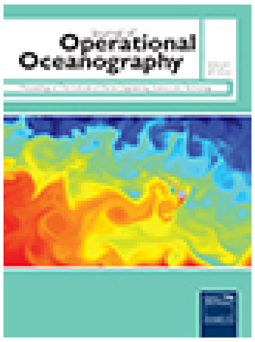

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ABSTRACT
Sustained global ocean observations are needed to recognise, understand, and manage changes in marine biodiversity, resources and habitats, and to implement wise conservation and sustainable development strategies. To meet this need, the Global Ocean Observing System (GOOS), a network of observing systems distributed around the world and coordinated by the Intergovernmental Oceanographic Commission (IOC) has proposed Essential Ocean Variables (EOVs) that are relevant to both the scientific and the broader community, including resource managers. Building a network 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 resources and technology should follow to enable the application of this training to engage meaningfully in global observing networks and in the use of the data. Investments in technical capacity fulfil international reporting obligations under the UN Sustainable Development Goal 14A. Important opportunities are emerging now for countries to develop research partnerships with the IOC and GOOS to address these obligations. Implementing these partnerships requires new funding models and initiatives that support a sustained research capacity and marine technology transfer.

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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. ‘Capacity development’ (or ‘capacity building’, as used by some organisations) is required to achieve sustained ocean observations that meet internationally-agreed standards, as well as their transformation into information that can support decision-making. In this paper, we describe capacity development as the provision of training to scientific staff and students in developing countries as well as the provision of tools and training to policy makers to enable them to collect, make use of data, products and services, as part of a long-term strategy to ensure that the skills and knowledge acquired are applied to the development of marine science and policy in those countries (e.g. those derived from Earth Observations). 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

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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 Sustainable Development Goal 14 (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) summarises information 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 efforts have increased in the last two decades due to an increase in multidisciplinary and international collaborations, and an increase in the application of scientific ocean observations for management purposes. At present, approximately 35% of the ocean science facilities globally have observations as their primary focus to support scientific studies on ocean change but only a few countries invest in observations over large spatial scales and over long-time spans. Few nations have the human capacity and access to technology to monitor even their own Exclusive Economic Zones (EEZ) (Isensee et al. 2017). The High Seas, or approximately 50% of the planet that lies outside the EEZs of nations has benefited from sustained observing programmes that measure limited physical and biogeochemical variables [e.g. Argo (http://www.argo.ucsd.edu/), OceanSites (http://www.oceansites.org/), and GO-SHIP (http://www.go-ship.org/)]. Global biological observations are much more limited and mostly focused on plankton communities (Edwards et al. 2012; O'Brien et al. 2017).

Capacity in ocean sciences, both human and technical, depend greatly on increased financial support (Isensee et al. 2017), however, resources will only become available if there is the political will and the institutional engagement to recognise capacity development as a priority. 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. 2011; Wernberg et al. 2011; Krumhansl et al. 2016), how such resources are affected by 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. 2013; Gill et al. 2017).

For existing and new observations to contribute effectively to global knowledge and enable solutions 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 (Golden et al. 2017; Pearlman et al. 2017). Increasing the global observation systems in this manner, will improve the information that is needed by particular sectors of society to understand global trends. It will provide a global context in which to interpret local observations. The technology to make these measurements and the applications of the information represent important opportunities for countries to develop partnerships to fully participate in and benefit from the blue economy (Dunn et al. 2016; OECD 2016; Golden et al. 2017). This capacity is required to design and contribute meaningfully to the United Nations Decade of Ocean Science for Sustainable Development (2021–2030; https://en.unesco.org/ocean-decade).

Several high-level policy initiatives have highlighted the need for concerted action to develop global capacity for ocean observations. Some of these are the SDGs of the United Nations (UNGA 2012), the capacity development strategy of the IOC (UNESCO 2016), the United Nations Conference 'Our ocean, our future: call for action' (UN 2017), and the European Marine Board strategy to strengthening Europe's capability in biological ocean observations (Benedetti-Cecchi et al. 2018). There are also good examples of regional and global initiatives supporting capacity development related to ocean science and observations. Some of these are the UNESCO/Flanders Fund-in-Trust (FUST: http://fust.iode.org/) which has been supporting UNESCO Science Programmes including sustained capacity building and technology transfer for 20 years, various projects framed in the Horizon 2020 programme of the European Commission (http://ec.europa.eu/programmes/horizon2020/) including the AtlantOS project (https://www.atlantos-h2020.eu/) which has built stronger collaboration between south and north Atlantic Ocean research organisations, and others. There has also been increasing collaboration between researchers at a national and international level as seen from the growing number of multi-authored and multi-national papers in the scientific literature (Valdés et al. 2017). However, the long-term maintenance and interconnection of these individual collaborations is often dependent on the funding and structural support of large scale programmes. At the global level, the best example has been undoubtedly the Census of Marine Life, a ten-year (2000–2010) scientific research and outreach programme involving more than 2700 scientists from over 500 institutions and more than 80 countries (Alexander et al. 2011). Even without being an explicit objective of the programme, the Census built individual, institutional, national, and regional capacity in marine biodiversity through its early career researchers and young alumni (Williams et al. 2010). The Census also created the Ocean Biogeographic Information System (OBIS), its database legacy, which today, under the auspices of the IOC provides significant capacity on marine biogeographic data management. The programme was quite advanced when it engaged with end-users and established broadened science-policy partnerships, mostly to respond to policy demands for information (Williams et al. 2010). However, opportunities for regional and international collaboration in developing regions such as the Census of Marine Life, are still hampered by a lack of appropriate and sustainable funding mechanisms, and further challenged by cultural differences and logistical issues. This results in a fractured and ineffective delivery of scientific information to decision makers at all levels. The Census was a US$ 650 million programme contributed by a broad international community of government agencies, international governmental and non-governmental organisations, conservation groups, industries, and other ocean stakeholders. Nevertheless, the driving engine that secured the programme for a decade and achieved a global investment of almost 10-fold was a US$201175 million commitment from the Alfred P. Sloan Foundation (Alexander et al.). It is vital then that the research and observing community collaborates to build progress and information to have maximum impact on national and international decisions and policy.

In this paper, we provide an overview of current capacity development opportunities in support of ocean observations and information services and make recommendations. 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. We also outline their role in providing the data analysis tools to convert these data to useful products for society.

The need for capacity development in ocean observations and services

Capacity development is an issue that transcends scientific, social, economic, cultural and political boundaries. 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. Both 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 invest in equipment and infrastructure where these are lacking and develop and disseminate data analysis tools to help convert these data to useful products and services.

