking as mentioned for summer schools. The difference between COEs and Summer Schools is that the former can provide sustainable and continuous training through research, involving a close relationship between trainer and trainee, including one-to-one training.

3.7 Distance Learning

New approaches using video conferencing, webinars, and formal distance education curricula can provide a range of training in marine sciences. DVDs can be used in situations where internet access is not adequate for online distance learning. Existing course work at different universities is already available, but there are also opportunities for further development and application of custom-tailored training. The Ocean Teacher program of IOC/IODE has provided a significant library of resources (http://classroom.oceanteacher.org/), primarily related to ocean data and information management, but also for some additional topics.

Recently IMBER started broadcasting lectures and video materials from its summer schools in real time, so that people unable to attend the summer school can follow and participate simultaneously with trainees in the various activities. Several UNEP-GEF supported Large Marine Ecosystem programmes have also developed specific 'Distance Learning and Information Sharing' (DLIST) modules to help provide access to information for all stakeholders who have an interest in the welfare of a particular region, its coastal areas and local communities, for instance, for the ASCLME (Western Indian Ocean, www.dlist-asclme.org) and the BCLME (Benguela Current Region in Southern Africa, www.dlist.org).

3.8 Alumni networks

Over time, CB activities create pools of former participants who can be linked together through alumni networks. Such networks can continue to produce benefits as the alumni continue to interact. Moreover, an alumni network can help to promote the involvement of young scientists from developing countries in regional and international research projects plus help maintain the collaborations between individual alumni, as well as with knowledge transfer and sharing of techniques. The Nippon Foundation (NF) and POGO created the NF-POGO Alumni Network for Oceans (NANO) to encourage networking and joint research among trainees from other NF and POGO activities (http://www.nf-pogo-alumni.org/home).

3.9 Mentoring

Mentoring usually takes the form of interactions between a senior scientist and an early-career scientist. Projects and organizations can use mentoring programs to transfer scientific knowledge and experience to help early-career scientists develop their careers. Mentoring can take place remotely, but is most commonly used as a component of scientific meetings (Urban and Boscolo, 2013). At scientific meetings, it can be helpful for early-career and more senior session chairs to be paired, so that early-career chairs can learn from their more experienced colleagues. Alternatively, developed and developing country scientists can be teamed. This "twinning" concept can also apply when a project is selecting chairs for its activities. Another aspect of mentoring can be related to junior and senior scientists or developed country and developing country scientists working together on scientific papers and elaborating ideas from cooperative research and from scientific meetings.

3.10 Regional graduate networks

SCOR is experimenting with the concept of regional graduate networks of oceanography education. The general idea is to form virtual networks of ocean science institutions in developing regions to bring together a critical mass of expertise and resources to train students in ocean science, with classes, cruise experience, summer schools, etc., contributed by institutions in the region. Some version of this concept could be implemented by international/regional projects in a more limited sense, to promote project goals in specific regions.

4. What Are the Issues/Gaps That Need to be Addressed?

4.1 Challenge: Alignment of the scientific goals of international research projects and the scientific needs and priorities of the researchers and countries/institutions involved in CB activities

The key scientific issues identified by a multidisciplinary research project are unlikely to overlap completely with the scientific needs of any specific country, so there will necessarily be a 'mix and match' alignment of the scientific directions of the project and any country or institution. The greater the overlaps in scientific interests between the project and the country or institution the greater the CB needs are likely to overlap. In developing countries there is a tendency to focus on coastal issues and the management of the coastal ecosystems that are of direct relevance to people and economics within these countries. Multidisciplinary marine projects generally have a wider range of issues than the coastal area and its management, with generally more focus on the underpinning science for such management and on open ocean

issues. This situation often leads to a mismatch between the CB needs of the global research project and national agencies.

Potential solution: To reduce the mismatch of CB priorities between projects and regions/countries there is a need to identify areas of overlap early in the project planning process so that CB needs can be addressed by the relevant institutions and the project to identify areas of mutual benefit. This will need to be done at the regional to country scale with projects identifying key issues and geographic areas for research early in the project planning stages. There are also likely to be changes in the international/regional project CB needs as a project progresses, for example, many projects move from (early) data collection to (later) analysis, modelling and synthesis. This implies that there should be regular discussions regarding the CB needs of the project and countries throughout the life time of the project to ensure the best alignment possible. Particular areas of common interest of projects and countries could be increasing scientific knowledge in national EEZs.

