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Science Collaboration for Capacity Building: Advancing Technology Transfer Through a Treaty for Biodiversity Beyond National Jurisdiction

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Marine technology transfer and capacity building are key elements in the development of a historic new agreement for the conservation and sustainable use of marine biodiversity in areas beyond national jurisdiction (BBNJ agreement) under the United Nations Convention on the Law of the Sea (UNCLOS). This vast, deep ocean area remains largely unexplored and poorly understood. Scientific knowledge gaps impede informed decision-making, and most countries lack the capacity to participate in ocean science activities in ABNJ or to benefit from discoveries of new ocean life, habitats, and processes. Consequently, science must play a central role in capacity building aspirations, however, the link between technology transfer and marine scientific research has yet to be examined in depth. Here, we examine the UNCLOS framework for marine technology transfer and highlight linkages with marine scientific research, identifying four capacity building themes: access to data, information and knowledge; equipment; training; and collaboration. We provide examples to illustrate current practices and identify gaps in implementation. We show that marine technology transfer and marine scientific research link in principle and in practice. We propose ways that the BBNJ agreement could strengthen the international framework for the transfer of marine technology in order to boost marine scientific research collaboration, fill knowledge gaps, and strengthen capacity through inclusive international participation.

Keywords: marine scientific research, marine technology transfer, capacity building, high seas, biodiversity beyond national jurisdiction, ocean governance

INTRODUCTION

Scientific research continues to reveal novel biological diversity from the 64% of the ocean that lies in areas beyond national jurisdiction (ABNJ) that is intricately connected (Danovaro et al., 2017), provides crucial ecosystem services (Ramirez-Llodra et al., 2010; Levin and Le Bris, 2015), and inspires innovation (Snelgrove, 2016) but faces threats from human activities (Merrie et al., 2014). The international community critically depends on science and technology to address such threats because scientific knowledge gaps impede informed decision-making (Rogers et al., 2014). Furthermore, while advancing scientific knowledge brings opportunities for new discoveries (Danovaro et al., 2014), inequity in scientific and technological capacity (IOC, 2017a) prevents many nations from participating in, and benefitting from, scientific research and potential associated benefits within ABNJ (Salpin et al., 2016). Consequently, the development of a new international legally binding instrument for the conservation and sustainable use of marine biological diversity in areas beyond national jurisdiction (BBNJ agreement) under the United Nations Convention on the Law of the Sea (UNCLOS; UNGA, 2017a) includes technology transfer and capacity building as key objectives.

Technology transfer has long been lamented as one of the most under-implemented areas of UNCLOS (Long, 2007). Many experts believe that the BBNJ agreement offers a historic opportunity to strengthen the international framework, including for capacity building and technology transfer, to better support the conservation and sustainable use of biodiversity (Warner, 2014; Wright et al., 2018). The BBNJ negotiations focus primarily on scientific and technological aspects of capacity building and the technology and cooperation mechanisms required to enable States to fulfill their rights and responsibilities (Long and Rodriguez Chaves, 2015; Wright et al., 2019). For example, "developing marine scientific and technological capacity" and "increasing, disseminating and sharing knowledge," with regard to the conservation and sustainable use of BBNJ, are among the key objectives for capacity building and technology transfer presented in Article 42 of the first draft text of the BBNJ agreement (BBNJ, 2019). The third session of the BBNJ intergovernmental conference appeared to achieve broad consensus that capacity building and technology transfer should take place at all levels and in several forms (IISD, 2019) including: the sharing of data, information and knowledge; infrastructure; and human resources, as per Article 46 of the first draft BBNJ agreement (BBNJ, 2019). However, divergences in views persist on achieving technology transfer and capacity building, including whether measures should be voluntary or mandatory (IISD, 2019). Articles 44, 45, and 46 of the draft text emphasize cooperation as pivotal to achieving capacity building and technology transfer in BBNJ (2019), but the text is otherwise light on implementation mechanisms.

All four elements of the BBNJ agreement critically depend on science: (i) area-based management tools, including marine protected areas; (ii) environmental impact assessments; (iii) marine genetic resources, including sharing of benefits; and (iv) capacity building and marine technology transfer. Scientific expertise and information is particularly vital for environmental impact assessments and the designation, implementation, and monitoring of area-based management tools. Furthermore, access to, and use of, marine genetic resources hinges upon scientific capacity (Broggiato et al., 2014, 2018; Harden-Davies and Gjerde, 2019). Promoting marine scientific research therefore adds a critical priority for the BBNJ agreement that poses a particular challenge given the uneven spread of scientific capacity worldwide (IOC, 2017a). The need for the BBNJ agreement to promote marine scientific research while delivering marine technology transfer punctuates the urgency in understanding the links between these two elements and their relationship to capacity building.

Here, we examine the link between marine scientific research and marine technology transfer, to identify opportunities and challenges facing the BBNJ agreement in relation to capacity building. Noting that capacity building could take different forms, we consider scientific and technological forms of capacity building ranging from global to regional to local scales. First, we examine the UNCLOS framework for marine technology transfer, marine scientific research, and capacity building. We consider definitions of these terms and highlight blurred distinctions. Second, we discuss illustrative examples, identify implementation challenges and consider key scientific gaps to fill. Third, we propose future considerations for the BBNJ agreement and corresponding opportunities to build capacity and advance technology transfer. We intend for this paper to inform ongoing discussion between scientists and policymakers about the role of science and technology in enabling all States to participate in the conservation and sustainable use of BBNJ. We propose that the BBNJ agreement offers a crucial and timely opportunity to strengthen the existing institutional framework for international science cooperation and thus support capacity building.

THE UNCLOS FRAMEWORK

As an implementing agreement under UNCLOS, the BBNJ agreement can and must build on the existing legal framework. This section examines the framework for marine technology transfer, marine scientific research and capacity building in UNCLOS. Gaps, ambiguities, and implementation challenges are identified.