Capacity development was identified as a major need by at least half of the 24 international conventions that relate to biological and/or ecological aspects of the ocean. These conventions are globally relevant and require long-term marine biological observations to achieve their goals (Miloslavich et al. 2018a). The need for capacity development to support countries, especially for Least Developed Countries (LDCs) and Small Island Developing States (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 as reported by the Earth Negotiations Bulletin (e.g. http://enb.iisd.org/biodiv/sbstta22-sbi2/10jul.html).

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 mobilisation (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.

It is crucial to develop capacity on all stages of the ocean observing process, from identifying requirements and designing systems through to the transformation of data into products and information. This includes not only the technical aspects of conducting ocean observations (from instrument deployment, servicing, maintenance to data collection using standard operating procedures), but also data management through quality assurance (QA), quality control (QC), analysis, reporting and modelling. Currently, some observing system elements (e.g. satellite-based remote sensing and underwater imagery) collect data at a much higher rate than the rate at which it can be analysed by many maritime nations. This limits the creation of potential products and wastes significant 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. Examples of these such include the Copernicus programme, World Register of Marine Species (WoRMS: http://www.marinespecies.org/), open source software and libraries in programming languages such as Python and R. A major challenge is to improve the societal and scientific relevance and benefits of products and observing networks. One way of achieving this is to build the (national and) global capacity that will support aggregating the data at the level that supports the kinds of questions that managers and policy makers address to demonstrate compliance with targets or trend indices.

Building a global observing system through enhancing capacity

Implementing a comprehensive sustained ocean observing system is challenging and costly. Although significant elements of the observing system are already in place through the Global Ocean Observing System (GOOS) and its many partners, ocean observations are still not evenly distributed throughout the world's ocean (O'Brien et al. 2017). Significant funds are required to set up and maintain the technical and scientific infrastructure of the system and to develop the human capacity to implement, deploy and maintain an end-to-end system. This capacity building effort needs to include applications and uses of data and information services for societal benefit. In building a global observing system we need to identify cost-effective approaches with integrated capacity development programmes based on best practice approaches to learning.

Agreeing on a set of variables that need to be measured globally can help with the realistic implementation of multidisciplinary observing networks that span biological, biogeochemical and physical observations. The Global Ocean Observing System (GOOS) typically has provided measurements of physics and biogeochemistry Essential Ocean Variables (EOVs) to support applications on ocean health, real time services and climate change assessments. These EOVs were defined based on specific scientific and societal requirements driven by climate change and the need for weather forecasts (Lorenzoni and Benway 2012; Bojinski et al. 2014; Bauer et al. 2015). 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 (Navarro et al. 2017; Muller-Karger et al. 2018; Miloslavich et al. 2018a).

Cost-effective approaches need to be identified that engage less well-resourced countries in ocean observing to address local problems and contribute to regional and global understanding. 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). Any of them 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 requires technical skills that are difficult to maintain, especially in LDCs and SIDS. Automated image analysis would provide a solution to ensure consistency and quality assurance, but to achieve this will require a significant investment in scientific validation and data processing expertise; such investments could be offered by countries with greater resources.

Automated processing of big data (from satellites, models, or genetic material) typically advances rapidly, and it is important to understand equipment and knowledge needs to conduct the minimum analyses necessary to evaluate changes in resources of interest at a particular location or region. 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. These need to respect individual country needs and meet the requirements of the individual monitoring programmes. Faster and cheaper access to the internet will be an important prerequisite for many LDCs and SIDS to more fully engage in global observation systems.

The observing community should identify training required and mechanisms for effective delivery. 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 (as a topic example, see Supplemental Table S1 for examples of programmes providing training for biological EOVs).

To learn about current training-based capacity development initiatives, we conducted (1) a review of the capacity development initiatives specifically related to ocean monitoring of more than 10 major (mostly global or large scale regional, well-established) programmes/organisations, covering a range of topics and training methods, and (2) a survey of the topics and methods used by these programmes/organisations or their projects and their relationships between training, EOVs, and SDG14 indicators. We also asked whether there was support provided to participants (e.g. financial/ in-kind, mentorship, infrastructure), and whether they were associated with an academic institution. Our objective is to use this survey information 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 programmes, the results highlight potential gaps in topics, EOVs and SDG indicators where more capacity building 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 below), these surveys could also help organisations to select and implement a type of training that is lacking for particular topics.

Capacity development activities in ocean observation at the global scale: Case studies

Currently, activities aimed at increasing marine research capacity include a variety of strategies, from summers schools to ship-board experience, distance learning, and mentoring among others (Morrison et al. 2013). Many operational and research programmes also include a capacity development component or have an education arm. Depending on the local and global requirements, some of these programmes could be expanded and be better coordinated with others with which they share common goals and best practices. Examples of key programmes follow.

The IOC and its Regional Sub-Commissions and Committees: The IOC, established in 1960 as a body with functional autonomy within UNESCO, is an 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 (UNESCO 2016; UNESCO-IOC 2005) are implemented through the International Oceanographic Data and Information Exchange (IODE) and are widely referred to in international policy settings. IOC also coordinates ocean observation and monitoring through GOOS, which aims to develop a 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 initiatives including 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 IOC Sub-Commissions (e.g. IOCARIBE for the Caribbean and Adjacent Regions, IOCWESTPAC for the Western Pacific, and IOCAFRICA for Africa and Adjacent Island States) and Regional Committees (e.g. IOCINDIO for the Central Indian Ocean, IOCEA for the Central Eastern Atlantic, IOCWIO for the Western Indian Ocean, and the BSRC for the Black Sea), 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 other IOC member states. The IOC, through IODE is developing a Clearing House Mechanism as a platform to share information on existing resources that can support capacity development and the transfer of technology. The IOC is also developing an Ocean Best Practices strategy and on-line platform (https://www.oceanbestpractices.net/) that should be used fully and extensively (Pearlman et al. 2017).

The Ocean Teacher Global Academy (OTGA; http://classroom.oceanteacher.org/) of the IOC's IODE is a network of Regional Training Centres (RTCs) spread across

Table 1. Summaries of training-based capacity development activities by 11 international and regional organisations. (a) Topics of training; (b) relation to GOOS EOVs; (c) relation to SDG-14 indicators; (d) summary of participation-based capacity development activities by 11 international and regional organisations; (e) summary of infrastructure-based capacity development activities by 4 international and regional organisations.