4.2 Challenge: Development of capacity to conduct multidisciplinary research

A key challenge is the development of capacity for the conduct of multidisciplinary research and for the overall synthesis of the project results. There is a lack of capacity in many countries, both developed and developing, to conduct effective multidisciplinary missions. There is a range of reasons for this gap. Many researchers tend to remain in their own research domain rather than challenge 'new disciplines', because of easier recognition by their disciplinary peers and society, more potential citeable research outcomes, and access to familiar funding sources. Learning the jargon of a new discipline is difficult, especially if attempted in a second language. In addition, research funding agencies in many countries use discipline-specific metrics to assess applications and having a 'track record' in the field of interest is a major evaluation criterion. For early-career researchers, maximizing their research output is critical for continued employment and promotion; moving into a new discipline area usually slows publication outputs. In addition, multidisciplinary research often leads to a large number of co-authorship papers, which can often disadvantage researchers in terms of career progression. In developing and economically emerging countries, researchers may have a limited capacity to explore new research domains, because of limited funding sources, and multi-disciplinary studies can be much more costly than traditional research linked to individual disciplines, especially for oceanography (e.g., in terms of infrastructure and expertise). In addition to the personal challenges of undertaking multidisciplinary research, there are also barriers within the education and training systems of most countries, with university courses primarily based around individual disciplines. This situation is seen more

often in developing countries where the teaching of essential oceanographic studies is often limited to one or two disciplines without the breath of coverage to create multidisciplinary studies.

Potential solution: The educational structure in many developing countries is still based on traditional disciplinary arrangements (e.g., biology, chemistry, geology, and physics), whereas modern oceanographic research requires an integrated and multidisciplinary approach. In such a situation, international projects provide an alternative for research-based training and education in 'integration and multidisciplinarity'. There is a need to have innovation in university education to offer comprehensive multidisciplinary educational curricula that bridge traditional disciplinary boundaries, and assist students to develop skills across the range of knowledge required to understand complex oceanic processes. Another option might be to offer bachelor's degrees with a second (or double) major, where students have a major in a traditional discipline (e.g., biology), but also take a second major in an oceanography-related program with both theoretical and practical training.

In many developed countries there are close affiliations between universities and government and private research institutions, for example, offering joint PhD programs that provide the advantages of university educational facilities combined with the advanced research facilities and staff capacity of a research institution. This approach could be adopted in developing countries, as close cooperation between universities and research institutions could offer better opportunities for students to become involved in advanced ocean science projects, while at the same time enabling senior research scientists to come into closer contact with students and early-career researchers by offering specialist lectures. Examples of such synergies include James Cook University/Australian Institute of Marine Sciences/Great Barrier Reef Marine Park Authority (Australia), Woods Hole Oceanographic Institution/U.S. Geological Survey/National Marine Fisheries Service (USA), and the Leibniz Research Centres affiliated with universities in Germany. There is also the potential at the regional scale to overcome the political obstacles between countries and promote trans-boundary recognition of university courses and degrees, so that universities can share their educational resources, and students can have access to staff and facilities that may not be available in every discipline in their home university.

Another way to address multidisciplinary training for young scientists is the provision of Summer Schools by the projects, enabling students and early-career scientists to engage in multidisciplinary training, for example, such as those facilitated by both SOLAS and IMBER, and the Austral Summer Institute (ASI) in Concepcion in recent years (see section 3.3). A

third way to address this issue is to ensure that project workshops and conferences take a multidisciplinary approach and use formats that are conducive to providing interaction among scientists of different disciplines (e.g., the IMBER IMBIZO series).

