Challenges for global ocean observation: the need for increased human capacity

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Abstract

Sustained global ocean observations are needed to recognise, understand and manage changes in marine biodiversity, resources and habitats. Technologically feasible Essential Ocean Variables (EOVs) that meet this need and are relevant to both the scientific and broader community have been proposed by the Global Ocean Observing System (GOOS). Implementing a multidisciplinary and responsive ocean observing system requires the engagement of all interested marine nations. Building a system that is truly global requires expanding participation beyond scientists from well-resourced countries to a far broader representation of the global community. New approaches are required to provide appropriate training, and the resources and technology to follow this training and engage meaningfully in global observing networks. Developing capacity around the world, from taking measurements using common standards and best practices, to interpreting and reporting data and analyses, has never been more urgent. Countries with the resources need to invest in their own technical capacity to contribute to improved marine resource management and to fulfill their international reporting obligations, while assisting other countries. Important opportunities are emerging now for countries to develop research partnerships. Implementing these partnerships requires new funding models and initiatives, as present funding mechanisms rarely support international teams or sustained observations.

Key words: capacity development, essential ocean variables, EOVs, global ocean observing system, ocean observations

Introduction

Increased and better focused sustained ocean observations are needed to support national and international scientific, governance and policy communities to determine and monitor appropriate trade-offs between conservation and economic development, and to implement sustainable ocean and coastal development practices.

Between 2011 and 2014, a series of regional workshops were carried out globally to report on capacity development needs in relation to ocean science and assessments under the auspices of the UN General Assembly (See A/67/87 Annex V in Ruwa et al. 2016) and compiled in the World Ocean Assessment under four major topics: (1) physical structure of the ocean, (2) waters of the ocean, (3) ocean biotas, and (4) ways in which humans interact with the ocean (UN 2016). There are specific needs for each of these four topics in relation to sampling, technology and infrastructure capacities, but a common need across all of them is to develop capacity for data analysis, mapping, modelling and interpretation that can be translated into useful and appropriate management practices (Ruwa et al. 2016; UN 2016). More recently, during the June 2017 UN Ocean Conference to address SDG14, the partnership dialogue on "Increasing scientific knowledge and developing research capacity and transfer of marine technology" stressed the importance of creating opportunities to improve data collection, transfer of technology and open-access marine databases, as well as the need for stronger engagement between scientists and decision makers, across disciplines and engaging civil society (UN 2017).

The Global Ocean Science Report (UNESCO 2017) provides a tool to help address where and how ocean science capacity is being used for societal benefit and to support management policies and data products. Ocean science productivity has increased in the last two decades due to a combination of factors, including an increase in multidisciplinary and international collaboration and significant funding commitments from governments and private sources. At present, approximately 35% of the ocean science facilities globally specialise in observations (UNESCO 2017); however, only a few countries invest in observations over large spatial and temporal scales, and few nations have the human capacity and access to technology to monitor even their own Exclusive Economic Zones (EEZ), let alone the 50% of the planet that lies outside these areas of national governance. Capacity in ocean sciences, both human and technical, depend greatly on increased financial support (Isensee et al. 2017). Many more countries need to engage in active and collaborative ocean observing in order to understand how regional living resources change due to migrations and changes in species ranges (Last et al. 2010; Wernberg et al. 2013, Krumhansl et al. 2016), how such resources are affected by local human activities and global environmental pressures like climate change and their interactions (Ling et al. 2009; Johnson et al. 2011; Poloczanska et al. 2013; Hughes et al. 2017), and how ultimately these changes affect the health and economy of human societies (Bell et al. 2011; Gill et al. 2017).

For existing and new observations to contribute effectively to global knowledge and enable increasingly successful responses to an increasing number of stressors and their cumulative impact, ocean observing efforts need to follow best practices and support the open sharing of fundamental observing capacity. Increasing the global observation systems in this manner, will improve society’s understanding of global trends and provide a reliable and comparable global context in which to interpret local observations. Important opportunities are emerging for countries to develop partnerships for research and applications to fully participate in and benefit from the blue economy (Dunn et al. 2016; OECD 2016; Golden et al. 2017), and to design and contribute to the United Nations Decade of Ocean Science for Sustainable Development (2021-2030; https://en.unesco.org/ocean-decade).

Many intergovernmental and non-governmental organisations work in ocean science and observations and include capacity development as part of their mandates. Several high-level policy initiatives have highlighted the need for concerted action to develop global capacity for ocean observations (e.g., Agenda 2030, UN Oceans, G7). One of the outputs of Dialogue 6 from the UN Oceans Conference (*Increasing scientific knowledge and developing research capacity and transfer of marine technology*) was recognizing the need to rely on science and technology to provide solutions to societal problems, address knowledge and technological barriers, and create opportunities to improve data collection that are open and publicly accessible. There is currently a lack of collaboration between marine researchers working in different or even the same country, resulting in a fractured and ineffective delivery of scientific information to decision makers at all levels. It is vital that the research community starts to work in such a way that we can build off each other's progress and information, building a coherent body of information that will have maximum impact on national and international decisions and policy.

In this paper, we provide a map of capacity development opportunities in support of ocean observations and information services. We discuss the role of international and regional organisations in providing the technical expertise and guidance on best practices to help collect the best possible data, and providing the data analysis tools to convert these data to useful products for society.