	Method of training					
a. Subject of training	Short course	Medium-term training course	Centres of Excellence/ Long-term training course	Internship/fellowship in research institution	Internship/fellowship in international Secretariat	Distance learning
Observations						
Sampling and analysis	IO, IOCC, G, P, SAH, SA, SO	SC	P	P/SC, SA, SO	SO	
Automated equipment deployment and/or servicing	IOCC, P, SA, SO	SC		P/SC		
Data						
Processing	E, G, IO, IOCC, O, P, SO	SC	P	E, P/SC, SA		E
Visualisation	E, G, IO, O, P, SO	SC		E, P/SC		E
Management	E, IO, IOCC, O, P, SO		P	E, P/SC, SO	SO	E
Mining/access/discovery	E, O, P, IO, SO	SC		E, P/SC		E
Modelling						
Software	G, IO, O, P, SO	SC	P	P/SC		
Techniques	G, I, O, P, SO			P/SC		
Data assimilation	O, P			O, P/SC		
Calibration/validation	O, P			P/SC		
Applications						
Development or use of data products/information services	E, I, IO, O			E		E
Socio-economics, science-policy interface	I, P, SO					
Personal development/soft skills						
Scientific writing and presentation skills	I, SO		P	SA, SO	SO	
Proposal writing	I		P		SO	
Leadership					SO	

	Method of training			
b. GOOS EOVs	Short course	Centres of Excellence/ Long-term training course	Internship/fellowship in research institution	Distance learning
Physics				
Sea state	P, SC	P	P/SC	
Ocean surface stress	P, SO		P/SC	
Sea ice	E, P, SO		E, P/SC	E
Sea surface height	E, P, SC, SO	P	E, P/SC	E
Sea surface temperature	E, P, SC, SO	P	E, P/SC, SO	E
Subsurface temperature	P, SC, SO	P	P/SC, SO	
Surface currents	P, SC, SO	P	P/SC	
Subsurface currents	SC, P	P	P/SC	
Sea surface salinity	P, SO	P	P/SC, SO	
Subsurface salinity	P, SO	P	P/SC, SO	
Ocean surface heat flux	P, SO		P/SC	
Biogeochemistry				
Oxygen	IOCC, P, SO	P	P/SC, SO	
Nutrients	G, IOCC, P, SO	P	P/SC, SO	
Inorganic carbon	IOCC, P, SC, SO	P	P/SC, SO	
Transient tracers	G, P, SC		P/SC	
Particulate matter	G, P, SO		P/SC, SO	
Nitrous oxide	IOCC, P		P/SC	
Stable carbon isotopes	P, SC		P/SC	
Dissolved organic carbon	P, SC, SO	P	P/SC, SO	
Biology and Ecosystems				
Phytoplankton biomass and diversity	E, G, O, P, SAH, SC, SO	P	E, P/SC, SO	E
Zooplankton biomass and diversity	G, O, P, SAH, SO	P	P/SC, SO	
Fish abundance and distribution	O, P, SC	P	P/SC	
Marine turtles, birds, mammals abundance and distribution	O		P/SC	
Hard coral cover and composition	O		P/SC	

Seagrass cover	O		P/SC	
	Macroalgal canopy cover	O		P/SC, SA
Mangrove cover	O		P/SC	
Ocean colour	E, P, SC		E, P/SC, SC	E

	Method of training			
c. SDG-14 indicators	Short course	Centres of Excellence/ Long-term training course	Internship/fellowship in research institution	Distance learning
14.1.1. Index of coastal eutrophication and floating plastic debris density	E, P, SAH, SO	P	E, P/SC, SO	E
14.2.1 Proportion of national exclusive economic zones managed using ecosystem-based approaches	E, O, SAH, SO		E	E
14.3.1 Average marine acidity (pH) measured at agreed suite of representative sampling stations	IOCC, P, SC, SO	P	P/SC, SO	
14.4.1 Proportion of fish stocks within biologically sustainable levels	SC			
14.5.1 Coverage of protected areas in relation to marine areas	E		E	E
14.6.1 Progress by countries in the degree of implementation of international instruments aiming to combat illegal, unreported and unregulated fishing				
14.7.1 Sustainable fisheries as a percentage of GDP in small island developing States, least developed countries and all countries				
14.a.1 Proportion of total research budget allocated to research in the field of marine technology	E, O		E	E
14.b.1 Progress by countries in the degree of application of a legal/regulatory/policy/institutional framework which recognises and protects access rights for small-scale fisheries				
14.c.1 Number of countries making progress in ratifying, accepting and implementing through legal, policy and institutional frameworks, ocean-related instruments that implement international law, as reflected in the United Nation Convention on the Law of the Sea, for the conservation and sustainable use of the oceans and their resources				

d.	Financial or in-kind support	Mentorship
Participation in regional/international networks, assessments, working groups etc	E, G, I, IOCC, O, P, SO	G, I, IOCC, P, SA, SAH, SO
Supporting participation in regional/international conferences, symposia, workshops	E, G, I, IOCC, O, P, SC, SO	G, I, SC, SO
Involvement of developing countries in regional/international research projects and/or cruises	G, P, SO	G, P, SO

e.

Organisation	Description
EUMETSAT	Support to broadcasting of satellite data. Data access portal.
GEOTRACES	Through loaning/sharing of equipment and/or ship time
OBIS	Through hosting services on OBIS site
POGO	Through purchasing of new equipment

E = EUMETSAT; G = GEOTRACES; IO = IODE; I = IMBER; IOCC = IOCCP; O = OBIS; P = POGO; SA = SARCE; SAH = SAHFOS; SC = SCOR; SO = SOLAS; Short course = attended in person, <4 weeks; Medium-term training course = 1–9 months; Long-term training course = 10 months +; Distance learning = e.g. on-line, web resources.

the globe. It makes 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 on a range of topics, including ocean/marine data and information management These courses address a need for additional biodiversity and biogeographical information, and seek a multiplier effect by 'training 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 data to and using the Ocean Biogeographic Information System (OBIS), etc. The main audience of these training courses are ocean professionals working in 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. 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. To date, through more than 180 courses, the OTGA has trained more than 2500 people from 134 Member States, with over 4200 registered users in the platform. Specifically, for OBIS, more than 270 trainees from 69 countries have received the training through 15 courses (http://iobis.org/training/alumni/).

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 courses 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 focused 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. To date, POGO has provided training to over 800 early-career scientists from around 80 countries, and surveys conducted 5–10 years after the training have demonstrated impacts on the former trainees' ability to implement new techniques, participate in research projects and international networks. The programmes also fostered long-term collaborations between scientists in developing and developed countries and led to publications and conference presentations. The former trainees had also passed on the knowledge gained to their students and colleagues (Urban and Seeyave In preparation).

