frontiers in Marine Science

PERSPECTIVE
published: 25 September 2018
doi: 10.3389/fmars.2018.00346

Linking Capacity Development to GOOS Monitoring Networks to Achieve Sustained Ocean Observation

Nicholas J. Bax[1,2]*, Ward Appeltans[3], Russell Brainard[4], J. Emmett Duffy[5], Piers Dunstan[2], Quentin Hanich[6], Harriet Harden Davies[6], Jeremy Hills[7], Patricia Miloslavich[1,8], Frank Edgar Muller-Karger[9], Samantha Simmons[10], O. Aburto-Oropeza[11], Sonia Batten[12], Lisandro Benedetti-Cecchi[13], David Checkley[11], Sanae Chiba[14], Albert Fischer[15], Melissa Andersen Garcia[4], John Gunn[16], Eduardo Klein[8], Raphael M. Kudela[17], Francis Marsac[18,19], David Obura[20], Yunne-Jai Shin[18,19], Bernadette Sloyan[2], Toste Tanhua[21] and John Wilkin[22]

[1] Institute for Marine and Antarctic Studies (IMAS), University of Tasmania, Hobart, TAS, Australia, [2] Oceans and Atmosphere, Commonwealth Scientific and Industrial Research Organisation, Canberra, ACT, Australia, [3] International Oceanographic Data and Information Exchange, United Nations Educational Scientific and Cultural Organization, Ostend, Belgium, [4] National Oceanic and Atmospheric Administration, Maryland, MD, United States, [5] Smithsonian Marine Station, The Smithsonian Institution, Florida, FL, United States, [6] Australian National Centre for Ocean Resources and Security (ANCORS), University of Wollongong, Wollongong, NSW, Australia, [7] Faculty of Science, Technology and Environment, University of the South Pacific, Suva, Fiji, [8] Departamento de Estudios Ambientales, Simón Bolívar University, Caracas, Venezuela, [9] College of Marine Science, University of South Florida, Tampa, FL, United States, [10] Marine Mammal Commission, Maryland, MD, United States, [11] SCRIPPS Institution of Oceanography, University of California, San Diego, San Diego, CA, United States, [12] SAFHOS, Vancouver, BC, Canada, [13] Dipartimento di Biologia, Università di Pisa, Pisa, Italy, [14] Japan Agency for Marine-Earth Science and Technology, Yokosuka, Japan, [15] United Nations Educational, Scientific and Cultural Organization, Paris, France, [16] Australian Institute of Marine Science, Crawley, WA, Australia, [17] Ocean Science Department, University of California, Santa Cruz, Santa Cruz, CA, United States, [18] Institut de Recherche pour le Développement (IRD), Université de Montpellier, UMR MARBEC, Montpellier, France, [19] Marine Research Institute, Department of Biological Sciences, University of Cape Town, Cape Town, South Africa, [20] Coastal Oceans Research and Development in the Indian Ocean, Mombasa, Kenya, [21] GEOMAR Helmholtz-Zentrum für Ozeanforschung Kiel, Helmholtz-Gemeinschaft Deutscher Forschungszentren (HZ), Kiel, Germany, [22] Institute of Marine and Coastal Sciences, Rutgers University, The State University of New Jersey, Brunswick, NJ, United States

OPEN ACCESS

Edited by:
Marion Gehlen, UMR8212 Laboratoire des Sciences du Climat et de l'Environnement (LSCE), France

Reviewed by:
Karen Stocks, University of California, San Diego, United States
Peter Wolfgang Swarzenski, IAEA, Environment Laboratories, Monaco

***Correspondence:**
Nicholas J. Bax
nic.bax@csiro.au

Specialty section:
This article was submitted to Ocean Observation, a section of the journal Frontiers in Marine Science

Received: *27 April 2018*
Accepted: *07 September 2018*
Published: *25 September 2018*

Citation:
Bax NJ, Appeltans W, Brainard R, Duffy JE, Dunstan P, Hanich Q, Harden Davies H, Hills J, Miloslavich P, Muller-Karger FE, Simmons S, Aburto-Oropeza O, Batten S, Benedetti-Cecchi L, Checkley D, Chiba S, Fischer A, Andersen Garcia M, Gunn J, Klein E, Kudela RM, Marsac F, Obura D, Shin Y-J, Sloyan B, Tanhua T and Wilkin J (2018) Linking Capacity Development to GOOS Monitoring Networks to Achieve Sustained Ocean Observation. Front. Mar. Sci. 5:346. doi: 10.3389/fmars.2018.00346

Developing enduring capacity to monitor ocean life requires investing in people and their institutions to build infrastructure, ownership, and long-term support networks. International initiatives can enhance access to scientific data, tools and methodologies, and develop local expertise to use them, but without ongoing engagement may fail to have lasting benefit. Linking capacity development and technology transfer to sustained ocean monitoring is a win-win proposition. Trained local experts will benefit from joining global communities of experts who are building the comprehensive Global Ocean Observing System (GOOS). This two-way exchange will benefit scientists and policy makers in developing and developed countries. The first step toward the GOOS is complete: identification of an initial set of biological Essential Ocean Variables (EOVs) that incorporate the Group on Earth Observations (GEO) Essential Biological Variables (EBVs), and link to the physical and biogeochemical EOVs. EOVs provide a globally consistent approach to monitoring where the costs of monitoring oceans can be shared and where capacity and expertise can be transferred globally. Integrating monitoring with existing international reporting and policy development connects ocean observations with agreements underlying many countries' commitments and obligations, including under SDG 14, thus catalyzing progress toward sustained use of the ocean. Combining scientific expertise with international capacity development initiatives can help meet the need of developing countries to engage in the agreed United Nations (UN) initiatives including new negotiations for the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction, and the needs of the global community to understand how the ocean is changing.