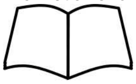
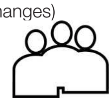
UNCLOS Basis for Marine Technology Transfer, Marine Scientific Research, and Capacity Building

Marine scientific research, capacity building and technology transfer are terms that are used widely and yet lack a common understanding. This section examines the framework for the development and transfer of marine technology established by UNCLOS (Part XIV), and highlights the envisaged role of international science cooperation as the engine for technology transfer. We then discuss the UNCLOS framework for marine scientific research (Part XIII), highlighting that the right to undertake research goes hand-in-hand with the responsibility to share and build capacity. We provide further illustrative examples of the relationship between science and technology transfer in the context of capacity building, highlighting four common themes: data, information and knowledge; training and exchanges; equipment and infrastructure; and cooperation and collaboration (**Table 1**). We illustrate the definitional gaps and blurred distinctions between marine technology transfer (section Marine Technology Transfer; **Table 2**), marine scientific research (section Marine Scientific Research), and capacity building (section Capacity Building).

Marine Technology Transfer

Although UNCLOS does not define the "transfer of marine technology," Part XIV implies a broad meaning and a

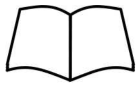
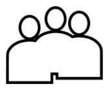
TABLE 1 | UNCLOS Part XIV summary.

Theme	Summary of provision for development and transfer of marine technology, UNCLOS Part XIV	UNCLOS article(s)
Data, information and knowledge 	• The acquisition, evaluation, and dissemination of marine technological knowledge and facilitate access to such information and data;	268 (a)
	• Acquisition and processing of marine scientific and technological data and information [via regional marine scientific and technological centers];	277 (e)
	• Prompt dissemination of results of marine scientific and technological research in readily available publications [via regional marine scientific and technological centers];	277 (f)
People (skills, training, exchanges) 	Training	
	• Develop human resources through training and education;	268 (d)
	• Access to skills for scientific and technological centers;	275 (2)
	• Training and educational programs at all levels on various aspects of marine scientific and technological research, particularly marine biology, including conservation and management of living resources, oceanography, hydrography, engineering, geological exploration of the seabed, mining, and desalination technologies; management studies; programmes on protection and preservation of the marine environment and the prevention, reduction and control of pollution.	277 (a, b, c)
	Exchanges	269 (c)
	• Conferences, seminars, symposia on scientific and technological subjects	277 (d)
	• Scientist exchanges	269 (d)
	• Provide technical experts	275 (2)
Equipment (development, access, transfer) 	Development of technology	
	• Develop appropriate marine technology	268 (b)
	• Develop technological infrastructure to facilitate the transfer of marine technology	268 (c)
	Access to technology	275 (2)
	• Provide for necessary equipment to facilitate the establishment and strengthening of national scientific and technological centers	
Cooperation and collaboration 	International cooperation:	268 (e),
	• At all levels, particularly at the regional, subregional and bilateral levels;	270,
	• New programs;	271,
	• Guidelines, criteria, and standards;	272,
	• Coordination of international programs by competent international organizations including regional or global programmes;	273, 274,
	• Cooperation with and between international organizations, including with regional marine scientific and technological centers.	277(i), 278, 276 (2)
	Programs:	270,
	• Facilitate marine scientific research, transfer of marine technology, particularly in new fields, and international funding for ocean research and development;	
	• Technical cooperation [to build marine scientific and technological capacity];	
	• Projects, joint ventures, other forms of bilateral and multilateral cooperation	269 (a, e)
	Establishment of national and regional marine scientific and technological centers:	275,
	• Stimulate and advance the conduct of marine scientific research, enhance national capabilities to utilize, and preserve marine resources; foster the transfer of marine technology;	275, 277
	• Advanced training facilities and equipment, skills, and know-how;	
	Policy:	
	• Create favourable conditions for the conclusion of agreements, contracts and other similar arrangements, under equitable and reasonable conditions;	269 (b)
	• Publicize national policies with regard to the transfer of marine technology and systematic comparative study of those policies.	277 (g)

The provisions of UNCLOS Part XIV (development and transfer of marine technology) can be summarized in four categories: (i) data, information and knowledge; (ii) people, including training and exchanges; (iii) technical and scientific equipment and infrastructure; and (iv) cooperation including through activities, programs, and common criteria, facilitated by new and existing international, regional and national institutions.

close link to marine science. For example Article 266(1) provides that "*States, directly or through competent international organizations, shall cooperate in accordance with their capabilities to promote actively the development and transfer of marine science and marine technology* (…)". UNCLOS provides a strong focus on promoting, and building capacity for marine

TABLE 2 | Examples of technology transfer for the conservation and sustainable use of BBNJ.

Marine technology (IOC, 2005)		Examples of technology transfer for the conservation and sustainable use of biodiversity beyond national jurisdiction	
a) Information and data, in a user friendly format, on marine sciences and related marine operations and services;		• Biodiversity data • Oceanographic data • Information on marine scientific research activities • Information and data on scientific capacity	Data and information
b) Manuals, guidelines, criteria, standards, reference materials;		• Open/FAIR data guidelines • Standardized science protocols • Operating instructions • Information on the conduct of technology needs assessment and capacity building strategy development	
c) Sampling and methodology equipment (e.g., for water, geological, biological, chemical samples);		• Access to research vessels and sampling equipment	Equipment and infrastructure
d) Observation facilities and equipment (e.g., remote sensing equipment, buoys, tide gauges, shipboard, and other means of ocean observation;)		• Open and deep ocean observing equipment	
e) Equipment for *in situ* and laboratory observations, analysis, and experimentation;		Laboratory equipment, including for genetic analysis	
f) Computer and computer software, including models and modeling techniques;		Data analysis, including computers, and software	
g) Expertise, knowledge, skills, technical/scientific/legal know-how, and analytical methods related to marine scientific research and observation.		• Training in scientific methods, data analysis, and technical aspects relevant to BBNJ • Long-term mentorship programs • Courses on science-policy	Skills

scientific research; for example, Article 266(2) provides that "*States shall promote the development of the marine scientific and technological capacity of States which may need and request technical assistance in this field* (…)". Indeed, Part XIV established a framework in which the development and transfer of marine technology goes hand-in-hand with marine scientific research (Long, 2007; **Table 1**). The word "transfer" appears only once in UNCLOS Article 268, which instead emphasizes: the *development* of technology including equipment; the sharing of scientific and technological knowledge, data, and information; the training of people; and the establishment of national and regional marine scientific and technological centers.