4.3 Challenge: Development of capacity to synthesize project results

Synthesis of a wide range of scientific information across disciplines is challenging and requires a unique set of skills. In the marine scientific research context, such synthesis or integration involves a capacity to use the knowledge obtained from an integration of biological, chemical and geological studies (e.g., biogeochemistry) with the processes regulating the supply and cycling of bio-limiting elements (i.e., physics) and the functioning of the ecosystems that provide humans with sustainable food systems, and means to achieve their well-being. Researchers undertaking such work must have the capacity to move between disciplines and utilise concepts and information from fields as diverse as physical oceanography, fisheries ecology, biogeochemistry, genetics and natural resource economics. The ability to think widely in terms of scale (10s–1000s of km) and time (seconds to hundreds or even up to millions of years) is an important component of such activity. Few existing ocean science training programs aim directly to develop such a capacity; if anything, there appears to be a continuing trend to 'reductionist' approaches, with many marine scientists becoming narrower and narrower in their focus. Development of skills to work across disciplines is difficult to achieve under the best of circumstances, but is especially problematic for researchers and other professionals from countries with limited research training opportunities and traditional training with a relatively narrow focus.

Potential solution: Development of project activities such as workshops and summer schools that have a focus on synthesis activities is an excellent way to build capacity. The potential to use data collected for the project as the basis for workshops that involve both experienced and early-career scientists in synthesis activities has great potential for building capacity. This is an approach adopted by GEOTRACES, which has facilitated biennial workshops on modelling and data synthesis where there is active involvement of both experienced and early-career scientists, modellers and sea-going scientists. Another opportunity is to ensure that when synthesis papers are a product of a workshop - for example, the IMBER IMBIZO series - that the authorship of these papers includes experienced and early-career scientists or students. There is also the opportunity for universities to develop synthesis skills in their students by ensuring that the coursework required for post-graduate training includes synthesis activities, not just discipline-based materials; courses to develop the ability of students in synthesis and integration of a wide range of scientific data are also needed.

4.4 Challenge: Ensuring that CB includes technical as well as scientific skills

Further scientific challenges include balancing the range of capacity required and ensuring that the CB is appropriate for the region, country and/or institutions. There is a need for projects to achieve a balance in building capacity across the spectrum from 'hands on' technical skills and data management, to multidisciplinary analysis and scientific synthesis of results. This balance is likely to change over the duration of a project and will also need to be aligned with the needs of the regions, countries, institutions and individuals. In considering this balance, thought needs to be given to the ability of those involved to make effective use of the training. For example, training should not focus primarily on highly specialised techniques that require expensive/specialised equipment or research infrastructure not widely available. An evaluation of the targeted personnel for the activity and the effectiveness, value-for-money and long-term impact of such training is needed.

Potential solution: One solution lies in increasing awareness of the need for technical training to support the scientific goals of both multidisciplinary global projects and national marine research activities. This training may be undertaken in a number of ways, including sea-based experience for both technical and scientific staff, such as that funded by POGO and provided by the Plymouth Marine Laboratory for AMT cruises. There are also opportunities for universities to contribute to this technical training by offering specialised training potentially at the master's degree level to produce highly skilled technical graduates.

4.5 Challenge: Maintaining the capacity built within the marine science community and also within countries or regions

The maintenance of scientific and technical capacity within the marine science community is important due to the limited resources available, in terms of both personnel and funds, to build capacity. For developing countries, the maintenance of trained people within the country that supported financially their training is also important in building a critical mass who will then potentially attract both resources and infrastructure to further develop capacity for marine science.

Potential solution: One of the solutions to this problem is to promote CB activities in a biogeographically coherent region, and to select techniques and methodologies appropriate to the sustainable development of that region. Another very important factor to limit brain drain is for research institutions, universities, and national governments to maximize the job opportunities in marine sciences so that the CB recipients can find relevant positions within their country and pursue their research career in marine science. This can be assisted by national or regional scholarships that not only support academic studies but also provide for

students to return to their own countries for a set period of time after their graduation. Projects also have an opportunity to assist in keeping the interest of scientists in marine research by developing alumni networks that provide support for, and interaction between, early-career scientists. This has been done successfully by the IGBP Analysis, Integration and Modelling of the Earth System (AIMES – http://www.aimes.ucar.edu/ysn/), which has developed a very active network of early career scientists in their Young Scholars Network, and by POGO through its NANO initiative.

4.6 Challenge: Designing CB that will meet project scientific needs

The decision to provide in-depth training to an individual or institution, or less extensive training to a larger group, is difficult and one often faced by projects. It is important to balance the needs of the project, the individuals involved, country and/or the institutional needs, plus the requirements of the research and/or development funding agencies that often place restrictions on how their funds are spent. The approach taken by a project will often depend on the type of capacity being built and is likely to vary with the focus of the activities and also the timing of a specific activity within the project.