Keywords: capacity development, technology transfer, global ocean observing system, GOOS, monitoring, essential ocean variables, international reporting, SDG14

INTRODUCTION

The ocean provides essential services—food, transport, climate modulation, and recreation—for all nations, and particularly Small Island Developing States (SIDS) as recognized by Sustainable Development Goal 14 of the United Nations (UN) Agenda 2030.[1] However, ocean changes such as warming, increased stratification, decreasing dissolved oxygen (Rhein et al., 2013; Schmidtko et al., 2017) and changes in productivity (Stock et al., 2017) are adversely impacting human activities and marine life. Reliable, spatially distributed, and interdisciplinary information is increasingly important to measure progress against agreed targets and support decisions that balance increased economic activities with long-term sustainability. This could be achieved by linking efforts to build ocean-observing capacity in developing countries with the growing global sustained observation networks.

Measuring progress toward achieving agreed performance targets requires robust indicators of state and trends of ocean health, but such indicators have been challenging to select and implement for several reasons (Tittensor et al., 2014; Inniss et al., 2016). First, indicators selected by international bodies are often limited to measures of governance or management, due to the limited availability of global scale information on the state and trends of marine life and ecosystem health. Secondly, it has been difficult to reach scientific consensus on what aspects of the ocean's complex biological communities most need to be measured. Thirdly, scientific and technical capacity is unevenly split among nations (IOC/UNESCO, 2017). In order for indicators of ecological state and trends to be of use, they need to be systematically and widely collected for comparability among regions and utility among stakeholder groups (Tittensor et al., 2014). Much of the world's ocean lies within the Exclusive Economic Zones of developing nations that host most of the world's biodiversity (Appeltans et al., 2016), and effective implementation of a global observing system will require their active engagement.

The international ocean observation community has proposed a framework to promote convergence of methods and reporting, particularly on *in situ* sampling (Lindstrom et al., 2012). The ocean observation community is also steadily developing and establishing observing networks with global aspirations. In this perspective, we explore whether linking continuing knowledge exchange, capacity development and technology transfer to established global ocean observing networks would meet the need expressed in Sustainable Development Goal (SDG) 14a supporting countries' efforts to sustainably manage their ocean resources. We focus on scientific capacity development, including human, institutional, and technological capacity, where technology transfer includes access to hardware, software, data and information, and equipment (IOC/UNESCO, 2005). The development of capacity would not only enable developing countries to manage their own resources more effectively, but also build the global scientific capacity to monitor, manage, and adapt to ocean change.

[1] https://sustainabledevelopment.un.org/sdg14

GLOBAL MARINE POLICY ENVIRONMENT

The world's oceans are faced with increasingly complex problems spanning different scientific domains and national jurisdictions (Ramirez-Llodra et al., 2011; Gjerde et al., 2013; Merrie et al., 2014). SDG14 is an international policy response to these "wicked problems" (Rittel and Webber, 1973), capturing the wide range of international aspirations for the conservation and sustainable use of marine resources and, through SDG14.7, recognizing their global importance for achieving all other SDGs (Singh et al., 2018). However, the fragmented and increasingly complex ocean governance framework, comprising a plethora of international legal instruments (Ardron et al., 2014; Warner, 2014; **Figure 1**) creates a complicated reporting environment for governments and a high demand for scientific information to underpin the design, monitoring, and evaluation of policy and implementation.

Meeting this information need requires a radical transformation in the way in which scientific information is acquired, made accessible, used, and reused. Increased capacity at national, regional and global levels to acquire and analyse relevant data will be required if all States are to participate equally. While indicators can be developed, applying them in effective management requires that data are synthesized into information that is useful for managers and policy makers, and reported in a standard and understandable way. However, there is a disconnect between the international legal and policy framework and the reality of global ocean science collaboration, capacity development, and technology transfer.