Consequently, in the context of Part XIV, technology transfer aligns with a multi-directional exchange of data and knowledge, skills, and research opportunities (**Table 1**), rather than a one-way hardware donation. This broad interpretation has been elaborated through the Intergovernmental Oceanographic Commission's Criteria and Guidelines on Transfer of Marine Technology (IOC, 2005), in response to Article 271 of UNCLOS (**Table 2**). These same guidelines have been identified as a cornerstone of the technology transfer regime to be developed under the BBNJ agreement (Long and Rodriguez Chaves, 2015). This framework alludes to four key pillars for technology transfer (**Table 1**):

(i) **Data, information and knowledge**: sharing data, information, and knowledge about marine scientific research activities and outputs, as well as technological development.
(ii) **People**: training in science and technology and exchanging skilled people;
(iii) **Equipment**: access to or transfer of research infrastructure and equipment, including both hardware and software; and
(iv) **Cooperation and collaboration**: for scientific research (including on criteria and standards, programs, funding for ocean science), through activities, programs including international, regional and/or national scientific and technical institutions.

Marine Scientific Research

Given the international marine scientific and technological cooperation envisaged as a key driver of technology transfer under UNCLOS Part XIV, it is necessary to consider the legal framework for marine scientific research (**Table 3**). UNCLOS identifies the "study, protection and preservation of the marine environment" as a core objective. Marine scientific research, though not defined in UNCLOS, can broadly include "any study or related experimental work designed to increase mankind's knowledge of the marine environment" (see UNCLOS art. 243). Marine scientific research is a freedom of the high seas (art. 87f) and all States have the right to conduct marine scientific research (art. 238) in marine ABNJ (arts. 256, 257). However, far from an absolute freedom, it is conditional on responsibilities including, for example, promoting international cooperation (art. 242) and the publication and dissemination of information and knowledge (art. 244). Furthermore, there are specific provisions for international cooperation in marine scientific research in the Area (art. 143) and transfer of technology (art. 144), including training of people, sharing research results, strengthening research capabilities, and promoting cooperative programmes of scientific research (**Table 3**). Thus, these provisions reinforce the obligations for technology transfer found in Part XIV whereby science provides both an enabler and an objective of marine technology transfer. The BBNJ agreement can build on this existing legal framework.

Capacity Building

Although UNCLOS does not specifically mention or define the term "capacity building," scientific and technological capacity building (technical, human, and institutional) is the centerpiece of Part XIV and provisions can be found in relation to the protection and preservation of the marine environment, the Area and marine scientific research (**Table 3**). For example, Article 266(2) identifies increasing scientific and technological capacity as an aim of technology transfer, with particular reference to the protection and preservation of the marine environment, and marine scientific research. As an illustration of the long-held aspirations regarding scientific and technological capacity, we note that the 1982 "Resolution on Development of National Marine Science, Technology and Ocean Service Infrastructure" emphasized an urgent need to close the scientific and technological gap and strengthen national capabilities in marine science and technology (UN, 1982). However, despite efforts to implement marine technology transfer (IOC, 2017b), concerns persist regarding lack of implementation of Part XIV (Holland and Pugh, 2010). Today, numerous declarations illustrate the persistence of this hurdle by highlighting a need to fill scientific knowledge gaps, transfer marine technology, and build scientific capacity at global, regional, and national scales, such as the United Nations Sustainable Development Goal 14a (UN, 2015), and the roadmap for the UN Decade of Ocean Science for Sustainable Development 2021–2030 (UNGA, 2017b). The inclusion of "capacity building and technology transfer" as one of the four elements of the BBNJ agreement further illustrates the importance of effective capacity building and the perceived link with technology transfer, to enable the conservation and sustainable use of marine biodiversity beyond national jurisdiction. In this paper, we consider forms of scientific and technological capacity building.

Implementation Challenges: Remaining Gaps

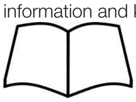
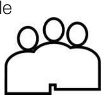
Weak obligations and unclear or absent institutional implementation mechanisms in UNCLOS likely constrain implementation of the transfer of marine technology. Scientists and scientific institutions are tasked with the "heavy-lifting" (**Tables 1**, **3**), however, mechanisms to support the strong emphasis on science cooperation to deliver marine technology transfer are lacking. No coherent mechanism exists to assist States to self-identify and communicate technological need, there is no common mechanism to request technology or capacity building, and no clear practical arrangements exist to deliver marine technology transfer or to monitor and evaluate progress toward capacity building. Even the avenues for implementation identified in the IOC Criteria and Guidelines for the Transfer of Marine Technology rest heavily on existing scientific cooperation, particularly via the IOC (2005). While several areas show progress, such as developing a clearinghouse mechanism to facilitate information sharing, holding events, establishing regional focal points, and assisting the implementation of technology transfer projects (Harden-Davies, 2017; IOC, 2017b); the long-time frames and uncertain funding of several such initiatives also illustrates the perils of ambitious aims that rely on an ambiguous legal framework beset by resource constraints and limited political will. The BBNJ agreement should endeavor to forge workable solutions against this backdrop.