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 International Surface Ocean - Lower Atmosphere Study (SOLAS), the Integrated Marine Biosphere Research (IMBER), the International Study of Marine Biogeochemical Cycles of Trace Elements and their Isotopes (GEOTRACES), and the International Ocean Carbon Coordination Project (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 has also conducted an evaluation of the impacts of its Visiting Scholars programme (Urban and Seeyave in prep.). SCOR, POGO and IOC/IODE have been cooperating and sharing their knowledge in capacity building over the past 10 years, to ensure better coordination, reduce duplication and establish joint initiatives.

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 developing 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 2014). This has also led to the successful implementation of ecosystem-based management practices (Malone et al. 2014). Specifically, for the Bay of Bengal 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 as 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 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 and to include biogeochemical variables.

EUMETSAT: EUMETSAT is responsible for delivering the Level1 and Level2 Sentinel-3 marine and lake products for the European Commission Copernicus programme (www.copernicus.eu), 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 latter is one aspect that is particularly targeted at LDCs with the last run achieving near global representation in participation. The programme is also working on the integration of cloud computing resources in to its training activities, to assist with the challenges of working with big data in low bandwidth environments.

The Global Alliance of Continuous Plankton Recorders (GACS): The CPR Survey programme, formerly hosted at the Sir Alister Hardy Foundation for Ocean Science (SAHFOS) has now been incorporated into the Marine Biological Organization (MBA) of the UK. 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. 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).

The Global Ocean Acidification – Observing Network (GOA-ON) Pier2Peer programme is an international mentorship programme matching senior and early-career researchers from around the world 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), organising a series of workshops and mentorships to engage, build and sustain the relevant local resources and capacity. The IOCCP also provides technical training in biogeochemical sensors and data analysis and techniques through summer schools to support ocean acidification studies.

The Pole to Pole Marine Biodiversity Observation Network (P2P-MBON) in the Americas, a programme built in partnership with the Group on Earth Observations Biodiversity Observation Network (GEO BON), the Group on Earth Observations System of Systems for the Americas (AmeriGEOSS), GEO Blue Planet, and the Marine Global Earth Observatory of 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). The P2P programme will run through 2020 but while it is just starting, it is leveraging on previous efforts by the South American Research Group on Coastal Ecosystems (SARCE), a network that provided baselines between 2010–2013 for detecting biodiversity changes in rocky shores in the South American continent and trained students through mentoring and exchange programmes. The P2P will focus on (1) capacity development in field sampling, (2) capacity development in data management, internationally accepted data formats (data analysis and visualisation in R + data sharing in OBIS), (3) delivery of satellite products (e.g. dynamic biogeographic seascapes), and remote sensing (RS) time series data. The first training workshop was held in Brazil in August 2018 for 27 participants representing 11 countries in the Americas, from Canada to Patagonia.

GEO and AmeriGEOSS CIEHLYC (Comunidad para la Información Espacial e Hidrográfica en Latinoamérica y el Caribe): The Group on Earth Observations GEO and the GEO group for the Americas (AmeriGEOSS) implemented CIELHYC to leverage Earth Observation (EO) resources to support timely and knowledge-based decision-making through effective training capabilities. CIELHYC has led and continues to organise workshops throughout Latin America and the Caribbean region on hydrometeorology, basic research and applied concepts in marine ecological remote sensing applications, terrestrial land classifications and ecological assessments using satellites. The Pole to Pole Marine Biodiversity Observation Network (MBON) in the Americas workshops described above are conducted in partnership with AmeriGEOSS and CIEHLYC.

Academic Research Institutions: Numerous academic institutions around the world offer a wide variety of capacity building programmes, from short workshops and certificate programmes, professional Master degrees, ocean policy and environmental law degrees, and traditional scientific research programmes focusing on undergraduate to graduate (Masters and PhD) degrees. Some programmes are not just run at the host institutions but have taught course elements that are delivered on site in Less Developed Countries. Marine labs and field stations are important players in undergraduate, graduate and professional education in ocean and coastal sciences; an example of this are the training courses of the International Council for the Exploration of the Sea (ICES) which are aimed to ensure a high quality of their advisory process and are linked to national institutes and universities and developed and evaluated by an operational training group. Wescott (2002) and Glegg (2014), among many others, provide overviews of academic training programmes that focus on marine conservation, resource use planning, and basic science relevant to societal benefit.

Cruises, Aquaria, Museums, Professional Associations and other Non-Profit Organszations: Tourism to coastal and marine areas presents many opportunities for training and capacity building. For example, aquariums, nautical museums, and seaside communities are well equipped to conduct outreach and professional training as well as educating the general public to learn about the oceans and their history (USCOP 2018). Professional associations such as the National Marine Educators Association (NMEA), the National Science Teachers Association, and the American Association for the Advancement of Science, and similar organisations throughout the world play a unique role in promoting marine capacity building and science education. These organisations reach many millions of people and play a key role in highlighting the importance of science-based management and sustainable development of coastal and marine regions.

Citizen science: Citizen science is another growing area which can also bring users closer to those making the measurements and involve the users themselves. In Southern California, baseline monitoring in Marine Protected Areas (MPAs) by citizen scientists demonstrated the important contribution that these stakeholders can make when engaging in the monitoring and management process and how success is highly dependent on the goals of the citizen science programme (Freiwald et al. 2018). The Reef Life Survey (RLS: https://reeflifesurvey.com), a citizen-science programme established in Australia in 2008 but extended globally to more than 3000 sites in nearly 50 countries, collects data of biodiversity on rocky and coral reefs through trained volunteer SCUBA divers (Stuart-Smith et al 2017). The RLS programme has provided invaluable data for ecosystem management and conservation and to evaluate ecological changes in coral reef biodiversity at the Great Barrier Reef after massive bleaching event (Stuart-Smith et al. 2018).

Finally, while not directly linked to ocean observations nor monitoring, it is worth mentioning the significant efforts done by the International Ocean Institute (IOI) to provide training and capacity development in ocean governance spanning all ocean decision and policy-making topics. Such training is provided since 1972 by a pool of trainers and channelled through the IOI regional programmes and training centres or support centres in 12 countries.

Examples of best practices in capacity development and lessons learned

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 sensu GEO BON 2015). However, policy makers often do not have the time, expertise or inclination to undertake such data analysis and therefore, need tools to synthesise large datasets to a series of indices or metrics to identify trends in ecosystem services. An example of such a tool to deliver marine assessments has been developed by the Centre for Environment, Fisheries and Aquaculture Science Cefas) of the UK (https://emeco.azurewebsites.net/). Therefore, 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.