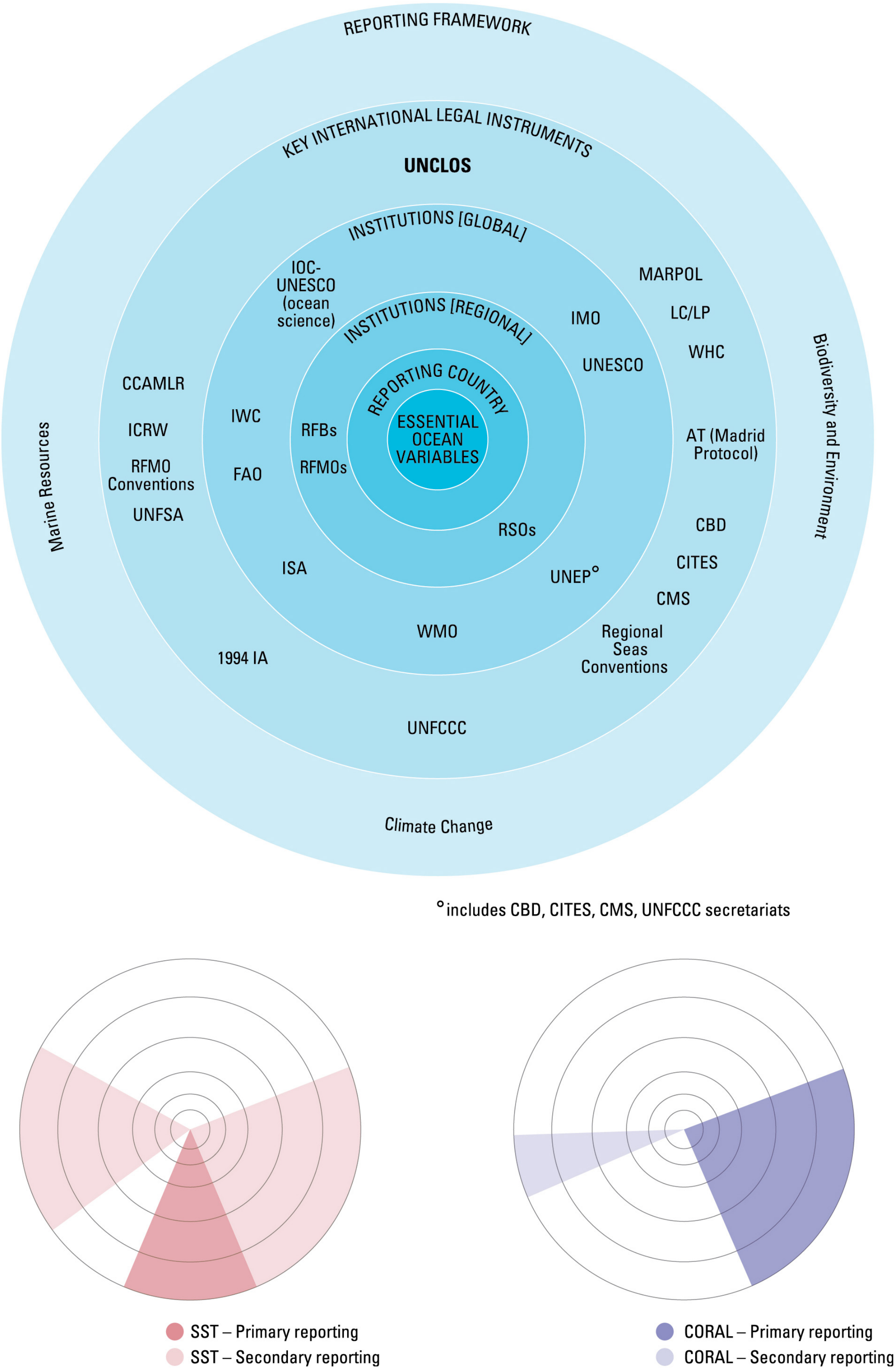

FIGURE 1 | Continued

FIGURE 1 | Reporting pathways for EOVs in major regional and global conventions and agreements, with examples of the primary and secondary reporting areas for the Sea Surface Temperature (SST), and Live Coral Cover EOVs. EOVs are reported through different national agencies (not shown) before being reported internationally. Regional institutions include: Regional Fisheries Bodies (RFBs), Regional Fisheries Management Organizations (RFMOs), and Regional Sea Organizations (RSOs). Global institutions include: Intergovernmental Oceanographic Commission (IOC-UNESCO), International Whaling Commission (IWC), Food and Agriculture Organization of the UN (FAO), International Seabed Authority (ISA), World Meteorological Organization (IMO), UN Environment (UNEP), and International Maritime Organization (IMO). Key international legal instruments include the UN Convention on the Law of the Sea (UNCLOS) that is described as the constitution for the oceans and provides the context for other instruments including: Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR), International Convention for the Regulation of Whaling (ICRW), UN Fish Stocks Agreement (UNFSA), and Agreement on the Implementation of Part XI of the Convention that refers to the International Seabed Area (1994 IA), UN Framework Convention on Climate Change (UNFCCC), Convention on Migratory Species (CMS), Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), Convention on Biological Diversity (CBD), 1991 Protocol on Environmental Protection to the Antarctic Treaty, Madrid Protocol (AT), World Heritage Convention (WHC), Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, London Convention/London Protocol (LC/LP), and International Convention for the Prevention of Pollution form Ships (MARPOL).