In-depth training may assist a country to develop a small number of very highly trained individuals on a specific set of topics, moving them from very basic training in research skills to the sophisticated scientific leadership that will help to maintain the critical size of capacity for marine sciences in the country. This 'one off' approach provides potential benefits for general step-wise improvement of scientific capacity in a country and could discover talented individuals to move into the more extensive training described earlier.

Potential solution: Projects need to be proactive in defining their scientific focus and linking this with the existing capacity of the research community, both internationally and within regions and countries. Project leaders then need to identify in what areas and to what level capacity needs to be enhanced to provide sufficient capacity to fulfil the project's science plan and then strategically identify the recipients to receive this CB.

4.7 Challenge: Providing activities that are accessible to a wide range of cultures

Where and when CB activities are held and how they are structured is important and can influence their effectiveness, value-for-money and long-term impact. Consideration needs to be given to cultural differences (attitudes, values and practices) of the participants and any language barriers, to ensure that the activities are as effective as possible. For example, in some cultures, even in universities, it is expected that young people will not challenge their scientific elders, yet the practice of challenging the scientific '*status quo*' is a major feature of the scientific cultures of the most scientifically productive societies. The language barrier is

also often an issue with scientific communication, creating barriers in both verbal and written interactions. This can be a significant drawback particularly for young scientists, but is declining in importance with improving technologies. Another aspect of this challenge is related to the gender issue where, in the past, numbers of female marine scientists have been relatively low (in comparison to females in the general student population or in university teaching positions), perhaps as a result of limitations on opportunities for sea-going activities due to family commitments.

Potential solution: Training abroad and/or international summer schools can help provide students from more hierarchical societies with experience in asking questions of their scientific elders and to 'debate without fear'. Mentoring programs within science conferences and workshops are another way cultural and language barriers can be bridged. Enlisting early-career, promising or emerging researchers to co-chair sessions at scientific meetings, as well as co-chairing international project and sub-project research and networking activities with more senior colleagues can assist in diminishing these barriers.

In developing CB there is a need to tailor activities to suit the differences in culture, accepting that such differences are present, benefitting from them and utilising different approaches, based on an open consideration of cultural relativism, yet without compromising moral principles that are common across cultures. This can again be facilitated by mentorship at meetings and conferences, plus co-supervision of postgraduate researchers. This can be rewarding for both younger and elder participants from countries with a strong marine science base.

4.8 **Challenge: Evaluation of CB activities**

There is need to undertake appropriate evaluation of all activities from both the attendees and presenters/providers of the training and an analysis of this information so that the effectiveness of the CB can be improved over time. Evaluation ideally should be completed soon after the CB activity and then repeated at a later date to estimate the longer-term impact of the CB. There are several issues to consider in assessing long-term impacts:

- Capacity and competencies are dynamic, not static over time;
- When is capacity or competence lost?;
- Evaluation of opportunities to use skills developed;
- Adjustment of impact expectation to reality; and,
- Cost of doing assessment.

At this time, there is a lack of standardised indicators or frameworks for assessing impacts of CB activities in marine science, but they exist in other research domains, e.g., environmental

public health (see e.g., NIH Partnerships for Environmental Public Health (PEPH) www.niehs.nih.gov/research/supported/dert/sphb/programs/peph/), agriculture and food science (e.g., FAO, www.fao.org/capacitydevelopment/en), and for various applications, including for local or regional community capacity development (e.g., Education Scotland, www.educationscotland.gov.uk/communitylearning and development/communitycapacity building/capacityforchange/assessingimpact/index.asp) .

Potential solution: Projects must be proactive in ensuring that evaluations of all CB activities are undertaken and that lessons are drawn from the evaluations and applied to future activities (Kuzmin, 2012).

In principle, CB activities should be designed to have enduring, long-term impacts, with assessment of the impact to determine if appropriate approaches have been used, and documenting the responses of participants and donors. The Danish Institute for International Studies provides a systematic framework for describing and understanding why observed organizational capacity changes have taken place during a given period of time (www.diis.dk/sw152.asp). The guidelines identify four major stages in the (qualitative) evaluation process (Boesen et al., 2002):

- Organise the evaluation process with the target institutions for support (to enhance acceptance and learning aspects from evaluation);
- Get the facts – what has changed from T_o to T_1?;
- Begin analysing how changes have occurred, for example, what is the relative importance of relevant CB support activities from all sources compared to other internal and external factors that have influenced institutional capacity;
- Reach conclusions on what changes have occurred in the life of the CB, what can be learned, that is, assess the degree to which observed capacity and output changes can be attributed to support; assess its effectiveness and relevance; draw lessons?