Building a global observing system through enhancing capacity

Implementing a comprehensive sustained ocean observing systems will be challenging and costly. Significant funds will be required not only to set up the technical and scientific infrastructure of the system itself, but also to support the capacity development that will enable the development and maintenance of the end-to-end systems, from deployment of observing systems through generation and use of data, and their transformation into information services for societal benefit. In building a global observing system we need both to identify new more cost-effective approaches that will reduce the resources required to 'go global' and identify the successful training and capacity development programmes.

Agreeing on a set of variables that need to be measured globally will reduce the impossible task and cost of supporting the full plethora of possible variables that could be measured -- especially in the biological domain. The Global Ocean Observing System (GOOS) typically has provided advice on the domains of physics, climate and biogeochemistry using Essential Ocean Variables (EOVs) as the common focus to support ocean health, real time services and climate. These EOVs were defined based on specific scientific and societal requirements driven mostly by climate change and the need for weather forecasts (Bauer et al. 2015; Lorenzoni and Benway 2013). Biological EOVs were recently identified based on their relevance to assess changes in marine ecosystems and help meet the requirements of the Sustainable Development Goals (SDGs) and other critical international agreements and platforms, that are related to climate change, biodiversity and ecosystem services (Miloslavich et al. 2018).

Cost-effective approaches need to be identified that engage less well-resourced countries in contributing to global observing (Fukuda-Parr and Lopes 2013). For example, it is now relatively straightforward and inexpensive to obtain underwater imagery from mobile and stationary platforms. Mobile platforms include divers, either scientific researchers or citizen scientists (Edgar and Stuart-Smith 2014), who can also place and retrieve stationary platforms such as baited remote underwater video (Langlois et al. 2010). Approaches are being developed to provide a level of consistency in how underwater imagery is coded for subsequent data analysis (Althaus et al. 2015). However, coding and annotating imagery will often require a level of technical skill that is difficult to maintain as part of a sustained observing system in LDCs and SIDS. Automated image analysis would provide a solution to provide consistency and quality assurance, but to achieve this will require a significant investment in scientific and data processing expertise from countries with greater resources. Automated processing of genetic material is already well underway but developments can be so rapid that dedicated centres are required to provide the equipment and resources to undertake the most recent and powerful analyses. Automation provides one approach to more cost-effective data processing, but it is not a unique solution. Alternative approaches ranging from distributed cloud-based systems to regional centres of excellence, will be needed that both respect individual country's needs and capacity and meet the requirements of the individual monitoring programme. Faster and cheaper access to the internet will be an important prerequisite for many LDCs and SIDS to engage in global observation systems.

For the observing community to move forward in a coordinated and multidisciplinary way, it is important to identify what training is required and how it is delivered most effectively. Under what circumstances can online programmes suffice, where is face-to-face engagement required and when will a series of engagements and mentorship be required to consolidate the training and achieve sustained engagement. Several programmes are already providing training that is applicable to EOVs (see Supplemental Table S1 for examples of programmes providing training for biological EOVs). To learn about current training-based capacity development initiatives, we conducted a survey of the topics and methods used as well as relationships between training, EOVs, and SDG14 indicators, and whether they provided support (e.g. financial/ in-kind, mentorship, infrastructure), and whether they were associated with an academic institution. As a first step, we targeted 11 major programmes, but the objective is to use this as a pilot to conduct a much broader assessment of the capacity development landscape. The survey indicated that most organisations focussed on short courses (< 4 weeks) and in-person rather than on-line training (Table 1). Although this was a limited set of organisations, the results highlight potential gaps in topics, EOVs and SDG indicators where more efforts need to be focussed. A more extensive survey could provide valuable information on where we need to focus, and where to avoid duplication. Combined with impact analyses, such as those conducted by POGO and SCOR (see Section 3), these surveys could also help organisations to select and implement a type of training that is lacking for particular topics.

The need for capacity development in ocean observations and services

While there are many challenges that need to be addressed before coherent global monitoring can be developed, capacity development is an issue that transcends scientific, social, economic, cultural and political boundaries. Providing training to develop the capacity to carry out and interpret observations, especially in Least Developed Countries (LDCs) and Small Island Developing States (SIDS) is fundamental to achieving a global system that all interested countries can participate in and profit from. Clearly, funding to support these efforts needs to be identified, but first the scientific community needs to make the case and identify the scale of global ocean observations needed. Countries that support an ocean observing system will be able to better address societal needs, contribute to improved management of marine (and terrestrial) resources, and fulfil reporting obligations to international commitments. Human capacity and technology development and transfer are the core of an observing system. Organisations and networks involved in capacity development need to share their technical expertise and best practices to help collect the best possible information and sustain local capacity, but also to develop and disseminate data analysis tools to help convert these data to useful products and services.

Capacity development was identified as a major driver by at least half of the 24 international conventions that relate to biological and/or ecological aspects of the ocean, are global in scale or globally relevant, and could potentially benefit from long-term biological observations in the ocean to achieve their goals (Miloslavich et al. 2018). The need for capacity development to support countries, especially LDCs and SIDS, to respond to or even report on UN Sustainable Development Goals, the Convention on Biological Diversity (CBD) Aichi Targets, the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES), the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and many other global initiatives, is routinely raised at international meetings and negotiations.