A critical issue for capacity building programmes, which is most often not considered, is what the trainees will do after the capacity building sessions. As a global and coordinated ocean observing network develops it is important that countries provide opportunities to trainees. Will trainees have a permanent or temporary position on completion of a capacity building programme? Will they return to/remain in their home country or are they mobile? Are they in a position to pass on the knowledge acquired (e.g. lecturing, mentoring/supervising students)? Giving these questions due consideration when designing the capacity development programme and training resources 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, (1) broad, multi-disciplinary, long-term postgraduate-level training (e.g. Master level), (2) medium-term, targeted fellowships/

internships providing postdoctoral or PhD-level training/mentorship/supervision, and (3) Short-term, international or regional training courses on specific topics for large groups (e.g. 20–30).

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 focused on needs. The impact of GOA-ONs Pier-2-Peer approach can be enhanced by linking to established regional networks, for example the IOC'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 preferred language used for training (English, French, Spanish or Portuguese, which reflects the current 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 and maybe targeted differently, either to the broad ocean community through the OceanExpert directory of about 5000 contacts (https://www.oceanexpert.net/) or through the Marine Data Management (n~80) and Marine Information Management (n ~ 50) national contact points. Although the targeted audience is the IOC Member States, the survey is open, and anyone can contribute, however the representativeness of the response rate being quite different if the survey is targeted to the broad or to the management community. In this regard, one continuous challenge is the relatively low response rate of these surveys, especially from the broad community. While there may be variety of reasons for this lack of response (e.g. people are already overwhelmed with their work commitments, or do not feel as being the appropriate person to complete it, or simply bad timing or lack of interest), these structured on-line surveys are still the best and most cost-effective way to have quantitative information from the process. An added challenge is that when people actually respond, all the subjects/topics proposed for developing a training course are voted rather similarly, making it difficult to identify what the priorities should be as all topics seem to be considered equally important.

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

Table 2. Synthesis of some key consideration for organising a training programme in ocean observations or science

Some criteria for selecting the trainee candidates	Some considerations to working in developing countries	Some financial considerations
• *Background and skills:* capacity to transfer knowledge and apply practical use with the highest impact. • *Choice of career stage:* should be 'early-career' enough to gain from the training, but senior enough to be able to pass on the knowledge to others. • Infrastructure and facilities of home institution: potential for the home institute to set up and maintain an observing system. • *Age:* 'threshold age' (e.g. 'early career') usually applies aiming to maximise the benefits for the trainee's institution, but not helpful when comparing candidates from countries where oceanography is at very different stages of development. Advisable to work on a case-by-case basis. • *Gender balance:* a priority for some organisations, but equal access to opportunities still an issue.	• Have a good local partner(s) to provide support with logistics, language/cultural barriers, navigating the intricacies of administrative systems. • Involve local scientists in the teaching to provide relevant expertise and as role models for early-career scientists. • Be realistic (and well informed) about time scales, facilities (for teaching/research, accommodation and hospitality)- make sure the instructors and participants know what to expect. • May need to adapt teaching styles to local education practices. • Potential limitations in internet access: can hinder significantly particularly when working with large datasets. Back-up copies of software, pre-prepared data, and cloud processing platforms can ameliorate these challenges. • Potential health considerations and requirements, such as vaccinations, malaria tablets, health insurance.	• May need to adapt procedures, e.g. to provide advance payments, and reimburse expenses quickly so that participants are not left out of pocket • Organisations may require a contribution from the participants if there are certain costs they cannot or will not cover (e.g domestic travel, visa costs, travel insurance); this is a good way to ensure that the participants are dedicated, but it risks excluding the participation of those who really cannot afford to contribute. In these cases, exceptions should be considered on a per case basis

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 centres 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 standardisation, 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 teaching methods that should be taken into consideration when providing training in a multicultural environment.

With regard to trainees, a trainee from a developing country who subsequently becomes a trainer 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 NF-POGO Alumni Network for Oceans (NANO) usually collaborate in joint publications based on the work undertaken as part of the training and/or as part of a joint alumni research project (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 with 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 travelling 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 a tool for consultation and further clarification that is case adaptable and fit for purpose also greatly improve the chances for a longer-term successful programme.

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. This can be done by identifying follow-on opportunities that participants may wish to consider for example – collaborative research exchanges, or contributions to conferences and publications.

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 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 a network depends greatly on coordinating activities (Pietri et al. 2015). In addition to these traditional networks, the use of digital social networks (e.g. LinkedIn) is also highly effective as a communication platform to enhance professional performance (Benson et al. 2017).

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% (149 responses were received). Although a higher response had been hoped for, and regular reminders were sent, the lack of response from half the trainees was 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. Post training can also be undertaken using Continuing Professional Development (CPD) programmes (e.g. from the Institute of Marine Engineering, Science and Technology or ImarEST: https://www.imarest.org/membership/education-careers/imarest-recognised-cpd-courses) to provide a framework. This can also lead the trainees to achieve a Chartered Scientist (CSci) status or fellow of a learned body that could facilitate a long-term career path and help attract and retain talented individuals.

Future perspectives: Way forward in capacity development

We need to consider the status and requirements of the global ocean observing system (e.g. IODE, GOOS, POGO, GEOBON MBON, GEO Blue Planet and all the constellation of academic and non-profit partners) in the next 5–10 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 can provide high-level scientific and technical expertise in almost all ocean topics to facilitate and strengthen 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. The GEO Blue Planet Initiative, which brings together many organisations, networks and programmes, from both 'user' and 'provider' communities, provides an ideal forum to foster these dialogues.

A second step is the compilation of manuals and best practices related to EOV observation (Muller-Karger et al. 2018). The Oceans Best Practice (OBP) Platform under the IODE is a significant step forward in this direction that will also allow for the identification of methodological gaps or where significant updates are required (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. Again, GEO Blue Planet, with its large network of contributors and partners, can help to gather such best practices for inclusion in IODE's Ocean Best Practices. The GOOS Regional Alliances can also ensure that regional best practices are included and documented by the Ocean Best Practice Platform to minimise duplication and enhance technology transfer.

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, courses 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, seagrasses) and 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 develop capacity around new EOVs (e.g. mangrove cover, coral reef cover/condition). A current group making linkages between users and providers of capacity building is the OceanObs Research Coordination Network (OceanObs RCN), sponsored by the US National Science Foundation. At an OceanObs RCN 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 biodiversity trends, 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 (EO) 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. There are many examples of very large datasets now available for open use by the science community, and by the public. For example, the European Space Agency has a Climate Change Initiative (ESA CCI) provides access to the global Earth Observing archives with data collected since the late 1980s with the goal of providing quality information on Essential Climate Variables (ECVs). In 2018, NASA initiated a complementary programme in collaboration with ESA under the umbrella of the Committee on Earth Observation Satellites (CEOS), intended to develop a virtual constellation of EO data from international global ocean colour, ocean winds, altimetry, and temperature missions into an operational context. Such an operational capability will help facilitate access to data for global monitoring from space, link to long-term satellite and in situ EO archives, and facilitate the development of models to address issues about the Earth System that are of broad societal concern (Muller-Karger et al. 2013).