A lack of information presents a further critical challenge to designing, implementing and evaluating capacity building and technology transfer programs, and even marine scientific research programs more broadly. A dearth of information exists on existing science capacity and capacity building needs. Despite some surveys of State practice (IOC, 2008), we still lack a long-term comprehensive reporting mechanism. The inaugural Global Ocean Science Report (IOC, 2017a) marks the beginning of a more comprehensive approach to monitoring ocean science capacity, but given that just 34 IOC Member States responded to the underlying survey that formed the basis of the first report, challenges clearly remain in acquiring baseline information regarding science capacity. Consequently, we lack clarity on possible ongoing capacity building activities that reporting does not capture, opportunities not being seized, and needs not being met. Noting that there are several different actors involved in capacity building (section Discussion: Considerations for the BBNJ Agreement), the following section presents examples of current practice within the international scientific community to advance elements of technology transfer and capacity building.

CURRENT PRACTICE

Following the four key themes identified above (data, information and knowledge; training; equipment; and cooperation and collaboration), this section discusses how marine scientific research creates opportunities for capacity building and marine technology transfer—and vice versa.

TABLE 3 | Summary of provisions relating to scientific and technological capacity building in UNCLOS Parts XI (the Area), XII (protection and preservation of the marine environment), and XIII (marine scientific research).

Theme	Summary of UNCLOS provision broadly referring to scientific and technological capacity building	UNCLOS art(s)
Data, information and knowledge 	Sharing data, information, and knowledge arising from research, e.g.,:	
	• Actively promote the flow of scientific data and information and the transfer of knowledge resulting from marine scientific research, especially to developing States;	244(2)
	• Effectively disseminating the results of research and analysis (from marine scientific research in the Area) when available.	143(3)(c)
	Sharing information about activities:	
	• Provide opportunity to obtain information necessary to prevent and control damage to the health and safety of persons and to the marine environment;	242(2)
	• Make available by publication and dissemination through appropriate channels information on proposed major programmes and their objectives as well as knowledge resulting from marine scientific research.	244(1)
People 	Training:	
	• Programmes of scientific, educational, technical, and other assistance, including training of scientific and technical personnel;	202 (a)(i)
	• Assistance, especially to developing States, concerning the preparation of environmental assessments;	202(c)
	• International cooperation in marine scientific research (in the Area) to train personnel, especially from developing States, in the techniques and applications of research;	143(3)(b)
	• Strengthen autonomous marine scientific research capabilities of developing States through programmes of education and training of technical and scientific personnel;	244(2)
	• Acquire, promote, and encourage transfer to developing States of technology and scientific knowledge, including training in marine science and technology.	144(1)(a), (b), (2)
Equipment 	Development of, access to and transfer of equipment programmes of assistance e.g.,:	
	• Supply necessary equipment and facilities;	202(a) (iii);
	• Enhance capacity to manufacture such equipment;	202(a) (iv);
	• Develop facilities for research, monitoring, educational and other programmes.	202(a) (v)
Cooperative activities 	Studies, research programmes, and exchange of information and data, e.g.,:	
	• Studies, programmes of scientific research, encourage the exchange of information, and data acquired about pollution of marine environment;	200
	• Participate actively in regional and global programmes to acquire knowledge;	200
	• Criteria for regulations, rules standards, practices and procedures;	201,
	• Programmes of scientific, educational, technical, and other assistance to developing States for the protection and preservation of the marine environment;	202 (a)(ii)
	• Facilitating participation in international programmes, including in the Area;	202 (a)(ii), 143(3)(a)
	• International cooperation in marine scientific research for peaceful purposes;	242(1),
	• Develop marine scientific research programs (in the Area) to strengthen research capabilities of developing States;	143(3)(b)(i),
	• Acquire scientific knowledge and technology to promote technology transfer;	144(2)(a)
	• Favorable conditions for the conduct of marine scientific research in the marine environment;	243
	• Integrate the efforts of scientists in studying the essence of phenomena and processes occurring in the marine environment and the interrelations between them.	243

Science for Capacity Building: Four Elements

Data, Information, and Knowledge Sharing

Data, information, and knowledge relevant to BBNJ could include many different elements. For example it may include *information* about marine scientific research activities; raw *data* arising from the research; or aggregated *knowledge* products arising from data analysis. Scientists, funding bodies and managers all widely support open data access facilitated through common approaches such as "FAIR" principles—findable, accessible, interoperable, reusable—(Wilkinson et al., 2016; Levin et al., 2019; Stall et al., 2019). However, the discussion concerning a clearinghouse mechanism for the transfer of marine technology in general, and for the BBNJ instrument in particular, illustrates the perceived need to improve the implementation of FAIR and open sharing of data and information in practice. Currently, available marine biodiversity data straddles multiple databases (some global, some regional, some project specific), with varying degrees of connectedness among key datasets and services (Bingham et al., 2017). Such connectedness crucially requires internationally recognized data portals. The Ocean Biogeographic Information System

(OBIS), for example, connects more than 500 institutions from 56 countries that have provided more than 57 million observations of over 120,000 marine species, including more than 3 million observations from ABNJ, and has a specific deep-sea node. As a collection of coordinated regional and national nodes, OBIS illustrates the role of decentralized network models in facilitating cooperation. However, several nodes rely on "soft" funding and even international coordination faces uncertain futures, for example, the International Oceanographic Data and Information Exchange Committee stressed to the IOC Assembly the need for funding to secure the continuation of OBIS beyond 2019 (Intergovernmental Oceanographic Commission (IOC), 2019). This uncertainty suggests fragility in the international framework that should be considered in the development of a clearinghouse mechanism the BBNJ agreement, guided by the scientific community. Furthermore, notwithstanding a growing trend of open access, not all institutions have access to peer-reviewed literature, the resources to cover fees, the technical capacity to download data, or the hardware and software required to analyse it.