Reporting requirements for countries are extensive, duplicative, and often conflicting; the European Environment Agency for example lists 146 national reporting obligations for "biodiversity change and nature" for European Union Member States http://dx.doi.org/10.1016/j.marpol.2017.05.030. These exhaustive reporting requirements place an undue burden on many countries (FFA, 2017), especially developing countries, many of which have limited technical capacity. The problem is exacerbated because global funding sources such as the World Bank or Global Environment Facility often link funding to the production of these reports. Further, progress toward global goals and targets, defined by high-level government officials and experts, is measured with highly technical and aggregated summary statistics, which are not readily usable by many stakeholders and do not always enable the evaluation of policy measures. Efforts through donor countries and philanthropic organizations risk becoming even more confounded as funding becomes increasingly diversified (California Environmental Associates, 2017). It might be hoped that these many similar reports would share common data and syntheses, yet this is rarely the case.

Solutions to these challenges require an enabling framework for science collaboration, technology transfer and capacity development. Although the international legal framework for marine scientific research under the United Nations Convention on the Law of the Sea (UNCLOS) is linked to technology transfer and capacity development https://sustainabledevelopment.un.org/post2015/moiandglobalpartnership, there is no specific institutional or financial mechanism. The International Oceanographic Commission (IOC) under the UN Educational Scientific and Cultural Organization (UNESCO) provides a leading role in coordinating marine scientific research, transferring technology and developing capacity. Resources to fully implement the IOC programs are inadequate, however, both for the IOC Secretariat (about 2% of UNESCO budget) and the national or regional implementation of IOC programs (Ardron et al., 2014; Warner, 2014; Harden-Davies, 2016). To be meaningful, such programs must boost national and regional capacity where it is needed, but vulnerabilities in the current system must first be overcome. These arise from the fact that most ocean observing initiatives, while globally and regionally coordinated, typically compete for national funding in an environment that does not encourage broader coordination.

Crucially, technology development, transfer, and capacity development to enable the sustainable use of the oceans must focus on actionable information. Such information requires a focus on elements of the ocean that are most relevant to the global community such as fisheries and living habitat, as well as the supporting physical and biogeochemical environment. EOVs provide a clear opportunity to focus on an agreed set of information that would assist countries in their international reporting obligations, while supporting national management, and policy development (Lindstrom et al., 2012).

MARINE OBSERVING COMMUNITY

There is an urgent need to measure the ecological response of the biological community to the ongoing physical and biogeochemical changes to inform progress against Agenda 2030 and the many international reporting pathways (**Figure 1**). Despite recent improvement in documenting trends in the drivers of change (Halpern et al., 2017), however, and some early successes in forecasting abundance and distribution of marine life from physical forcing (Payne et al., 2017), few marine ecological assessments include long time series of data (Miloslavich et al., 2018). Most are limited by geographic range and taxonomic representation, with only modest global progress made in agreeing the primary indicators of marine biodiversity or methods to measure them The most common assessments of life in the sea are for fisheries resources through the Food and Agriculture Organization of the UN, Regional Fisheries Bodies, national assessment institutions, and some assessments that focus on marine mammals, sharks, sea birds, turtles, plankton, and coral reefs.

There is considerable scope for marine ecologists to acquire more timely and relevant measurements. Rapid advances in assessing the physical state of the ocean by satellite supported by *in situ* observations, such as the 3800 Argo robotic floats, and 300 biogeochemical Argo robotic floats that upload data within 24 h (Gould et al., 2004), will require increased and more standardized observing and improved delivery of data to interested parties. A large fraction of marine environmental data collected today is not available in a timely manner, if at all, through open access databases and varies widely in format (Tenopir et al., 2015), it is often overlooked in national and global assessments. Developing countries, in particular, typically lack the personnel, financial resources, and technical expertise to collect observations, much less to process and publish them in international databases, and rarely have the human or infrastructure capacity to access the available open data.

The global ocean observing community is providing guidance and incentives for researchers to systematize and share their measurements. The Framework for Ocean Observing published in 2012 (Lindstrom et al., 2012) outlines a series of standards, and a process through which EOVs can be identified and progressed from conceptual through prototype to a mature level where they support global observation and reporting (Constable et al., 2016). The usefulness of the Ocean Biogeographic Information System as a general repository for marine biodiversity data is being substantially upgraded (Appeltans et al., 2016; De Pooter et al., 2017). Collaboration with the Marine Biodiversity Observation Network and the Smithsonian's MarineGEO observatory (Duffy et al., 2013; Muller-Karger et al., 2014) is helping to develop an integrated and practical pathway toward a Global Ocean Observing System (GOOS) that includes biological measurements supported by existing physical and biogeochemical EOVs.

In future, improving understanding of the condition of the ocean will require: sustained engagement of national stakeholders; capacity development; standardized methodologies; increased sampling effort; improved access to historical, and new data; consistent measurements that are relevant to management and policy decisions; appropriate model-based analytical capacity to synthesize scientific data into relevant information products; and continued efforts to enable uptake of relevant information into national and global decision-making processes.

ESSENTIAL OCEAN VARIABLES

In the past two decades, IOC-GOOS has worked closely with the Joint World Meteorological Organization–IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM) and the Global Climate Observing System (GCOS) to coordinate global climate observing and information products. The focus on Essential Climate Variables (Stephan et al., 2014) was successful in coordinating the international research community and communicating important physical indicators of the changing ocean such as ocean temperature, salinity, and sea surface height. This concept was adopted in the Framework for Ocean Observing that has at its core EOVs that are defined as an interdisciplinary, feasible set of observations needed to characterize change and improve predictive skills for identifying and communicating ocean state and trend (Lindstrom et al., 2012).