4.9 Challenge: Reduce overlap and duplication in CB activities

A further challenge for projects and agencies is to ensure that their CB activities are complementary to the initiatives of other projects, international organisations, and regional and national institutions.

Potential solution: Duplication of CB activities between projects is likely unless there is collaboration between projects to ensure that their CB activities are complementary; in some cases, projects require similar capacity development, and attempts should be made to run relevant activities jointly. Good collaboration between projects requires regular communication between the International Project Offices and the Scientific Steering

Committees of the projects. In some cases, CB activities are introduced by national research projects through collaborations with international projects. In such cases, it is suggested that the stakeholders of CB facilitate the activities by establishing early cooperation with the external scientists. For example, lessons learnt from the collaborative activities on the Mekong River Delta (http://www.unesco-ihe.org/) and international activities on the study of Benguela Current System (http://www.dlist.org/) show that CB activities need to be adaptive to the culture of the country and individuals who are being targeted, and the training of people and infrastructure development should be embedded in the collaborations, from project design through to the achievement of research project goals.

There is a need to promote greater trans-boundary recognition of university courses and degrees, so that universities can share their educational resources, and students can have access to staff and facilities that may not be available in every discipline in every university. Such sharing has not occurred to any great extent in the past due to the different policies adopted by different countries in addressing international student mobility, although the Bologna Process and the European Higher Education Area (EHEA, www.ehea.info) is attempting this kind of sharing among European universities.

4.10 Challenge: Bringing together human capacity, resources and infrastructure

For CB to have a long-term impact on the scientific outcomes for countries, institutions and international projects, three key components need to be brought together - resources, infrastructure and scientific skills (Figure 2). Oceanographic research requires expensive infrastructure, particularly ocean-going facilities, which many developing countries are unable to afford. Keeping this situation in mind, the development of infrastructure is a crucial component in terms of sustainability of CB in marine sciences. For instance, scientists from developing countries often lack access to equipment, research funding and infrastructure, as well as the recent literature and state-of-the-art techniques which, all together, make it difficult for scientists from developing countries to integrate their knowledge from regional studies and contribute to the global synthesis of knowledge. This is a significant challenge, as to achieve sustainable CB, projects must work with regional and national organisations and institutions to evaluate the best options for effective CB that will have a long-term impact.

INSERT FIGURE 2 ABOUT HERE

Potential solution: The lack of marine research infrastructure in developing regions/countries can be overcome, in part, by using ships of opportunity in these regions where an international project has a research focus. By inviting scientists from developing countries to join research

ships operating in their region, the lack of infrastructure can be partially addressed at least for the duration of the research project. There is also the potential for the focus and collaboration with an international research project to break down barriers to sharing resources and infrastructure regionally.

An example of such collaboration and also of the use of ships of opportunity is the role of the German research vessel FS *Maria S. Merian* in CB activities off Namibia in September-December 2011 (Cruise MSM19). In a structured CB program conducted over a one-month period, 33 young scientists from southern Africa experienced an oceanographer's work at sea and, under the guidance of senior scientists, acquainted themselves with modern tools in ocean research by participating in sea observations, sample collection, data handling and presentation of results. The exercise was conducted in three short cruise legs of about one week each, focussing on physical oceanography, biological oceanography and marine geology. The cruise formed part of the preparatory work for a long-term German research initiative in Earth system sciences in cooperation with Namibia, Angola and South Africa. The research program is accompanied by measures including a scholarship program and hands-on training on board ship, to enable young scientists to participate effectively.

Another way to facilitate regional collaboration for CB is the development of a Regional Graduate Network for Oceanography (RNGO, http://www.scor-int.org/ RGSO_Design_Principles.pdf). This could be the basis for institutions to develop twinned relationships either within regions or between regions to enable the sharing of resources, infrastructure and training opportunities.