People

Ocean science activities often bring together researchers from different countries providing an opportunity to advance international cooperation, and to identify and pursue common interests (Berkman, 2010), create standardized approaches, and support quantitative and inter-comparable data collection. For example, research cruises provide a platform to share experiences, build collaborations, and train scientists across national borders. However, participation in such initiatives requires opportunity, resources–and research vessels. Technology continues to open up new avenues to involve researchers in cruises–satellite technology and telepresence can enable shore-based researchers to link into research vessels at-sea, enabling online participation in sampling and experimentation. Such technology also enables remote participation in training programs through distance learning, in addition to in-person training courses and workshops.

Ongoing collaborations are important to ensure continued professional development and partnership building, particularly between scientific institutions with differing levels of capacity. Longer-term training through masters and PhD programs can provide an important foundation for such mentoring connections and enduring linkages. Ensuring that capacity building programs train the trainers can promote strengthening of in-country capacity in the long term. But sustaining such efforts depends on people, networks, and resources to support continuing professional development. International ocean observation and monitoring programs, such as the Global Ocean Observing System, offer an important platform to facilitate networking, deliver training, and sustain international science collaboration (Bax et al., 2018; Miloslavich et al., 2018) on which the BBNJ agreement can build.

Equipment

Scientific tools have moved far beyond lowering plumb lines from ships to determine bottom depth and composition, or pulling crude nets and trawls through the water and over seafloor to sample ocean life. Today, new technologies and tools such as next generation sequencing, other omics technologies, novel sensors, autonomous underwater vehicles, imaging, artificial intelligence and machine learning, and *in situ*/shipboard application of these tools (e.g., Scholin et al., 2009) offer promise–for both improving monitoring of ocean health and enabling access and benefit-sharing for marine genetic resources. Although logistically possible with available technology, high costs prohibit many measurements–especially in the deep remote marine areas beyond national jurisdiction (Danovaro et al., 2017), and few nations can afford this technology (IOC, 2017a), further increasing the capacity gap. Maintenance and sustained operation costs add additional challenges, even for comparatively low technology approaches such as net tows or temperature measurement. Technologies that are low-cost to access and maintain are important in improving capacity (Veitayaki and South, 2001), examples include the open access 3D printable microscope (Chagas et al., 2017), the foldscope (Cybulski et al., 2014), USB DNA sequencers (Hsiao, 1991), and image capture using low-cost, off-the-shelf waterproof cameras.

Accelerating technology readiness and affordability in monitoring ocean health requires continued development of new technologies. Tool limitations include, for example, taxonomic capacity for species quantification, availability of genetic and other tools for understanding connectivity across different spatial scales and temporal scales, computational capacity and field verification for ocean predictive models, acquiring sufficient data to determine ecosystem function, and measuring perturbations from individual and cumulative effects. Admittedly, traditional taxonomic expertise based on morphology represents a major bottleneck, but as genetic barcoding libraries expand and help to catalog unknown biodiversity, the technology gap between developed and developing countries will grow. Effective closing of major scientific gaps concerning marine biodiversity of ABNJ critically depends on deploying new technology, as part of sustained and expanded long-term ocean observing infrastructure. For example, ongoing efforts seek to expand ocean observations into the deep ocean (Levin et al., 2019) and offer an important platform to address such knowledge gaps and provide scientific information to inform the implementation of the BBNJ agreement at global and regional scales.

Cooperation and Collaboration

The previous discussion illustrates that science plays a multi-faceted role in capacity building that could take place at global, regional, and national scales. In order to acquire data and knowledge to share, to create opportunities to train people, and to enable opportunities to develop and deploy technology, scientific knowledge gaps must be filled. Large portions of the ocean—perhaps as much as 95%—remain unsampled by science. Even after more than a century of research, $<$10% of the global seafloor has been mapped to the 100 m resolution already attained for the moon or for Venus (Sandwell et al., 2014). OBIS reports on where sampling has taken place demonstrate a clear need for greatly accelerated sampling effort in many parts of the world (Webb et al., 2010). Estimates of unknown biological diversity vary from 50% to considerably more than 90% (e.g., Mora et al., 2011), and new habitats were discovered even in the last few decades (Danovaro et al., 2014). Furthermore, many of the questions that inspired early investigators of the deep and open ocean more than a century ago remain at least partially unanswered today. Major knowledge gaps for BBNJ include:

i) **Baseline knowledge of which species live or pass through a given environment**. For most ABNJ we lack even the most basic knowledge of a complete, or even partial, species list (Webb et al., 2010).
ii) **Understanding connectivity between habitats.** Our lack of understanding regarding the connections between populations and habitats (e.g., Baco et al., 2016; Dunn et al., 2019) limits our capacity to assess scales of dispersal, food, and energy flow.
iii) **The role of biodiversity in ecosystem functioning.** Limited evidence suggests that living organisms in the deep sea play a fundamental role in ecosystem processes such as nutrient regeneration (Danovaro et al., 2008), habitat provisioning (Baker et al., 2012), and trophic support (Drazen and Sutton, 2017), but we lack any broad understanding of how species loss or change might affect the delivery of these functions and their role in the Earth system.
iv) **Predicting distributions and patterns from limited sampling.** The vast size of the deep sea and high cost in sampling suggest a need to develop proxies and indicators (e.g., Vierod et al., 2014) that allow extension of limited sampling over broader spatial and temporal scales.
v) **The response of biodiversity to perturbation, or vulnerability.** Although we recognize greater vulnerability of some ecosystems and species to perturbation than others, we lack any comprehensive framework to anticipate how different human activities might cause biodiversity change or loss (Auster et al., 2010).