In the past decade, the addition of biogeochemical EOVs (e.g., dissolved oxygen, nutrients, inorganic carbon and dissolved organic carbon), has broadened the approach from strictly climate-related issues to include other issues impacting the ocean (Feely et al., 2004). These measurements across domains are critical to understanding the changing ocean state and the processes driving these changes. Examples include ocean acidification driven by the ocean's uptake of anthropogenic carbon and the increasing size of dissolved oxygen minimum zones which are the habitat volume of the ocean for many organisms.

Since 2013, IOC-GOOS has worked to identify biological EOVs based on societal need for information, their scientific relevance and scalability (Miloslavich et al., 2018).The selected EOVs are broad in scope, societally relevant, capitalize on a long history of ocean observations and prioritize key components of benthic and pelagic environments. Together with the established physical and biogeochemical EOVs (**Table 1**), they would provide a comprehensive picture of the state and trends of the ocean that would be of immediate relevance for national management and global reporting. It is anticipated that the same framework used above will be used to identify additional biological EOVs, such as marine microbes or genetic diversity, as science and technology advance and new observation types become part of policy and management discussions.

The biological EOVs depend on the measurement of a series of more specific sub-variables, many of which correspond to EBVs as defined by the Group on Earth Observations Biodiversity Observation Network (GEO BON) (Pereira et al., 2013). Coordination of ocean relevant EBVs within the EOV framework is imperative to avoid duplication, maintain consistency and ensure they achieve the goal of reporting on progress toward achieving SDGs (Reyers et al., 2017).

CAPACITY DEVELOPMENT AND TECHNOLOGY TRANSFER

National inventories of ocean science capacity exist only in a few countries (IOC/UNESCO, 2017). Building scientific capacity, including local scientific expertise and suitable data management systems, is crucial to realizing the benefits from ongoing research results and data (Salpin et al., 2016). But SIDS and Least Developed Countries (LDCs) often do not even have sufficient vessels and deployable technologies to conduct ocean observations and research. Furthermore, biological processes are localized and context-dependent so typically need more *in situ* observations than physical and biogeochemical processes. Building such time-series observations is hampered in SIDS and LDCs by a lack of long-term resource commitment. Sustained observing requires a coordinated, collaborative and culturally appropriate process, incorporating indigenous and local knowledge, with long-term resourcing that meets identified local, national and regional needs (Veitayaki and South, 2001; Keppel et al., 2012; Veitayaki and Manoa, 2014).

Traditionally, capacity development focused on project-based needs, rather than strategic capacity development, resulting in disconnected and ephemeral activities (National Research Council, 2008). Successful capacity development efforts need

TABLE 1 | Essential Ocean Variables (EOVs) identified by the UNESCO/IOC Global Ocean Observing System (www.goosocean.org/eov, accessed 2/8/18).

Physics	Biogeochemistry	Biology and Ecosystems
Sea state	Oxygen	Phytoplankton biomass and diversity
Ocean surface stress	Nutrients	Zooplankton biomass and diversity
Sea ice	Inorganic carbon	Fish abundance and distribution
Sea surface height	Transient tracers	Marine turtle, bird and mammals abundance and distribution
Sea surface temperature	Particulate matter	Hard coral cover and composition
Subsurface temperature	Nitrous oxide	Seagrass cover
Surface currents	Stable carbon isotopes	Macroalgal canopy
Subsurface currents	Dissolved organic carbon	Mangrove cover
Sea surface salinity	Ocean color	
Subsurface salinity		
Ocean surface heat flux		

EmergingEOVs include Microbe biomass and diversity, and Benthic invertebrate abundance and distribution.

to engage and receive support from local communities, key stakeholders, and national leaders, and include sustainability plans to maintain and grow the capacity with regular employment. It must also be regularly reviewed (National Research Council, 2008). This may be more than the training, education, mutual assistance approach initiated by IOC and used in Large Marine Ecosystem (LME) projects globally (Hempel et al., 2016). Long-term engagement, repeated intervention, and mentoring are some of the processes that can help in building the relationships that are often more important than the knowledge imparted at the time.

Political will and international partnerships will be crucial to overcoming the resource constraints that currently restrict the capacity of IOC, and its regional sub-commissions such as IOC-Sub-Commission for the Western Pacific, to deliver the strategy (Harden-Davies, 2016).