While this data availability provides huge potential for impact, it also represents a new gap in terms 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 and/or remote cloud processing will be required for many LDCs and SIDS to take advantage of these new tools and information systems. One example is the EO Thematic Exploitation Platforms (TEPs), unveiled by ESA in 2014. The ESA TEPs are intended to facilitate the application of the new ESA Sentinel satellite sensor series, the Copernicus Contributing Missions, the Earth Explorers, and a large database of in situ observations. The Marine Biodiversity Observation Network (MBON) of the GEO BON has initiated complementary training sessions to facilitate access to products relevant to understanding changes of life in the sea, linking historical biodiversity databases like OBIS and GBIF, in situ environmental data, and remote sensing observations from NOAA, NASA, and ESA. An important element that has to be brought into the fold is linking these data and applications to socio-economic data. MBON is working on this, making the applications relevant to the analysis of status and trends within Exclusive Economic Zones (EEZ), Marine Protected Area (MPA) boundaries, and other relevant marine jurisdictions or areas of interest.

The recent proliferation of Massive Open Online Courses (MOOCs) could also be applied in the context of building capacity in ocean observing. An Ocean MOOC has recently been developed by German partners (http://www.oceanmooc.org/en/index.php) which was attended by several thousand participants at once. This approach has considerable potential to broaden the reach of capacity development activity and should be given consideration for future training.

Although capacity development mostly involves experts and early-career scientists, the role of those who benefit directly from marine ecosystem services 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 invested in the projects, including human, facilities, and financial resources.

The IOC Capacity Development Strategy (2015–2021) has also emphasised the need for countries to develop ocean research policies so that there is a clear link between the need for ocean science at the local level (and the observing systems required to underpin the science) and the drivers for such science at both local and regional level (UNESCO 2016). This is a prerequisite for scientists and managers making the case for funding to their national governments. It is also critical to have as complete as possible a picture of existing capacity development activity. A considerable amount of capacity development activity is undertaken on a bilateral (country to country) basis as well as the initiatives outlined earlier in this paper. The recently established IOC Group of Experts on Capacity Development will begin to identify capacity development requirements among IOC member states. This will need to be assessed against the wide range of capacity development activity already provided or planned either bilaterally or through other established mechanisms.

It is understood that capacity building in marine and coastal research is faced with many challenges (Morrison et al. 2013). Perhaps the most urgently applicable to ocean observations are the need for (1) a stronger alignment with societal and policy-relevant needs, (2) training in multidisciplinary observations from physics to biogeochemistry to biology and ecology, (3) increasing capacity for overall synthesis of scientific data, and (4) the sustained development of the individual along its career pathway and avoiding the 'brain drain' or desertion due to lack of working opportunities. From the information developed in this paper, it is clear that there have been significant efforts to sustain capacity development, however it success has been partial as huge gaps in knowledge still exist in the developing world. At present, it is not even possible to provide a full picture of national inventories on ocean science capacity due to human, technical and financial limitations (Isensee et al. 2017). For this reason, it is important to expand the current capacity-building approaches outside of the traditional areas. Citizen science for example, may be one way of addressing part of the sustainability needed for long-term observations. According to the World Bank (2017), various parts of the world where marine resources are greatly endangered, such as the Pacific island region, West Africa and South West Indian marine regions, need a coordinated intervention to tackle problems affecting their marine activities. This support can be engaged through capacity building from the regional IOC 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 (Miloslavich et al. 2018a), political will and economics will determine its success (Golden et al. 2017). Acquiring knowledge without the resources, infrastructure or technology to use it is not sufficient to improve sustainable use of the local marine environment. '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 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. We have learned that we cannot rely on a few Governments alone to fund all the sustained observations to the required level. We need all maritime and coastal nations within the IOC to make their contribution, but collaboration and partnerships with all stakeholders, in particular with industry will be critical to achieve success. The Decade of Ocean Science for Sustainable Development represents a great opportunity to build and consolidate the bridges between science, policy, society and industry. The observing community has been undergoing major reorganisations in recent years to ensure coordination, maximise resources and focus on societally relevant contributions. They are also looking at ways to expand the spatial coverage of observations by making them cheaper and more automated through collaboration with developers of innovative technologies and improved sensors (Miloslavich et al.

2018b). The observing community is ready for the challenge and prepared to deliver. What is needed now is the political will to secure the resources that will come hand in hand with their decisions, regardless of their source.

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References

Alexander V, Miloslavich P, Yarincik K. 2011. The census of marine life—evolution of worldwide marine biodiversity research. Mar Biodivers. 41:545–554. doi:10.1007/s12526-011-0084-1.

Althaus F, Hill N, Ferrari R, Edwards L, Przeslawski R, Schönberg CHL, et al. 2015. A standardised vocabulary for identifying benthic biota and substrata from underwater imagery: The CATAMI classification scheme. PloS One. 10: e0141039. doi:10.1371/journal.pone.0141039.

Barbière J, Heileman S. 2016. Intergovernmental oceanographic commission – UNESCO's support for management of large marine ecosystems. Environ Dev. 17:349–352. doi:10.1016/j.envdev.2015.08.001.

Bauer P, Thorpe A, Brunet G. 2015. The quiet revolution of numerical weather prediction. Nature. 525:47–55.

Beermann J, Boos K, Gutow L, Boersma M, Peralta AC. 2018. Combined effects of predator cues and competition define habitat choice and food consumption of amphipod mesograzers. Oecologia. 186:645–654. doi:10.1007/s00442-017-4056-4.

Bell JD, Ganachaud A, Gehrke PC, Griffiths SP, Hobday AJ, Hoegh-Guldberg O, et al. 2013. Mixed responses of tropical Pacific fisheries and aquaculture to climate change. Nat Clim Chang. 3:591–599. doi:10.1038/nclimate1838.

Benedetti-Cecchi L, Crowe T, Boehme L, Boero F, Christensen A, Grémare A, Hernandez F, Kromkamp JC, Nogueira García E, Petihakis G, et al. 2018. Strengthening Europe's Capability in Biological Ocean Observations. In: Muñiz Piniella A, Kellett P, Larkin K, Heymans JJ, editors. Future Science Brief 3 of the European Marine Board, Ostend, Belgium; p. 76.

Benson V, Tuninga R, Saridakis GL, editor.2017. Analyzing the strategic role of social networking in firm growth and productivity. IGI Global. doi:10.4018/978-1-5225-0559-4.