Collectively, these science questions could inform prediction tools that allows scientists to extend knowledge from limited sampling to a broader range of habitats and taxa, a critical need for policy measures for the conservation and sustainable use of biodiversity beyond national jurisdiction. The questions strongly interlink; neither the questions, nor the knowledge arising, are produced or used in isolation. Addressing these knowledge gaps could support informed decision-making across the BBNJ agreement, including use in environmental impact assessments and area-based management tools (**Table 4**), such as through conducting strategic environmental assessments. Crucially, this type of basic scientific research can also bring opportunities to derive and share benefits from marine genetic resources (Rabone et al., 2019). However, no single nation can address the major scientific knowledge gaps of BBNJ.

The vast area and volume of marine ABNJ, complex and costly logistics, and remote locations of ABNJ collectively require a collaborative approach. Such an approach also aligns with the notion of cooperation and collective good inherent in the UNCLOS provisions for ABNJ. Past programs set a strong precedent for science collaboration of this kind. The Census of Marine Life (2000–2010), for example, embraced international collaboration in engaging more than 2,600 scientists from more than 80 nations to address questions on diversity, distribution, and abundance of life in the global ocean. The program attracted funding of close to US$ 700 million (Snelgrove, 2010) by leveraging philanthropic seed funding to fund and build public and private partnerships and international science networks, some of which live on today (e.g., the International Network for the Investigation of Deep Sea Ecosystems, INDEEP). Lessons from programs such as this can inform future deep-sea scientific investigations to advance knowledge of BBNJ, such as through the UN Decade of Ocean Science for Sustainable Development (2021–2030).

TABLE 4 | Scientific knowledge needs for the conservation and sustainable use of BBNJ, including relevance to both EIA and ABMTs.

Knowledge gap	Relevance to EIA	Relevance to ABMT
1. Baseline knowledge of species	Attributing changes in species presence or abundance to specific activities requires baseline knowledge on the "*who*" of species presence	ABMTs typically require baseline knowledge on species, including where priority species ("*who*") occur, which are most *vulnerable*
2. Connectivity	Activities that alter potential supplies of recruits, food, or other attributes from one location to another requires knowledge of *connectivity*	Understanding their *connectedness* can inform design of effective MPA networks, fisheries closures, and other strategies to enhance recruitment and sustainability
3. Ecosystem function	EIAs often address impacts of activities on ecological integrity of focus areas, which links to knowledge of *ecosystem functioning*	Evaluating *ecosystem functioning* and species impact on Earth processes can inform strategies to help sustain those functions, such as Marine Protected Area planning
4. Prediction	Sampling limitations may require proxies of status in some cases, requiring good *predictors*	*Predicting* which habitats support the highest biodiversity
5. Measuring response to perturbation	Assessing how different species and ecosystems respond to environmental impacts requires evaluation of response of biodiversity to perturbation, or *vulnerability*	Establishing effective protection and "insurance" against future change requires identifying areas resilient to change and mitigating impacts on those most vulnerable to change

Science advances also offer an opportunity to standardize approaches and methodologies that simultaneously build global capacity and also generate comparable data sets that support meta-analyses and cross-system comparisons. The Census of Marine Life demonstrated the benefits of standardized approaches, as well as the potential for capacity building and technology transfer through targeted workshops and integrated research involvement of research communities varying in focus and capacity. Standards provide a framework for common approaches to measuring ocean variables that enables coordination of scientific research and comparability of the ensuing results. Repeatable protocols and other such guidelines or manuals provide a hierarchy of methodologies appropriate for different levels of scientific capacity, and greater potential for quantitative comparisons among regions and jurisdictions. Several initiatives illustrate the ongoing efforts of the scientific community to streamline and standardize sampling protocols (Konar et al., 2010; Snelgrove, 2010; Woodall et al., 2018), support the acquisition, curation, storage, and sharing of samples and data in the context of genetic resources (Rabone et al., 2019), and international coordination of ocean best practices (Pearlman et al., 2019). In particular, the Global Ocean Observing Systems (GOOS) is developing shared "essential ocean variables" (EOVs) toward a more effective integrated ocean observing system that moves beyond piecemeal efforts, including biological and ecosystem variables (Muller-Karger et al., 2018) to support policy development (Miloslavich et al., 2018), capacity building (Bax et al., 2018), and open data (Bax et al., 2019). These approaches can help to reduce the capacity gap between countries and transfer technology by sharing protocols and co-designing methods that are appropriate and accessible for all. These coordination mechanisms bring cost, but currently rely largely on voluntary and in-kind contributions of individuals and institutions.

Common Challenges and Opportunities

Marine Scientific Research and Marine Technology Transfer Are Mutually Supportive

Scientific advancement goals often catalyze technology development in order to address science objectives. Whether such developments arise as "fit for purpose" or adapt technologies developed for other purposes, they nonetheless create opportunity for innovation and, potentially, inclusivity. Science cooperation offers opportunity for marine technology transfer, through shared approaches to ocean infrastructure and equipment, as well as training. One such initiative, the EAF-Nansen program, provides scientists from developing countries access to a fisheries vessel to manage better their fisheries and protect threatened marine environments. The benefits of international marine scientific research cooperation include standardized approaches supporting inter-comparison among studies, multi-scaler analyses, shared infrastructure platforms (e.g., ships) and instruments, opportunities for training and the exchange of skills and ideas, and tackling far more complex, larger-scale, and interdisciplinary challenges than otherwise possible. In these ways, marine scientific research demonstrably supports the transfer of marine technology, as envisaged in UNCLOS. In turn, technology transfer and capacity building could then generate new data and knowledge and data from previously unknown locations, thus providing positive feedback on scientific advancement. Such efforts should accelerate understanding of biodiversity beyond national jurisdiction and, in doing so, strengthen global capacity to study, protect, and sustain a healthy, functioning marine environment. However, harnessing this potential for capacity building depends on cooperation and collaboration. Learning from the experiences, achievements and challenges of existing capacity building programs, particularly those undertaken by intergovernmental organizations, will be informative in this regard (Cicin-Sain et al., 2018).