Pacific Island countries have recognized the importance of sustained marine scientific capacity development programs and technology transfer programs(Veitayaki and South, 2001; Veitayaki and Manoa, 2014). The Pacific Islands Forum Fisheries Agency and the Secretariat of the Pacific Community have a long history of implementing and supporting data collection and reporting programs that enable SIDS members to monitor fishing effort and impacts within their extensive waters under national jurisdiction, and in adjacent areas beyond national jurisdiction (Harden-Davies, 2016). These data are analyzed by these regional institutions, through capacity building programs that mentor government officials and provide critical support for governments as they manage and monitor fishing activities and impacts (Hanich and Tsamenyi, 2009). Technology transfer, facilitates these activities, including sophisticated maritime domain open-source access to satellite databases, such as the automatic identification system for fishing vessels (Hanich et al., 2008; Goodman, 2017). These efforts are mandated and owned by the SIDS themselves and align closely with SIDS development priorities, which collectively empower SIDS to voluntarily commit institutional and national resources in deciding where, how, and what to monitor. The approach is long term and programmatic in nature, with a regional institutional focus on development and strengthening sovereign rights, and a flexible approach that works within diverse national contexts and regionally agreed reporting frameworks (McNulty, 2013). Given the high dependence of this region on coral reefs and trans-boundary fisheries (FFA/SPC, 2015), and the inherent limited capacity of Pacific SIDS (Hanich and Tsamenyi, 2009), these collective approaches that link data collection and capacity development are fundamental to the ocean observing needed to inform management decisions.

A similar regionally focused country-led and integrated approach has been used by the IOC Sub-Commission for the West Pacific (WESTPAC) to establish an interdisciplinary observing network to monitor the ecological impacts of ocean acidification on coral reefs. It provides a good example of using the EOV approach to build regional and global capacity. WESTPAC works closely with aligned countries of Southeast Asia and the Coral Triangle, the United States. National Oceanic and Atmospheric Administration, and the Global Ocean Acidification Observing Network (GOA-ON). Developing local capacity was supported by engaging with GOA-ON to provide consistent, comparable, and cost-effective standard operating procedures that built on existing regional capacity and programs. These were introduced and tested in the laboratory and at pilot sites through a series of regional and national training and scientific workshops including the transfer of knowledge and technology among experts and institutions within and outside the region. Workshops continue to review the lessons learnt from implementing the agreed approach while identifying partnership building opportunities to further expand the program and associated research opportunities.

The importance of capacity development and technology transfer has been clearly expressed at many UN meetings. The World Ocean Assessment noted a gap in capacity for integrated assessment of the marine environment (Inniss et al., 2016). Similarly, a review of the LME program identified a critical need to intensify efforts to build capacity for developing countries and in particular SIDS and LDCs (Vousden and Scott, 2017).Capacity development is a key element in current negotiations under UNCLOS to develop a legally binding implementing agreement to conserve and sustainably use marine biodiversity in areas beyond national jurisdiction. Capacity development is also vital for robust management and regulation of emerging and potentially impactful ocean activities such as deep sea mining (Bradley and Swaddling, 2016; Bourrel et al., 2017). The IOC criteria and guidelines for the transfer of marine technology outline the necessary components that could link national efforts to a global monitoring system (IOC/UNESCO, 2005).

The call for action from the UN SDG14 Oceans Conference http://www.un.org/ga/search/view_doc.asp?symbol=A/RES/71/312&Lang=E, recognized the need for global collaboration and the need to support SIDS and LDCs in particular. Linking global observing networks and their expertise with local capacity development based on national need provides a mechanism to shape and unite progress toward sustainable ocean development. The UN Decade of Ocean Science for Sustainable Development (2021–2030) provides a time frame to achieve a globally integrated ocean observing system.

AUTHOR CONTRIBUTIONS

NB conceived and contributed to writing. WA, RB, JED, PD, QH, HHD, JH, PM, FM-K, and SS contributed to conception and writing. OA-O, SB, LB-C, DC, SC, AF, MAG, JG, EK, RK, FM, DO, Y-JS, BS, TT, and JW contributed to writing.

REFERENCES

Appeltans, W., Dujardin, F., Flavell, M., Miloslavich, P., and Webb, T. J. (2016). *Biodiversity Baselines in The Global Ocean. The Open Ocean: Status and Trends*, Paris: UNESCO, 206–223.

Ardron, J. A., Rayfuse, R., Gjerde, K., and Warner, R. (2014). The sustainable use and conservation of biodiversity in ABNJ: what can be achieved using existing international agreements? *Mar. Policy* 49, 98–108. doi: 10.1016/j.marpol.2014.02.011

Bourrel, M., Swaddling, A., Atalifo, V., and Tawake, A. (2017). Building in-country capacity and expertise to ensure good governance of the deep sea minerals industry within the Pacific region. *Mar. Policy* 95, 372–379. doi: 10.1016/j.marpol.2017.03.022

Bradley, M., and Swaddling, A. (2016). Addressing environmental impact assessment challenges in Pacific island countries for effective management of deep sea minerals activities. *Mar. Policy* 95, 356–362. doi: 10.1016/j.marpol.2016.06.017

California Environmental Associates (2017). *Our Shared Seas: Overview of Ocean Threats and Conservation Funding*. Los Altos, CA: David and Lucille Packard Foundation.