Indeed, the UN Sustainable Development Goal 14 target 14a is to "*Increase scientific knowledge, develop research capacity and transfer marine technology, taking into account the Intergovernmental Oceanographic Commission Criteria and Guidelines on the Transfer of Marine Technology, in order to improve ocean health and to enhance the contribution of marine biodiversity to the development of developing countries, in particular small island developing States and least developed countries*." The IOC Member States have approved a Capacity Development Strategy (2015-2021) with the following vision statement: "*Through international cooperation, IOC assists its Member States to collectively achieve the IOC's high-level objectives (HLOs), with particular attention to ensuring that all Member States have the capacity to meet them*." The six major outputs expected to be achieved by implementing this strategy are 1) Development of human resources, 2) Established or improved access to physical infrastructure, 3) Strengthening of global, regional and sub-regional mechanisms, 4) Promotion of development of ocean research policies in support of sustainable development objectives, 5) Increased visibility and awareness, and 6) Reinforced sustained (long-term) resource mobilization (see www.ioc-cd.org/). To achieve each of these, a series of activities are proposed, which rely heavily on public information, continuous professional development, facilitating access to infrastructure, information sharing, development of national marine management procedures and policies, and financial support from member states and other opportunities.

It is crucial to develop capacity on survey and collection standards or operating procedures, data quality assurance (QA), quality control (QC), analysis, reporting and modeling. Currently, observing systems (e.g., satellite-based remote sensing and underwater imagery) collect data at a much higher rate than it can be analyzed. This limits the creation of potential products and wastes significant and costly investments. There is a major opportunity to take advantage of and expand these established systems through technology transfer and *in situ* observation, but also by facilitating data sharing and analysis tools. A major challenge faced in expanding observing systems is to improve their societal and scientific relevance and benefits. One way of achieving this is to build the (national and) global consistency that will support aggregating the data at the level that supports the kinds of questions that managers and policy makers address.

Existing capacity development activities at the global scale: Case studies

Many scientific and research programmes include a capacity development component or have an education arm, either by their own altruistic initiative, or imposed as a funding requirement. Depending on the local and global requirements, some of these programmes could expand and be better coordinated with others with whom they share common goals and best practices. This would facilitate integration and multidisciplinarity, supporting ocean observations that will most likely bring benefit to society. Example of some key programmes follow.

IOC Regional Sub-Commissions and Committees (IOCARIBE, IOCWESTPAC, IOCAFRICA, IOCINDIO, BSRC): The IOC, established in 1960 as a body with functional autonomy within UNESCO, is the only competent organisation for marine science within the UN system. It works with its 148 Member States to achieve: healthy ecosystems, effective early warning systems, resilience to climate change and variability, and enhanced knowledge of emerging issues. Its capacity development and technology transfer guidelines (IOC-UNESCO 2015) are widely referred to in international policy settings. IOC coordinates ocean observation and monitoring through GOOS which aims to develop a unified network providing information and data exchange on the physical, chemical, and biological aspects of the ocean. Governments, industry, scientists, and the public use this information to act on marine issues. IOC also coordinates and fosters the establishment of regional intergovernmental coordinating tsunami warning and mitigation systems in the Pacific and Indian Oceans, in the North East Atlantic, Mediterranean and Caribbean seas.

Capacity development is delivered regionally and in part through Sub-Commissions and Committees, which identify the capacity needs of their members and gaps that need addressing. The regional groups are at different stages of development with some only recently re-engaging after a period of hiatus, while others have effective regional networks, training and education opportunities for scientists, and work with global monitoring systems to build local capacity. Capacity development needs vary depending on the region, but range from basic infrastructure and resources to support scientists who have undertaken training (often through academic institutions), to more advanced professional training to support the continued advancement of active researchers. There is a need to improve engagement with SIDS and LDCs both within these regions and for IOC member states who fall outside these regional groups. The IOC is developing a Clearing House Mechanism to facilitate the provision of capacity development and the transfer of technology.

The Ocean Teacher Global Academy (OTGA) is a network of Regional Training Centres (RTCs) spread across the globe, making use of a common e-Learning Platform and videoconferencing to deliver (short) training courses in ocean-related topics in different languages (besides English being the main language used for training purposes, it currently includes courses in Spanish, French and Portuguese). It offers training courses on a range of topics, including ocean/marine data and information management and biogeographical data as well as courses to "train the trainers". The OTGA supports IOC's capacity development activities in general, including topics such as marine spatial planning, harmful algae blooms, Tsunami Warning System, contributing to and using data from the Ocean Biogeographic Information System (OBIS), etc. The main audience of these training courses are ocean professionals, working on National Oceanographic Data Centres, marine libraries, marine research institutes, etc. OTGA also partners with other organisations on specific topics, for example on ocean colour remote sensing training. OTGA is a project under the IODE (International Oceanographic Data and Information Exchange of the Intergovernmental Oceanographic Commission of IOC) (http://classroom.oceanteacher.org/). Taking advantage of the OTGA platform, the OBIS team provides targeted courses specifically for node data managers, trainers, data providers, scientists, students, agencies and regional organisations to improve skills on data assessment, control, management, use and product delivery.