Capacity Building and Collaboration: Toward an Enabling Environment

Global, regional, and national networks can play crucial roles in oiling the wheels of international science collaborations–by diversifying funding sources, sustaining support for data storage and platform sharing, amplifying efforts for standardization, and connecting scientists. Several intergovernmental organizations undertake capacity building programs relating to science and technology; examples include the Food and Agriculture Organization, the International Maritime Organization, the International Seabed Authority, and many more (Cicin-Sain et al., 2018). Many scientific networks are voluntary, and future endeavors that might rely on science in this way should therefore consider how to sustain support for such networks, whose finite lifespans rarely extend beyond 5 years. Such preparation in the BBNJ agreement could avoid an over-reliance on unspecified, unsupported, and unpredictable mechanisms for capacity building. Operating a reliable and enduring system collectively requires coordination and support at the global level and strong relationships with regional and national bodies.

Accelerated development and deployment of marine technology could significantly benefit capacity, whether for institutions in small island states or for global scientific community as a whole. For example, the development and deployment of equipment, the adoption of FAIR and open data principles, the strengthening of cooperation mechanisms, or enhancing the scientific knowledge base could promote marine scientific research and boost collective scientific capacity. Such a strategy could focus on advancing knowledge of marine biodiversity itself, by increasing and sharing information from marine science, or of human activities in ABNJ, perhaps using technologies such as vessel tracking (Dunn et al., 2018). It could emphasize training in data analytics, accessing training materials, courses, or information about how to use specialized equipment. Actors in this initiative could include research institutions, private sector members, and philanthropists.

However, tying these threads together in a way meaningful for capacity building requires an enabling environment whereby all elements of technology transfer can be mobilized collectively, in a holistic and integrated manner to meet needs (**Figure 1**). No single form of technology can address science capacity needs alone. For example, equipment requires corresponding skills and resources to maintain and utilize it—a DNA sequencing machine will not be useful in the absence of trained staff to use and maintain it, no access to biological samples to utilize it, no computers and software to analyse data, and no funding for other operating and maintenance costs. Similarly, data access is useful only in tandem with corresponding capacity for interpretation and use; conversely, a trained data scientist cannot reach their full potential without necessary equipment and inputs. Such needs will vary considerably among countries, depending heavily on existing and desired capacity. The following sections address

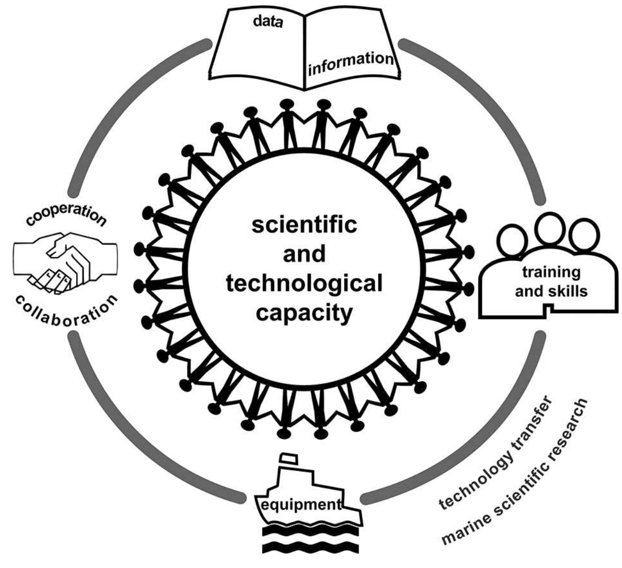


FIGURE 1 | A holistic approach to scientific and technological capacity. Several forms of technology transfer could collectively contribute to capacity building, including data and information; training and skills; equipment and research infrastructure; and cooperation and collaboration. Marine scientific research drives such activities.

ways that the BBNJ agreement could enable States to better identify and meet capacity building needs through marine scientific research and technology transfer.

DISCUSSION: CONSIDERATIONS FOR THE BBNJ AGREEMENT

The examples described above demonstrate the mutually supportive nature of international cooperation in promoting marine scientific research and delivering technology transfer, both in principle and in practice, to the benefit of capacity building. Scientific research presents opportunities to deliver on technology transfer and build capacity at multiple scales–whether for boosting institutional capacity in less-developed States or regions, or for advancing scientific best-practices and cooperation mechanisms for the global marine scientific community as a whole. This opportunity requires a paradigm shift that considers capacity building as more than a training initiative, and technology transfer not merely as bilateral hardware donation, but rather as a strategy to boost science collaboration for the benefit of global science (Bax et al., 2018). Embracing such a shift would position the BBNJ process to follow a broader path that recognizes the crucial role of collaboration in building the body of knowledge crucially needed to address global challenges and the need for mechanisms that support such collaboration (Royal Society, 2011, and Organisation for Economic Cooperation and Development (OECD), 2012). Although a BBNJ agreement cannot solve all ocean science capacity issues, it offers a truly historic opportunity to draw attention to best-practices and areas of weakness, and strengthen the global framework for an enabling environment for science capacity. Seizing these opportunities critically requires leadership, coordination, and support.

In several ways, a BBNJ agreement could strengthen cooperation and coordination of marine scientific research, technology transfer, and capacity building activities.

Coordination

First, the BBNJ instrument could provide institutional clarity and promote institutional support for international cooperation and coordination in scientific research, capacity building, and technology transfer. The closest that the draft text of the BBNJ agreement gets to this specification of institutional responsibility for capacity building and technology transfer is in the management of a clearinghouse mechanism, in Article 51, which suggests potential roles for a secretariat and/or the IOC, in collaboration with relevant organizations such as ISA and IMO. Agreement among states on this issue clearly require further discussions. Whichever institution is tasked with the clearinghouse mechanism could play an important role not only in sharing information about activities, but in coordinating activities more broadly. Such an effort should consider existing coordination mechanisms and bodies.