Constable, A. J., Costa, D. P., Schofield, O., Newman, L., Urban, E. R., Fulton, E. A., et al. (2016). Developing priority variables ("ecosystem Essential Ocean Variables" eEOVs) for observing dynamics and change in Southern Ocean ecosystems. *J. Mar. Syst.* 161, 26–41. doi: 10.1016/j.jmarsys.2016.05.003

De Pooter, D., Appeltans, W., Bailly, N., Bristol, S., Deneudt, K., Eliezer, M., et al. (2017). Toward a new data standard for combined marine biological and environmental datasets - expanding OBIS beyond species occurrences. *Biodivers. Data J.* 5:e10989. doi: 10.3897/BDJ.5.e10989

Duffy, J. E., Amaral-Zettler, L. A., Fautin, D. G., Paulay, G., Rynearson, T. A., Sosik, H. M., et al. (2013). Envisioning a marine biodiversity observation network. *Bioscience* 63, 350–361. doi: 10.1525/bio.2013.63.5.8

Feely, R. A., Sabine, C. L., Lee, K., Berelson, W., Kleypas, J., Fabry, V. J., et al. (2004). Impact of anthropogenic CO2 on the CaCO3 system in the oceans. *Science* 305, 362–366. doi: 10.1126/science.1097329

FFA (2017). *Independent Review of FFA's Performance*. Honiara: Pacific Islands Forum Fisheries Agency.

FFA/SPC (2015). *Future of Fisheries: A Regional Roadmap for Sustainable Pacific Fisheries*. Honiara: Pacific Islands Forum Fisheries Agency.

Gjerde, K. M., Currie, D., Wowk, K., and Sack, K. (2013). Ocean in peril: reforming the management of global ocean living resources in areas beyond national jurisdiction. *Mar. Pollut. Bull.* 74, 540–551. doi: 10.1016/j.marpolbul.2013.07.037

Goodman, C. (2017). "The cooperative use of coastal state jurisdiction with respect to highly migratory stocks: insights from the western and central pacific region," in *Natural Resources and the Law of the Sea: Exploration, Allocation, Exploitation of Natural Resources in Areas under National Jurisdiction and Beyond*, eds L. Martin, C. Salonidis, and C. Hioureas (New York, NY: Juris), 474.

Gould, J., Roemmich, D., Wijffels, S., Freeland, H., Ignaszewsky, M., Jianping, X., et al. (2004). Argo profiling floats bring new era of in situ ocean observations. *Eos Trans. Am. Geophys. Union* 85, 185–191. doi: 10.1029/2004EO190002

Halpern, B. S., Frazier, M., Afflerbach, J., O'Hara, C., Katona, S., Stewart Lowndes, J. S., et al. (2017). Drivers and implications of change in global ocean health over the past five years. *PLoS One* 12:e0178267. doi: 10.1371/journal.pone.0178267

Hanich, Q., Teo, F., and Tsamenyi, M. (2008). *Closing The Gaps: Building Capacity In Pacific Fisheries Governance And Institutions*. Honiara: Pacific Islands Forum Fisheries Agency.

Hanich, Q., and Tsamenyi, M. (2009). "Developments in cooperative approaches to fisheries management in the pacific islands region," in *From Hook to Plate: The State of Marine Fisheries. A Commonwealth Perspective*, eds R. Bourne, N. M. Collins (London: Commonwealth Foundation), 69–86.

Harden-Davies, H. (2016). Marine science and technology transfer: can the intergovernmental oceanographic commission advance governance of biodiversity beyond national jurisdiction? *Mar. Policy* 74, 260–267. doi: 10.1016/j.marpol.2016.10.003

Hempel, G., Thulin, J., Hermes, R., Ekau, W., Vousden, D., and O'Toole, M. (2016). Large marine ecosystems training and capacity development. *Environ. Dev.* 17, 322–329. doi: 10.1016/j.envdev.2015.07.005

Inniss, L., Simcock, A., Ajawin, A. Y., Alcala, A. C., Bernal, P., Calumpong, H. P., et al. (2016). *The First Global Integrated Marine Assessment: World Ocean Assessment I*. Cambridge: Cambridge University Press.

IOC/UNESCO (2005). *IOC Criteria and Guidelines on The Transfer of Marine Technology*. Paris: IOC-ABE-LOS.

IOC/UNESCO (2017). *Global Ocean Science Report: The Current Status of Ocean Science Around the World*. Paris: UNESCO.

Keppel, G., Morrison, C., Watling, D., Tuiwawa, M. V., and Rounds, I. A. (2012). Conservation in tropical Pacific Island countries: why most current approaches are failing. *Conserv. Lett.* 5 256–265. doi: 10.1111/j.1755-263X.2012.00243.x

Lindstrom, E., Gunn, J., Fischer, A., McCurdy, L. K., and Glover, A. (2012). *A Framework for Ocean Observing. IOC Information Document*. Paris: UNESCO. doi: 10.5270/OceanObs09-FOO

McNulty, J. (2013). Western and central pacific ocean fisheries and the opportunities for transnational organized crime: monitoring, control and surveillance (mcs) operation kurukur. *Aust. J. Marit. Ocean Aff.* 5, 145–152. doi: 10.1080/18366503.2013.10815747

Merrie, A., Dunn, D. C., Metian, M., Boustany, A. M., Takei, Y., Elferink, A. O., et al. (2014). An ocean of surprises –trends in human use, unexpected dynamics and governance challenges in areas beyond national jurisdiction. *Glob. Environ. Chang.* 27, 19–31. doi: 10.1016/j.gloenvcha.2014.04.012

Miloslavich, P., Bax, N., Simmons, S., Klein, E., Appeltans, W., Aburto-Oropeza, O., et al. (2018). Essential ocean variables for sustained observations of marine biodiversity and ecosystems. *Glob. Chang. Biol.* 24, 2416–2433. doi: 10.1111/gcb.14108

Muller-Karger, F. E., Kavanaugh, M. T., Montes, E., Balch, W. M., Breitbart, M., Y. A., et al. (2014). A framework for a marine biodiversity observing network within changing continental shelf seascapes. *Oceanography* 27, 18–23. doi: 10.5670/oceanog.2014.56

National Research Council (2008). *Increasing Capacity for Stewardship of Oceans and Coasts: A priority fo rhte 21st Century*. Washington, DC: The National Academic Press.