The Partnership for Observation of the Global Oceans (POGO) runs a range of programmes aimed to train young scientists from developing countries in oceanographic observation methods and techniques (http://www.ocean-partners.org/training-education). Different types of training are organised to suit different requirements and career stages, ranging from short courses (3-5 days) in either developing or developed countries, to several-week long Visiting Professorships in developing countries (generally including a research project component) through to one- to three-month Visiting Fellowships and a ten-month Centre of Excellence programme at renowned oceanographic institutions. POGO has focussed strongly on the provision of shipboard training, and these efforts were consolidated in 2017 as the "Ocean Training Partnership" programme (www.oceantrainingpartnership.org), which calls for international organisations and research institutions to collaborate in the provision of spare berths and "spare ships" for capacity building. Some of these programmes are held in collaboration with other organisations, such as the Scientific Committee on Oceanic Research (SCOR) and the Nippon Foundation.

The Scientific Committee on Oceanic Research (SCOR): In addition to the POGO-SCOR Visiting Fellowships, SCOR supports visiting scholars, regional graduate networks, ocean summer schools (e.g., through its international projects SOLAS, IMBER, GEOTRACES, and IOCCP) and requests clear capacity-building plans from its Working Groups, even if these working groups are primarily aimed at developing innovative science (http://www.scor-int.org/). SCOR, its projects and partners have documented approaches for using large-scale international research projects (Morrison et al. 2013) and open science meetings (Urban and Boscolo 2013) for capacity-building purposes. SCOR, POGO and IOC/IODE have been cooperated and shared their knowledge in capacity building over the past 10 years.

The Global Environment Facility (GEF) was requested in 2016 to support the establishment of the Capacity Building Initiative for Transparency (CBIT). The CBIT was established within the UN Framework Convention on Climate Change (UNFCCC) to strengthen institutional and technical capabilities of developing countries to meet the transparency requirements of the Paris Agreement.

The GEF also supports sustainable governance in 23 of the 66 large marine ecosystems (LMEs), which involve multinational collaboration on long-term ocean governance. The LME programme, supported mainly by the GEF, the UN and national efforts provides an example of how much human capacity and technical infrastructure has been developed in the last years in Third World countries (Barbiere and Heileman 2016; Hempel et al. 2016). The Benguela Current and Yellow Sea LMEs illustrate success stories in which capacity development and ecosystem restoration has been achieved through regional cooperation and by adopting a holistic approach taking into account governance, LME resources, environmental health and socioeconomic benefits (Carlisle et al. 2014). This has also led to the successful implementation of ecosystem based management practices (Malone et al. 2013). Specifically for the Bay of Benguela LME (BoBLME), the approach to capacity strengthening included an inventory of current capabilities, identifying the requirements (e.g. project management, monitoring and evaluation, ocean governance, fish stock assessment, operational oceanography, ecosystem modelling among a few others), and using a mix of capacity strategies such short courses, academic courses, study visits and taking advantage of emerging opportunities (Hempel et al. 2016). While GEF funding is mostly focused on improving sustainable development and does not directly fund monitoring activities, it provides support to initiatives that may lead countries to fulfil their reporting obligations to the Convention on Biological Diversity (CBD) and other conventions, which actually do require monitoring. The LME programme is currently being assessed by the IOC. One of the key messages is that management of LMEs could be considerably improved by improving the quality of data and information generated, and by carrying out assessments at sub-LME scales, reinforcing the initial statement of the need to have trustworthy data from sustained ocean observations (http://www.geftwap.org/water-systems/large-marine-ecosystems). Another recent review of the LME programme noted that despite successes in other areas, there was room for improvement in capacity development, uptake of science into government, and regional collaboration, suggesting that going forward the LME programme will have an increasingly important role in regional and global capacity development and reporting (Vousden and Scott 2017).

The Argo programme is a collaboration of a relatively small number of countries that has put together a global array of free-drifting profiling floats (currently around 3,800) continuously measuring temperature, salinity and velocity of the upper 2,000 m of the ocean, with data made publicly available within 24-hours after collection. The programme has three capacity development approaches: a) development of material for classroom use, b) outreach workshops focused on data access and analysis and/or instrument operation and deployment (provided on demand and subject to funding), and c) online resources (http://www.argo.ucsd.edu/Educational_use.html). The Argo programme provides one of the better examples of countries with differing technology and human resource capacity working together to provide global coverage for an essential monitoring programme that supports a wide range of societally relevant products from local weather forecasting to global analyses of climate change. The programme is currently being expanded to increase coverage of the shallower margins and deeper depths of the ocean.

The Global Ocean Acidification – Observing Network (GOA-ON) Pier2Peer programme is an international mentorship programme matching senior and early-career researchers to facilitate expertise exchange and capacity development focused on specific user needs (http://www.goa-on.org/GOA-ON_Pier2Peer.php) with respect to observing ocean acidification, its biological effects, and facilitating forecasts. Pier2Peer employs an adaptive and self-driven approach to capacity development; its guiding principles are to establish communities of practice, focusing on user needs spanning local, regional, national, and international scales in order to foster inter-regional and global collaboration. It operates through existing regional bodies like the IOC sub-commission for the Western Pacific

(WESTPAC), organizing a series of workshops and mentorships to engage, build and sustain the relevant local resources and capacity.