Bojinski S, Verstraete M, Peterson TC, Richter C, Simmons A, Zemp M. 2014. The concept of essential climate variables in support of climate research, applications, and policy. Bull Am Meteorol Soc. 95:1431–1443. doi:10.1175/BAMS-D-13-00047.1.

Carlisle KM. 2014. The large marine ecosystem approach: application of an integrated, modular strategy in projects supported by the global environment facility. Environ Dev. 11:19–42. doi:10.1016/j.envdev.2013.10.003.

Dunn DC, Maxwell SM, Boustany AM, Halpin PN. 2016. Dynamic ocean management increases the efficiency and efficacy of fisheries management. Proc Natl Acad Sci USA. 113:668–673. doi:10.1073/pnas.1513626113.

Edgar GJ, Stuart-Smith RD. 2014. Systematic global assessment of reef fish communities by the reef life survey program. Sci Data. 1. doi:10.1038/sdata.2014.7.

Edwards M, Healouet P, Johns D, Batten S, Beaugrand G, Chiba S, et al. 2012. Global marine ecological status report: results from the global CPR survey 2010/2011. Plymouth (UK). https://www.sahfos.ac.uk/media/1290/gacs-status-11-low-res.pdf.

Freiwald J, Meyer R, Caselle JE, Blanchette CA, Hovel K, Neilson D, et al. 2018. Citizen science monitoring of marine protected areas: case studies and recommendations for integration into monitoring programs. Mar Ecol. 39:e12470. doi:10.1111/maec.12470.

GEO BON. 2015. Bi-annual progress report 2014-2015. Leipzig: Group on Earth Observations Biodiversity Observation Network Secretariat. http://www.geobon.org/Downloads/biannual_progress_report/Biannual_progress_report_201415_high.pdf.

Gill DA, Mascia MB, Ahmadia GN, Glew L, Lester SE, Barnes M, et al. 2017. Capacity shortfalls hinder the performance of

marine protected areas globally. Nature. 543:665–669. doi:10.1038/nature21708.
Glegg G. 2014. Training for marine planners: present and future needs. Mar Policy. 43:13–20. doi:10.1016/j.marpol.2013.03.011.
Golden JS, Virdin J, Nowacek D, Halpin P, Bennear L, Patil PG. 2017. Making sure the blue economy is green. Nat Ecol Evol. 1:0017. doi:10.1038/s41559-016-0017.
Hempel G, Thulin J, Hermes R, Ekau W, Vousden D, O'Toole M. 2016. Large marine ecosystems training and capacity development. Environ Dev. 17:322–329. doi:10.1016/j.envdev.2015.07.005.
Hughes TP, Kerry JT, Álvarez-Noriega M, Álvarez-Romero JG, Anderson KD, Baird AH, et al. 2017. Global warming and recurrent mass bleaching of corals. Nature. 543:373–377.
Isensee K, Pae S, Horn L, Inaba K, Schaaper M, Valdés L. 2017. Research capacity and infrastructure. In: L. Valdés et al., editor. Global ocean science report - The current status of ocean science around the world. Paris: UNESCO; p. 54–79.
Johnson CR, Banks SC, Barrett NS, Cazassus F, Dunstan PK, Edgar GJ, et al. 2011. Climate change cascades: shifts in oceanography, species' ranges and subtidal marine community dynamics in eastern Tasmania. J Exp Mar Biol Ecol. 400:17–32. doi:10.1016/j.jembe.2011.02.032.
Krumhansl KA, Okamoto DK, Rassweiler A, Novak M, Bolton JJ, Cavanaugh KC, et al. 2016. Global patterns of kelp forest change over the past half-century. Proc Natl Acad Sci USA. 113:13785–13790. doi:10.1073/pnas.1606102113.
Langlois T, Harvey E, Fitzpatrick B, Meeuwig J, Shedrawi G, Watson D. 2010. Cost-efficient sampling of fish assemblages: comparison of baited video stations and diver video transects. Aquat Biol. 9:155–168. doi:10.3354/ab00235.
Last PR, White WT, Gledhill DC, Hobday AJ, Brown R, Edgar GJ, et al. 2011. Long-term shifts in abundance and distribution of a temperate fish fauna: a response to climate change and fishing practices: long-term shifts in a temperate fish fauna. Glob Ecol Biogeogr. 20:58–72. doi:10.1111/j.1466-8238.2010.00575.x.
Ling SD, Johnson CR, Frusher SD, Ridgway KR. 2009. Overfishing reduces resilience of kelp beds to climate-driven catastrophic phase shift. Proc Natl Acad Sci USA. 106:22341–22345. doi:10.1073/pnas.0907529106.
Lorenzoni L, Benway HM. 2012. *Global Intercomparability in a Changing Ocean: An International Time- Series Methods Workshop*, November 28- 30, 2012, (Bermuda Institute of Ocean Sciences,St.Georges, Bermuda). Ocean Carbon and Biogeochemistry (OCB) Program and International Ocean Carbon Coordination Project (IOCCP), 61 pp.
Malone TC, DiGiacomo PM, Gonçalves E, Knap AH, Talaue-McManus L, de Mora S. 2014. A global ocean observing system framework for sustainable development. Mar Policy. 43:262–272. doi:10.1016/j.marpol.2013.06.008.
Miloslavich P, Bax NJ, Simmons SE, Klein E, Appeltans W, Aburto-Oropeza O, et al. 2018a. Essential ocean variables for global sustained observations of biodiversity and ecosystem changes. Glb Chg Bio. 24:2416–2433. doi:10.1111/gcb.14108.
Miloslavich P, Pearlman F, Pearlman J, Muller-Karger F, Appeltans W, Batten S, et al. 2018b. Implementation of global, sustained and multidisciplinary observations of plankton communities. Paris (France): Intergovernmental Oceanographic Commission (IOC). http://goosocean.org/index.php?option=com_oe&task=viewDocumentRecord&docID=22500.
Morrison RJ, Zhang J, Urban ER, Hall J, Ittekkot V, Avril B, et al. 2013. Developing human capital for successful implementation of international marine scientific research projects. Mar Pollut Bull. 77:11–22. doi:10.1016/j.marpolbul.2013.09.001.
Muller-Karger FE, Miloslavich P, Bax NJ, Simmons S, Costello MJ, Sousa Pinto I, et al. 2018. Advancing marine biological observations and data requirements of the complementary essential ocean variables (EOVs) and essential biodiversity variables (EBVs) frameworks. Frontiers in Marine Science. 5. doi:10.3389/fmars.2018.00211.
Muller-Karger F, Roffer M, Walker N, Oliver M, Schofield O, Abbott M, et al. 2013. Satellite remote sensing in support of an integrated ocean observing system. IEEE Geoscience and Remote Sensing Magazine. 1:8–18. doi:10.1109/MGRS.2013.2289656.
Navarro LM, Fernández N, Guerra C, Guralnick R, Kissling WD, Londoño MC, et al. 2017. Monitoring biodiversity change through effective global coordination. Curr Opin Environ Sustain. 29:158–169. doi:10.1016/j.cosust.2018.02.005.
O'Brien T, Lorenzoni L, Isensee K, Valdés L. 2017. What are marine ecological time series telling us about the ocean? A status report. Paris: IOC-UNESCO.
OECD. 2016. The ocean economy in 2030. Paris: OECD Publishing. doi:10.1787/9789264251724-en.
Pearlman JS, Buttigieg PL, Simpson P, Mas CM, Heslop E, Hermes J. 2017. Accessing existing and emerging best practices for ocean observation a new approach for end-to-end management of best practices. In: OCEANS–Anchorage, 2017 (IEEE). p. 1–7.
Pietri DM, Stevenson TC, Christie P. 2015. The coral triangle initiative and regional exchanges: strengthening capacity through a regional learning network. Glob Environ Change. 33:165–176. doi:10.1016/j.gloenvcha.2015.05.005.
Poloczanska ES, Brown CJ, Sydeman WJ, Kiessling W, Schoeman DS, Moore PJ, et al. 2013. Global imprint of climate change on marine life. Nat Clim Chang. 3:919–925. doi:10.1038/nclimate1958.
Richardson AJ, Walne AW, John AWG, Jonas TD, Lindley JA, Sims DW, et al. 2006. Using continuous plankton recorder data. Prog Oceanogr. 68:27–74. doi:10.1016/j.pocean.2005.09.011.
Ruwa R, Ajawin A, Green S, Kamara OK, Rice J, Inniss L, et al. 2016. Capacity-building needs in relation to the status of species and habitats. Chapter 53. United Nations Division for Ocean Affairs and the Law of the Sea. http://www.un.org/depts/los/global_reporting/WOA_RPROC/Chapter_53.pdf.
Shackeroff Theisen JM, Atkinson SR, Awad A, Beaudoin Y, Canals P, Durussel C, et al. 2016. Capacity development for oceans, coasts, and the 2030 agenda. Institute for Advanced Sustainability Studies (IASS). doi:10.2312/iass.2016.017.
Stuart-Smith RD, Brown CJ, Ceccarelli DM, Edgar GJ. 2018. Ecosystem restructuring along the great barrier reef following mass coral bleaching. Nature. 560:92–96. doi:10.1038/s41586-018-0359-9.
Stuart-Smith RD, Edgar GJ, Barrett NS, Bates AE, Baker SC, Bax NJ, et al. 2017. Assessing national biodiversity trends for rocky and coral reefs through the integration of citizen