Payne, M. R., Hobday, A. J., MacKenzie, B. R., Tommasi, D., Dempsey, D. P., Fassler, S., et al. (2017). Lessons from the first generation of marine ecological forecast products. *Front. Mar. Sci.* 4:289. doi: 10.3389/fmars.2017.00289

Pereira, H. M., Ferrier, S., Walters, M., Geller, G. N., Jongman, R., H. G., et al. (2013). Essential biodiversity variables. *Science* 339, 277–278. doi: 10.1126/science.1229931

Ramirez-Llodra, E., Tyler, P. A., Baker, M. C., Bergstad, O. A., Clark, M. R., Escobar, E., et al. (2011). Man and the last great wilderness: human impact on the deep sea. *PLoS One* 6:e22588. doi: 10.1371/journal.pone.0022588

Reyers, B., Stafford-Smith, M., Erb, K.-H., Scholes, R. J., and Selomane, O. (2017). Essential variables help to focus sustainable development goals monitoring. *Curr. Opin. Environ. Sustain.* 26, 97–105. doi: 10.1016/j.cosust.2017.05.003

Rhein, M., Rintoul, S. R., Aoki, S., Campos, E., Chambers, D., Feely, R. A., et al. (2013). "Observations: ocean," in *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, eds T. F. Stocker, D. Qin, G. K. Plattner, M. M. B. Tignor, S. K. Allen, and J. Boschung (Cambridge: Cambridge University Press), 1535.

Rittel, H. W. J., and Webber, M. M. (1973). Dilemmas in a general theory of planning. *Policy Sci.* 4, 155–169. doi: 10.1007/BF01405730

Salpin, C., Onwuasoanya, V., Bourrel, M., and Swaddling, A. (2016). Marine scientific research in pacific small island developing states. *Mar. Policy* 95, 363–371. doi: 10.1016/j.marpol.2016.07.019

Schmidtko, S., Stramma, L., and Visbeck, M. (2017). Decline in global oceanic oxygen content during the past five decades. *Nature* 542, 335–339. doi: 10.1038/nature21399

Singh, G. G., Cisneros-Montemayor, A. M., Swartz, W., Cheung, W., Guy, J. A., Kenny, T.-A., et al. (2018). A rapid assessment of co-benefits and trade-offs among Sustainable Development Goals. *Mar. Policy* 93, 223–231. doi: 10.1016/j.marpol.2017.05.030

Stephan, B., Michel, V., Thomas, C. P., Carolin, R., Adrian, S., and Michael, Z. (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

Stock, C. A., John, J. G., Rykaczewski, R. R., Asch, R. G., Cheung, W. W., Dunne, J. P., et al. (2017). Reconciling fisheries catch and ocean productivity. *Proc. Natl. Acad. Sci. U.S.A.* 114, E1441–E1449. doi: 10.1073/pnas.1610238114

Tenopir, C., Dalton, E. D., Allard, S., Frame, M., Pjesivac, I., Birch, B., et al. (2015). Changes in data sharing and data reuse practices and perceptions among scientists worldwide. *PLoS One* 10:e0134826. doi: 10.1371/journal.pone.0134826

Tittensor, D. P., Walpole, M., Hill, S. L. L., Boyce, D. G., Britten, G. L., Burgess, N. D., et al. (2014). A mid-term analysis of progress toward international biodiversity targets. *Science* 346, 241–244. doi: 10.1126/science.1257484

Veitayaki, J., and Manoa, P. E. (2014). "Building Capacity in the Marine Sector in the Pacific Islands and the role of The University of the South Pacific," in *Higher Education and Community Engagement in the Pacific. Development and Policy Issues*, eds M. R. Dakuidreketi and G. I. Lingam (Suva: University of the South Pacific Press), 71–91.

Veitayaki, J., and South, G. R. (2001). Capacity building in the marine sector in the pacific islands: the role of the university of the south pacific's marine studies programme. *Mar. Policy* 25, 437–444. doi: 10.1016/S0308-597X(01)00028-8

Vousden, D. H., and Scott, L. (2017). Large marine ecosytems and sustainable development: a review of strategic management processes and goals. New York, NY: United Nations Development Program.

Warner, R. M. (2014). Conserving marine biodiversity in areas beyond national jurisdiction: co-evolution and interaction with the law of the sea. *Front. Mar. Sci.* 1, 1–23. doi: 10.3389/fmars.2014.00006

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The reviewer KS declared a shared affiliation, with no collaboration, with the authors DC and OA-O to the handling Editor at the time of review.