The Pole to Pole Marine Biodiversity Observation Network (MBON) in the Americas, a programme built in partnership with the Group on Earth Observations Biodiversity Observation Network (GEO BON), AmeriGEOSS, GEO Blue Planet, and the Smithsonian Institution's MarineGEO is working with the IOC's Ocean Biogeographic Information System (OBIS) to implement best practices in coastal ocean observing, including sharing data using common data schema (e.g., Darwin Core).

EUMETSAT: EUMETSAT is responsible for delivering the Level1 and Level2 Sentinel-3 marine and lake products for Copernicus, and as such also plays a key role in promoting data to users and providing training opportunities. EUMETSAT Copernicus Marine and Ocean Training (CMOTS) programme is framed around participants working on their management questions (problem-based learning), with tools for data access and manipulation provided to make this easy. Participants are required to create and share what they create (constructivist learning). The programme uses solely open-access data and software, and is seeking to integrate with cloud-hosted processing to enable users in low-bandwidth environments to overcome bandwidth limitations. Beyond the courses, the training programme also seeks to develop resources that can be used in training by others or for independent learning – such as instructional videos, code repositories, and Massive Open Online Courses.

The Global Alliance of Continuous Plankton Recorders (GACS): GACS was initiated in 2011 to bring together the regional CPR surveys and develop an integrated network that could address global plankton diversity issues, particularly the plankton EOVs then in discussion and development. A significant emphasis in the early years has been on capacity building by identifying and documenting CPR best practices, exchanges of personnel between labs, and training workshops. Training has been provided on CPR deployment, servicing and processing and analysis of the collected samples with the goal of providing the skills required to fully implement a regional survey. This has resulted in the initiation of new surveys and a set of manuals that provides the basis for existing and future regional surveys to be standardised and fully integrated with existing GACS partners. POGO and SCOR have been key in funding some of these activities but it has also relied on the willingness of the host organisations to provide the physical and human resources required. A driver of this process has been that the outcomes are seen as mutually beneficial. New regional surveys are integrated with GACS, which provides greater context for their data and valuable accreditation to a small-scale regional survey and the GACS community sees gaps in observing filled and an increased ability to deliver a globally consistent dataset. While training on data analysis is not given, there is a large body of literature available which can address this (see for example Richardson et al. 2006).

Examples of best practices in capacity development and lessons learnt

Planning a capacity development programme

When planning a capacity development programme or activity, it is important to first define what the objectives are and whom the programme or activity is targeting. These may have already been defined in a strategy document or funding proposal. "Capacity development" (or "capacity building", as used by some organisations) is a very broad term, and may mean different things to different people, organisations, or sectors. For many international marine science organisations, this often refers to the provision of training to scientific staff and students in developing countries, but it implies a long-term strategy to ensure that the skills and knowledge acquired are applied to the development of marine science in those countries.

However, the provision of training and education in developed countries can, and is, also considered capacity development. The term can also be applied to the provision of tools and training to policy makers to enable them to make use of data, products and services (e.g., those derived from Earth Observations). This is the definition generally used by the Group on Earth Observations (GEO) (GEO BON 2015). If the goal is to achieve a transition to ensure ecosystem-based-management (MEBM) within the government decision process, capacity development will be focused on strengthening local and regional capacities to support this transition (Shackeroff Theisen et al. 2016)

Programmes must consider whether the required infrastructure is already in place, or whether investments in equipment or other infrastructure are required for the programme to be successful in the long term. Another important aspect of capacity development is continued scientific collaboration with the recipient institution/country, for example through joint projects, PhD co-supervision and research visits. It is also important to think about what the trainees will do after the training – Will they return to/remain in their home country or use their enhanced CV to obtain a position in a developed country? Do they have a permanent position to return to? Are they in a position to pass on the knowledge acquired (e.g., lecturing, mentoring/supervising students)? Giving all these questions due consideration when designing the capacity development programme will greatly increase the chances of long-term, sustained success.

Different types of training will be better adapted to different capacity development strategies and target audiences. For example, POGO has a variety of training programmes, which can be divided as follows: (1) Postgraduate-level training (mostly Master's level), (2) Postdoctoral or PhD-level training, and (3) Regional training courses. The first consists of a 10-month training programme in observational oceanography, mostly aimed at students who already have a Master's and want to continue on to a PhD after the training usually at a NF-

POGO Centre of Excellence. The second involves visiting fellowships for early-career scientists to receive one-to-one training and supervision on a specific project related to ocean observations, usually through POGO-SCOR fellowships and POGO/NF-POGO shipboard training fellowships. The third consists of short, intensive courses (1-3 weeks) often catering for a range of career stages (from Master's students to professors).

Alternatively, some programmes are voluntary one-on-one relationships that are as strong or weak as the individuals communication and connection they provide. GOA-ONs Pier-2-Peer is such an example, motivated by personal investment of time. Benefits of this approach are the lack of bureaucracy and the personal nature of the exchange; limitations are when either party does not stay engaged or on focus of needs. The impact of GOA-ONs Pier-2-Peer approach can be enhanced by linking to established regional networks, for example the IOC Regional Sub-commission for the Western Pacific (WESTPAC).