science and scientific monitoring programs. BioScience. 67:134–146. doi:10.1093/biosci/biw180.

UNESCO. 2016. IOC capacity development strategy (2015-2021). Paris. http://unesdoc.unesco.org/images/0024/002440/244047m.pdf.

UNESCO. 2017. In: L. Valdés et al., editor. Global ocean science report: the current status of ocean science around the world. Paris.

UNESCO-IOC. 2005. IOC criteria and guidelines on the transfer of marine technology (CGTMT). Paris: IOC Advisory Board of Experts of the Law of the Sea (IOC/ABE-LOS). http://unesdoc.unesco.org/images/0013/001391/139193m.pdf.

United Nations. 2016. First global integrated marine assessment (first world ocean assessment)-summary. New York: United Nations Division for Ocean Affairs and the Law of the Sea. http://www.un.org/depts/los/global_reporting/WOA_RPROC/Summary.pdf.

United Nations. 2017. Report of the united nations conference to support the implementation of sustainable development goal 14: conserve and sustainably use the oceans, seas and marine resources for sustainable development. New York: United Nations Headquarters. http://www.un.org/ga/search/view_doc.asp?symbol=A/CONF.230/14&Lang=E.

United Nations General Assemby (UNGA). 2012. Resolution 66/228. The future we want. New York: United Nations. http://www.un.org/ga/search/view_doc.asp?symbol=A/RES/66/288&Lang=E.

Urban E, Boscolo R. 2013. Using scientific meetings to enhance the development of early career scientists. Oceanography. 26. doi:10.5670/oceanog.2013.16.

Urban E, Seeyave S. In preparation. Developing capacity for ocean science in emerging regions through visiting scientists.

US Commission on Ocean Policy (USCOP). 2018. An ocean blueprint for the 21st century. Washington DC Available at: https://oceanconservancy.org/wp-content/uploads/2015/11/000_ocean_full_report-1.pdf.

Valdés L, Lee Y-H, Isensee K, Schaaper M. 2017. Research Productivity and Science Impact. In: Valdés L., editor. IOC-UNESCO, Global Ocean Science Report—The Current Status of Ocean Science Around the World. Paris: UNESCO; p. 98–125.

Vousden DH, Scott L. 2017. Large marine ecosystems and sustainable development: A review of strategic management processes and goals. New York: United Nations Development Program. https://www.google.com.au/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&ved=0ahUKEwi30_TD-v7ZAhXLgbwKHePCAYkQFggvMAE&url=http%3A%2F%2Fwww.undp.org%2Fcontent%2Fdam%2Fundp%2Flibrary%2FSustainable%2520Development%2FUNDP%2520Report%2C%2520Large%2520marine%2520ecosystem_WEB.PDF%3Fdownload&usg=AOvVaw2N2C1RC0N8VuY1oPAIxsSm.

Wernberg T, Russell BD, Thomsen MS, Gurgel CFD, Bradshaw CJA, Poloczanska ES, et al. 2011. Seaweed communities in retreat from ocean warming. Curr Biol. 21:1828–1832. doi:10.1016/j.cub.2011.09.028.

Wescott G. 2002. Partnerships for capacity building: community, governments and universities working together. Ocean Coastal Manage. 45:549–571. doi:10.1016/S0964-5691(02)00086-8.

Williams MJ, Ausubel J, Poiner I, Garcia SM, Baker DJ, Clark MR, et al. 2010. Making marine life count: A new baseline for policy. PLoS Biol. 8:e1000531. doi:10.1371/journal.pbio.1000531.

World Bank. 2017. Oceans, fisheries and coastal economies (BRIEF). World Bank Group; [accessed 2018 March 22]. http://www.worldbank.org/en/topic/environment/brief/oceans.