5. Priorities and Conclusions

CB for marine scientific research is being addressed by many international organizations and agencies, particularly by SCOR, IOC and POGO, through both specific individual activities and others in partnership. These activities are contributing to enhancing the awareness of ocean-related scientific issues among nations and to broadening the reach and scope of participating countries in international marine research programs. The following priorities for action are based on the experience gained from these activities as well as from the Asia-Pacific Network for Global Change Research (APN) exercise on capacity development under the IMBER project for the Asia-Pacific Region (Zhang et al, 2013).

[1] CB targets must be realistic and assessable and their results measurable. They need to respond to both short and long-term needs of countries and should address skills development in academic, technical and administrative fields.

[2] Although CB activities are being conducted by many organizations and institutions at the global, regional and national levels, better coordination among these could help minimize overlaps and duplications, thus making more effective use of resources. The linkages between national, regional and international activities need to be improved. The existing IOC-SCOR-POGO partnerships for capacity development could play an important role here.

[3] Endorsed national components of global programs very often involve bilateral cooperation with developing countries and are contributing to CB in partner nations. This activity can be further developed and refined by having a committee or a member of the advisory board of global projects designated to oversee the CB activities and to liaise with other national, regional and international organizations and initiatives.

[4] CB activities should involve sea-based training (i.e., hands-on and on-the-job) components in order to familiarize trainees with the conditions of work at sea. In addition to continuation of the current mechanisms offered by SCOR, IOC and POGO, efforts should be made to gain access to ships of opportunity for CB exercises.

[5] Countries need to create an enabling environment in which the offered CB activities are best utilized. This requires investment at the national level in education, and in creating opportunities to keep the built capacity locally and in the field. Currently, in many countries, demands for economic development have been a constraint in the development of capacity for marine sciences.

[6] CB activities should strive to recruit and involve active young scientists. This will require implementation of, for example, performance evaluation in developing countries. The developing countries can contribute by facilitating uncomplicated access to excellent scientific topics and themes in their region. Young scientists from developed countries are usually reluctant to contribute to the CB in another country because of heavy burden of personal development and the lack of recognition.

[7] CB should be an important component of all international programs and projects. It should be considered early in program development and involve representatives of countries in need of CB. This will help to set realistic goals and align national and international missions.

[8] Adequate consideration should be given to the differences in culture and languages of the participants.

There are some key steps a project can undertake to promote effective CB that help solve many of the challenges listed above. For both international and regional projects, great benefits are seen in the identification of a ‘Project Office’ staff member with special

responsibility for supporting the CB activities of the project, and also in the identification of project scientific steering committee members who will make CB their priorities. Moreover, each project's CB activities should be designed to adjust to the different stages of research projects. There is an urgent need for the many actors and stakeholders in marine research to engage themselves in the implementation of the CB recommendations to help achieve transition towards sustainability in an open knowledge world.

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Table 1. Matrix of Capacity Building Approaches for Ocean Science, Observations, and Data/Information Management

	IAEA	IFS	INOC	IOC	IOI	PICES	POGO	SCOR	START
Grants to attend meetings	X	X		X		X		X	X
Grants for training in data and information management			X	X					
Summer schools			X	X		X		X	
Ship-board experience			X	X			X		
Visiting professorships							X	X	X
Centers of excellence in oceanography training				X			X		
Distance learning				X					
Alumni networks							X		
Mentoring					X			X	
Regional graduate networks								X	

Note: IAEA = International Atomic Energy Agency, IFS = International Foundation for Science, INOC = Inter-Islamic Science and Technology Network on Oceanography, IOC = Intergovernmental Oceanographic Commission, IOI = International Ocean Institute, PICES = North Pacific Marine Sciences Organization, POGO = Partnership for Observation of the Global Oceans, SCOR = Scientific Committee on Oceanic Research, START = The System for Analysis Research and Training

Legends for Figures

Figure 1. The role of capacity building in individual professional development. Undergraduate studies provide basic education, while UN Agencies and non-governmental science organizations (NGOs) are important partners supporting research and research training through international activities. A young graduate has to address personal skills development (e.g., research techniques, writing to publish in high-ranked journals, fund raising) with career development, networking to develop both scientific and funding partnerships, and maintaining a reasonable career-life balance.