With regards to training requirements, IODE of UNESCO/IOC conducts regular training needs surveys in order to identify the needs of its Member States. The surveys are done online, and structured around existing training topics addressing ocean/marine data and information management, such as Harmful Algal Blooms (HABs) and Marine Spatial Planning (MSP), and also allow the entry of other emerging topics that need specific training (open ended question). The respondents are also requested to indicate prefered language used for training (English, French, Spanish or Portuguese, which reflect the currently possible languages used for training through the OTGA network of RTCs) as well as geographical region. The results of these surveys inform the decision process for the OTGA course calendar. Although the targeted audience is the IOC Member States, the survey is open and anyone can contribute. However, one continuous challenge is the relatively low response rate of these surveys. An added challenge is the lack of significant difference on the topics requested.

Key considerations for organising a training programme

Some of the key considerations when creating a capacity development programme or training course include selecting the right instructors and the right trainees, being prepared for specific aspects of working in developing countries and the financial issues (see Table 2 for a synthesis of some of these considerations). With regards to choosing the right instructors, surveys by POGO and SCOR have shown that the people involved in providing this type of training are motivated purely by their willingness to share their expertise. The greatest benefits derived from the provision of training were found to be personal satisfaction, broadened cultural horizons, and continued research collaboration between the supervisor/instructor and the trainee(s)/host institution. Other potential benefits such as fulfilling the requirements of an employment contract or grant, enhancements to one's CV, or the production of joint research publications did not figure prominently in these surveys. The success of training programmes therefore relies to a large extent on their ability to attract instructors who are truly motivated, believe in the capacity development objectives, and are able to dedicate sufficient time and resources to the programme. On the latter point it can still be difficult for experts to dedicate time and resources to capacity building when they are not compensated for their time and other costs and the impact is often not recognised in a formal way by their institutions. To address this, opportunities can be sought to collaborate on capacity building and to integrate capacity building events into funded research projects. This is something that funding agencies and research centers should consider (give points to) in their evaluations. Beyond enthusiasm for their subject, instructors who are aware of the diverse range of training, learning and cultural types can be of great value to capacity building programmes. Instructors who are aware of these differences and are adaptive and willing to use innovative techniques and platforms are likely to be able to provide capacity building that is suitable for a broader range of participant requirements. In this regard, the

OTGA e-Learning Platform provides courses to “train the trainers” to guarantee standardization, unified information, agreement on best practices, and that the science and technologies are always up to date. Additionally, OTGA also provides training to its trainers on pedagogy aspects that should be taken into consideration when providing training in a multicultural environment.

With regard to trainees, a trainee from a developing country can make a significant difference to advance the science capacity at his/her home institution. While there is a significant technological gap between developed and developing countries, a trained professor or researcher will be able to guide students better towards answering the current pressing questions, aiming for international standards, and applying and adapting concepts learned into local circumstances. Equally important will be the links established between the trainee and the international programme and its network of experts which, as a network, will continue not only to improve the research capacity locally, but also to provide opportunities for further collaboration, access to funding and resources (including to non open access scientific literature). Students from the NANO-POGO network usually collaborate in joint publications which are conceived, sampled and analyzed during the training courses (e.g. Beerman et al. 2018). Therefore, choosing a candidate not only requires an evaluation of his/her CV, it should also consider the impact that this training will have at the home institution and country (see some criteria in Table 2). Working in developing countries will bring significant local benefits as it will usually bring some technical and infrastructure support such as a basic sampling kit, ideas on how to adapt the existing infrastructure to maximise its benefits, standard procedures, initiating collaboration (e.g. joint research and proposals) among many others.

With regard to finances, costs associated to training vary from country to country and also depend greatly on the topic (e.g. a field course requiring ship time and equipment versus a data analysis course requiring computers and internet capabilities). For example, the IOC/OTGA through its distributed Regional Training Centres has been, since 2015, successfully addressing many of the challenges described in Table 2, namely regarding logistics and local infrastructure, provision of local trainers who can use local and regional case studies and speak the trainees' language, among others. The use of a common e-Learning Platform ensures that training resources are shared with the community. Invited experts also occasionally contribute to specific training topics via videoconferencing. Since most training still uses the face-to-face model, the use of Regional Training Centres enables the reduction of travel costs, as well as mitigates 'jet lag' problems since participants should be traveling from within the region. The OTGA of IOC/IODE has also developed a Manual and Guidelines for course organisation to be used by all OTGA Regional Training Centres, that covers all aspects of the organisation of a (short) training course. The manual guidelines that need to be considered before, during and after the course takes place.

Evaluating the impacts

It is important to gather feedback from the trainees immediately after the CD event (or need for continuous evaluation if it is a continuous CD effort), both for reporting purposes (e.g., to show funders and other stakeholders that the funds have been spent efficiently and the activity has been successful), but also to be able to continuously improve and address issues that may have arisen. In some cases, the funding agency requests an (external) evaluation of the CD project/programme(s). Providing a follow-up supporting mechanism such as an online "Help-desk" that can serve as tool for consultation and further clarification that is case adaptable and fit for purpose also greatly improve the chances for a longer term successful program.

Each course provides a learning experience on what can be improved. IODE/OTGA and EUMETSAT, for example, have a standardised online survey at the end of each of their training courses. However, these post-course surveys do not provide information on the long-term impact of the CD programme and whether the programme is going beyond providing training to the effective uptake essential to developing capacity. It is therefore equally important to keep in touch with the trainees or recipients and evaluate the longer-term impacts of the programme. Alumni networks can be particularly valuable in following the career trajectory of capacity building participants, and provide a way to reach them for ongoing surveys (e.g. the NANO-POGO network) but also for them to continue to be connected and aware of projects and opportunities (https://nf-pogo-alumni.org/about/opportunities/). Within the Coral Triangle Initiative on Coral Reefs, Fisheries, and Food Security, the consolidation of a regional learning network contributed to improve local and regional knowledge, establish connections, and bridge across cultures, however, the sustainability of such network depends greatly on coordinating activities (Pietri et al. 2015).

Keeping track of the trainees therefore provides a mechanism against which the long-term impact of the course can be measured. To evaluate success in providing training that has resulted in sustained capacity building, POGO and SCOR developed a series of online questionnaires aimed at (1) the past trainees, (2) the "providers" of the training (i.e., supervisors and instructors), and (3) the institutions with which the trainees were affiliated. A group of alumni were consulted in the design of the survey with the aim to extract the most useful information while making the survey "attractive" to the recipients (e.g. easy to understand, easy to answer, brief (<10min to complete), quantitative and online, with the possibility to save and return to it later (recognition of email address) and the option to answer anonymously).

The trainees' survey consisted of a number of background/demographic questions followed by several questions aimed at evaluating the impacts of the training (immediate and longer-term impacts, impacts on the wider scientific community at the home institute (knowledge transfer), and products resulting from the training (publications, presentations, etc). The respondents were also asked whether they had spent some time abroad since receiving the training, to assess whether the training was unintentionally contributing to "brain drain" of qualified young scientists away from their home countries.

The survey was successful in showing the main positive impacts on the trainees (e.g. participation in new research projects, implementing new techniques, using new equipment and/or using new software/models that were previously unavailable at the home institute, and enhanced collaboration). It also showed some differences between the different types of programme (e.g. fellowship programmes were more likely to enhance mobility with a potential for "brain drain"). The response rate was just under 50%, despite regular reminders being sent. This relatively low response rate is probably linked to the fact that the survey was deliberately sent to trainees more than 5 years post-training, in order to evaluate the medium- to long-term impacts.

Future perspectives: way forward in capacity development

We need to proactively consider the status and requirements of the global ocean observing system (e.g., GOOS, POGO, GEOBON MBON, GEO Blue Planet and all the constellation of partners) in the next 5 to 10 years and how we need to develop the observing community and bring opportunities to meet the well-publicised need for capacity development to the attention of groups responsible for implementing different policies and conventions. Using as an example the ocean science categories related to marine ecosystem functions and processes and ocean health (UNESCO 2017), it is clear that to implement and achieve monitoring of biological EOVs, the observing system needs to insert itself into ongoing programmes for capacity development, take advantage of platforms already measuring physical and biogeochemical variables, and then identify the gaps and strategies to fill them. The main strength of GOOS, POGO and its partners is a robust, expert community, which is able to provide high-level scientific and technical expertise in almost all ocean topics to facilitate and strengthening the establishment of collaborating communities of practice. In the same way that there is a need for robust, sustained and coordinated observations focused on specific measurements to assess changes in marine ecosystems, there is also the need for capacity development related activities to be coordinated so that their impact is maximised.

The first step towards improving capacity development for ocean observations is to initiate a dialogue between the different stakeholders, the "providers" of observations (e.g. GOOS, POGO, the Committee on Earth Observation Satellites or CEOS, and affiliated programmes) and the "users" (e.g. policy makers, government, managers, NGOs, industry and societal sectors) to establish partnerships with ongoing capacity development programmes (e.g the IOC Regional sub-commissions and the OTGA) that can support the strengthening of EOV-observing capacity and to support open access to monitoring data (e.g. through OBIS for biological information). This will allow the creation of a shared understanding of the need to support ocean capacity development activities. Such a partnership of organisations with common goals will increase the chances of funding and a more efficient allocation of resources.

A second step is the compilation of manuals and best practices related to EOV observation. The Oceans Best Practice (OBP) Platform under the IODE is a significant step forward in this direction (https://www.oceanbestpractices.net/) (Pearlman et al. 2017). Such best practices should span from observations to data analysis therefore, expanding to include big data analysis from eDNA, video, satellite, and other technologically innovative tools.

For the third step, the observing community and their partners in capacity development, need to continue to work with multilateral conventions and global organisations (e.g. CBD, UN, LMEs) to support the development of data-driven indicators for ocean related targets (SDG14, relevant Aichi Targets) and global assessments (e.g. the World Ocean Assessment-WOA and the Intergovernmental Platform for Biodiversity and Ecosystem Services-IPBES). There is a danger that global assessments report at such a high aggregated information level, that the quality of the underlying data is missed and any needs for improvement lost. Clearer links are needed between observation and global reporting, but this first requires improved coordination and expanded coverage of most observing systems.