Figure 2. Three key components involved in capacity building, while national/regional agencies focus more on resources and infrastructure building, and universities provide more opportunity on personal skills development. Multidisciplinary large-scale marine research activities (e.g. IMBER) contribute to the three components through training, networking, financial support, data sharing, etc.

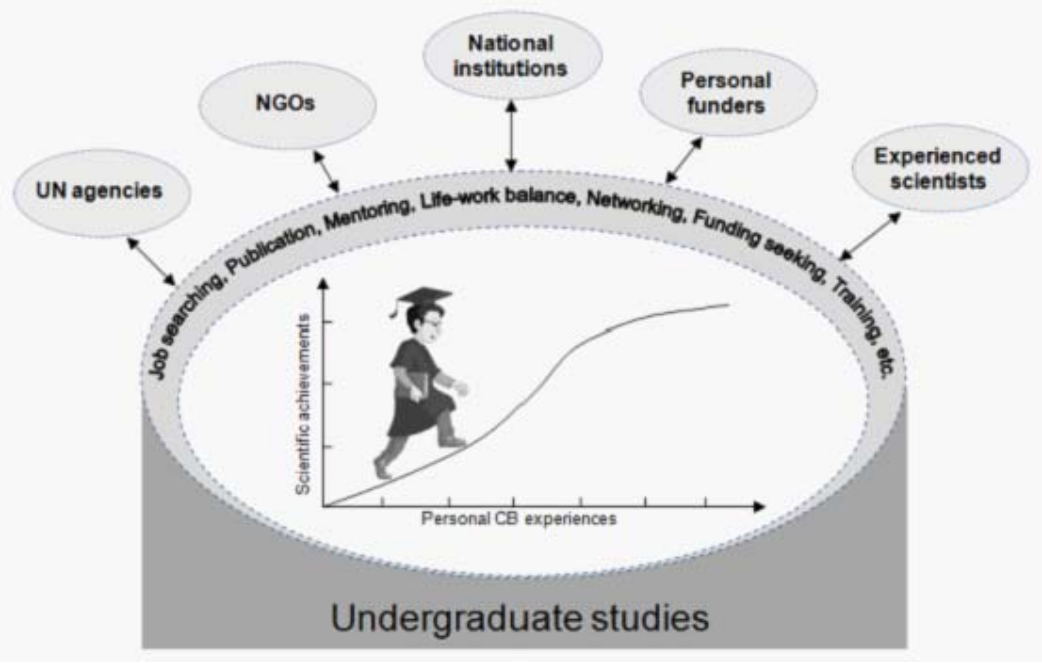


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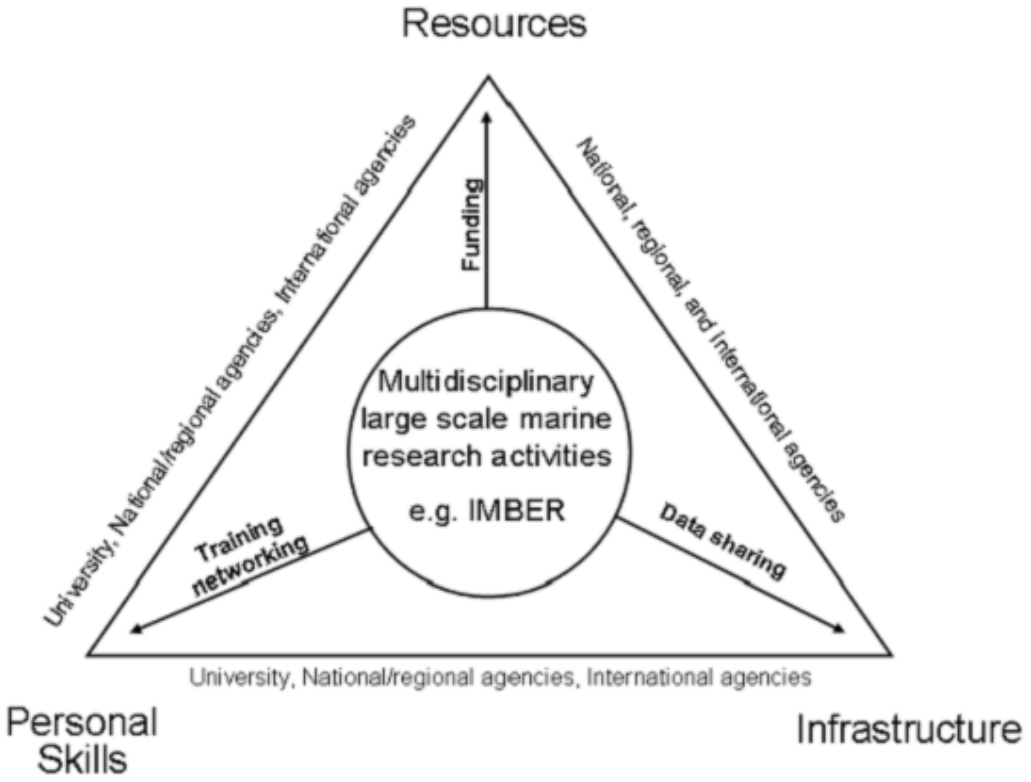