In this regard, a course on monitoring of particular EOVs, including how monitoring information would be useful to address the SDGs and Aichi Targets or address other reporting needs could be proposed under the IOC/OTGA platform. Given that IOC/OTGA courses are offered by demand from the regions, such a course would fit into local and regional policy requirements especially if these are focused around EOVs that are of local interest (e.g., coral reefs, mangroves, seagrasess) and also build on existing local and regional capacity initiatives. For example, the Coral Reef Alliance CORAL works on restoring and protecting coral reefs in partnership with the communities living nearest the reefs through a variety of strategies, mostly based on education. The coral reef scientific community also offers course opportunities on coral reef monitoring (e.g., Reef Check: http://www.reefcheckitalia.it/bangka-bando-2017.html), but these could be greatly improved if they were under a global platform (e.g. IOC/OTGA), coordinated with the needs of the Global Coral Reef Monitoring Network (GCMRN) which could provide the network for long-term sustainability (see Table 1 for a review of capacity initiatives related to each EOV).

A partnership with CEOS would help strengthen the global network observing capacity already established for some EOVs (e.g., ocean colour, primary productivity), but would also to develop capacity around new EOVs (e.g. mangrove cover, coral reef cover/condition). Following conversations held at the Research Coordination Network meeting in December 2016 in San Francisco, developers of remote sensing technology expressed their will to learn 1) the needs of the biological observing community, 2) what could be improved and/or developed to enable relevant measurements to detect changes in marine life, and 3) how to make the implementation and use of these technologies more understandable, achievable and user-friendly. Further, the European Commission Copernicus programme supports capacity building at several levels and is likely to be a major source of open-access Earth Observation products for the foreseeable future.

The Earth Observation and ocean modelling sectors are indicative of a move towards the use of “big data” in ocean observations. Across many marine science sectors, datasets are becoming larger as a result of the increased spatial and temporal resolution offered by many techniques, and through the drive towards climate-scale analysis. While this data availability provides huge potential for impact, it also represents a new gap in terms of of capacity development. Equipping participants with the relevant tools for their analysis is critical to fully exploit this wealth of data. Open-source and community developed platforms have great potential to address the broad range of needs for the global user base. Programming tools are particularly relevant in this context, with languages such as Python and R as accessible options for the inexperienced user thanks to the large community support and development of libraries and tutorials. Improved internet access will be required for many LDCs and SIDS to take advantage of these new tools and information systems.

Although capacity development mostly involves experts and early-career scientists, the role of ecosystem beneficiaries should not be ignored. Participation of stakeholders is very important because this will enable scientists to be made aware of societally important issues, and the stakeholders to have an improved knowledge base in their decision-making processes. Researchers should also share their knowledge and understanding of marine environmental conditions with local people who, in turn, may be able to provide longer term and more local perspectives useful in interpreting the research data. A participatory approach is required to achieve holistic success in capacity building, which will enable us to take advantage of the resources investing in the projects, including human, facilities, and financial resources.

It is understood that capacity building in marine and coastal research are faced with challenges and there is a need to implement new capacity-building approaches in developing countries. According to the World Bank (2017), various parts of the world where marine resources resources are greatly endangered, such as the Pacific island region, West Africa and South West Indian marine regions, need collective intervention to tackle problems affecting their marine activities. This support can be engaged through capacity building from the associations. Some of this training and programmes can be conducted in developing regions and more research collaborations can result from them.

Final remarks

We have provided an overview of the need for capacity development to achieve a global ocean observation system that will help meet the requirements of the Sustainable Development Goals and other critical international agreements and platforms, that are related to climate change, biodiversity and ecosystem services. We have also discussed some capacity initiatives, their benefits and challenges along with some lessons learnt and some recommendations that may help overcome these challenges in the short term. However, while improving knowledge will certainly have a major impact in advancing the global observing system, economics will determine its success (Miloslavich et al. 2018). Acquiring knowledge without the resources or technology to use it to improve sustainable use of the local marine environment cannot suffice. "Capacity development" keeps appearing in every policy document of the UN (e.g. UN 2017), of the IOC (UNESCO 2016) and of the LME programme (e.g. Barbiere and Heileman 2016) as critical to empower societies in developing countries, for managers to transition into Ecosystem-based-management practices, for scientists to understand better the effects of human pressures and climate change and inform policy for actions to be taken, and for communicators to interface between science, society and politics. Member states of the UN have recently proclaimed a Decade of Ocean Science for Sustainable Development (2021-2030) "*to gather ocean stakeholders worldwide behind a common framework that will ensure ocean science can fully support countries in the achievement of the Sustainable Development Goal 14 on the ocean*." Some of the key goals of the Decade related to capacity development will be to form a new generation of ocean scientists and technicians, establish new research networks and a new generation of enhanced observational systems. Some expected outputs will be "*increased scientific knowledge about the impacts of cumulative interacting stressors such as warming, acidification and habitat destruction; and achieving integrated observations and data sharing including the use of satellites, fixed and moving observing platforms, all feeding into common data management and the Global Ocean Observing System (GOOS).*"

While this is certainly good news not only for all ocean stakeholders but for the whole world at large, the time has come for member states to actually stand up for their political decisions and make serious financial commitments. A global observing system, and developing the capacity needed to implement it in a sustained way, including technology development, is a daunting task and cannot be supported alone by just a few countries or organisations. The Decade of Ocean Science is a great opportunity to build and consolidate the bridges between science, policy and society. The observing community has been undergoing major reorganisations in recent years to ensure coordination, maximise resources and focus on societally relevant contributions. They are ready for the challenge and prepared to deliver. What is needed now is the political will to secure that resources will come hand in hand with their decisions.

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