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Box 1. IMBER Training in Data Management

Marine researchers generate and require access to a large variety of data. For data to be fully used, they must be made available and must also be organized and documented in a way that supports easy and accurate re-use by colleagues. Data management and exchange have been important components of IMBER strategic goals since its inception. An IMBER Data Management Cookbook (Pollard et al., 2011), a compendium of step-by-step data management "recipes", was prepared by the IMBER Data Management Committee to make data management easy to understand and implement by the IMBER community. Although the Cookbook was initially created based on IMBER research needs, it should be also suitable for any project that gathers marine data and wishes them to be available and useful in the long term.

Data Management Workshops or Dry Cruises have been conducted in conjunction with IMBER IMBIZOs since 2010 to enhance awareness of the need to establish and implement good data management procedures, the advantages arising from following these procedures, and to provide training on data management and data preservation. During the most recent of these 'Data management training course and workshop' held prior to the IMBIZO III (2013), one additional goal was also to provide real-world examples of these data management procedures as implemented in IMBER-related or other relevant research projects. Finally, some recommendations were made regarding the management of marine social science data, and to identify any gaps that might exist in the data management needs of IMBER research activities. As a follow-up to this activity, a revision and addendum are now under consideration for the IMBER Data Management Cookbook in order to take into account new types of data, from economics to social sciences, in the field of marine research.

Box 2. Summer Schools to Help Achieve Project Scientific Goals

The Surface Ocean-Lower Atmosphere Study (SOLAS, www.solas-int.org) focuses on processes that occur at the air-sea interface, and immediately below this interface. Success of the SOLAS project has required building new linkages between the ocean and atmospheric science communities and training early-career scientists in methods that cross these disciplinary boundaries. The SOLAS project has conducted six summer schools so far. The aim of the summer schools is to offer young scientists who have research interests in air-sea interactions - including biogeochemical and physical processes and feedbacks - the opportunity to expand their knowledge in all aspects of SOLAS science and to create and strengthen future collaborations with SOLAS scientists from around the world.

SOLAS Summer Schools bring together for two weeks about 70 young scientists, mostly PhD-level students and 15 world-leading researchers, from a variety of fields, for a combination of plenary lectures and hands-on practical workshops in small groups on core SOLAS science but also on “soft skills”, such as communication. Two individuals who have taught at the summer schools on a regular basis prepared a textbook based on the material presented at the schools (Le Quéré and Saltzman 2009), for use in future schools.

Box 3. At-sea Training in the GEOTRACES Project

SCOR's GEOTRACES project (www.geotraces.org) is increasing the capacity for at-sea observations of trace elements and isotopes by inviting developing country scientists to participate in GEOTRACES cruises. The model works like this: SCOR provides funding through a grant from the U.S. National Science Foundation for the developing country scientist to travel to the departure port and to return from the arrival port of the research cruise. The national cruise program sponsoring the cruise provides a berth on the ship, on-board support, and training in GEOTRACES-related methods. So far, a Brazilian scientist and a Tunisian scientist have been trained on Dutch GEOTRACES cruises and a South African scientist was trained on an Australian GEOTRACES cruise. Finally, a scientist from Mauritania participated in a U.S. GEOTRACES cruise as an observer, as required for access of the U.S. ship to Mauritania's Exclusive Economic Zone. In each case, the participating developing country scientist has gained experience that would not otherwise be available.