Identifying and Communicating Capacity Needs

Second, the BBNJ agreement could enable the identification and communication of capacity building needs–which will undoubtedly exceed scientific and technological needs alone. Not all countries have developed national ocean policies or corresponding ocean science and technology strategies or research agendas. Meanwhile information gaps relating to current scientific and technological capacity persist, and we lack a simple mechanism to identify technological need, or to communicate that need. Article 44 of the draft text of the BBNJ agreement notes the importance of ensuring that capacity building activities respond to the needs and priorities of developing States and the potential role of a needs assessment in this regard (BBNJ, 2019).

Technical information and guidelines could support self-identification of technological and scientific capacity building requirements, encouraging States to draw on knowledge contained in national and regional institutions. The process could usefully link to existing assessment processes, such as the IOC Global Ocean Science report. The potential role for the Scientific and Technical Body under the BBNJ agreement to collaborate with existing bodies in undertaking needs assessments, as mentioned in Article 49 of the draft BBNJ text, merits further consideration as a pathway to support coherence across reporting approaches. In addition to national, and potentially regional or subregional initiatives, global assessments of scientific capacity in relation to BBNJ could play a role in shaping future collaborations. A clearinghouse mechanism, as envisaged in Article 51 of the draft BBNJ text, could communicate capacity needs.

Beyond communicating capacity needs, it would be necessary to enable all relevant actors to report on science cooperation, technology transfer and capacity building activities in order assess their effectiveness and identify gaps to be filled. Article 47 of the draft BBNJ text reflects the need for a process of monitoring and review. Existing networks, as mentioned above, should be invited to play an active role in sharing information. New and existing forums could provide space to exchange experiences and lessons learned between different actors.

Meeting Needs

Third, the BBNJ agreement could include measures that better enable actors, from individual to institutional scales, to access and utilize science and technology in order to participate in the implementation of the agreement. As discussed above, no single form of technology transfer will work–rather, science requires an enabling system in which skilled people can access equipment, information, knowledge, and data for meaningful use. Nevertheless, specific measures for specific categories of technology transfer could be useful, for example:

(i) **Promote access to equipment**: Accelerated development and deployment of new technologies requires additional effort in order to enable accessibility for all nations. The agreement can encourage collaborative research ventures, create mechanisms to request equipment, encourage open-source technology, and task an institution to facilitate such activities.

(ii) **Encourage sustained training of people**: Enhancing cooperation between existing training programs to better identify gaps could offer one pathway to improve the human aspects of technology transfer under the BBNJ agreement. Support for existing and new information sharing mechanisms for human capacity building, including long-term mentoring schemes, remote participation, and collaboration networks, could all play a role.

(iii) **Access to data, information, and knowledge**: The BBNJ agreement could further promote coordination of data standards and support for databases to strengthen the international framework for data sharing. This strategy could include public-private partnerships, support global and regional data nodes, and promote standards and common approaches such as FAIR and open principles. A well-designed and maintained clearinghouse mechanism, developed with strong buy-in from the scientific community, could facilitate information sharing, including on marine scientific research activities and opportunities for capacity building and collaboration. Such sharing of information could also avoid duplication of initiatives and the targeting of capacity building to meet self-determined needs. Furthermore, despite its inherently cooperative activity, marine science currently lacks a central point to share information about activities, pointing to the utility of a portal to share information about marine scientific research activities linked to the clearinghouse mechanism (Rabone et al., 2019).

The clearinghouse mechanism is positioned with a key role in sharing information and delivering technology transfer and capacity building by matching needs with available providers, in Article 51 of the draft BBNJ text (BBNJ, 2019). A human element using existing networks, in addition to a web-based platform, could help to ensure ownership and buy-in to such a system. Developing a usable interface that policymakers, managers, and scientists alike can participate in requires early consultation with potential users.

Implementing the agreement will critically depend on funding, as will enabling all countries to participate in scientific advances. The current text relating to financial resources and funding, in Part VII, Article 52, of the Draft BBNJ text, remains in brackets, suggesting divergent views about the provision of funding. The experiences of scientific networks, intergovernmental organizations, and national management agencies could usefully inform future discussions on the role of funding in delivering scientific and technological capacity building in order to identify potential opportunities to leverage existing initiatives and remaining gaps to fill.

CONCLUSION

UNCLOS established a framework for marine technology transfer that inextricably links marine scientific research and capacity building through: (i) training and exchanging skilled people; (ii) sharing data, information and knowledge; (iii) access or transfer of research infrastructure and equipment; and (iv) cooperation and collaboration. In practice, science cooperation creates opportunities for technology transfer. For example, the Census of Marine Life illustrated the crucial role of well-coordinated international science cooperation in leveraging the funding and capacity needed to undertake ambitious scientific investigations. Such initiatives create opportunities for technology transfer by streamlining standards, opening up access to data, providing opportunities to build long-term global collaboration networks, training, and shared infrastructure access.

Persisting inequity in science capacity worldwide has motivated many States to increase the implementation of UNCLOS Part XIV on the development and transfer of marine technology. At the same time, those nations with such scientific and technological capacity depend upon a fragile mix of public and private funding and fragmented institutional architecture. The absence of a mechanism to enable countries to communicate their capacity building needs to the international community misses an opportunity for strategic and sustained integrated approaches.

Marine scientific and technological capacity represent crucial crosscutting issue for the BBNJ agreement. Designing, monitoring, and managing area-based management tools and conducting environmental impact assessments requires the same types of basic knowledge that motivates discovery-based science. Strengthening capacity at global, regional, and national levels to advance scientific research requires better scientific understanding.

The BBNJ negotiations represent an important opportunity to strengthen the international framework for marine technology transfer, marine scientific research and capacity building. The BBNJ agreement can strengthen the existing framework for marine technology transfer and promote marine scientific research through enhanced coordination; promoting support for data, sharing information about training mechanisms and access to infrastructure; and critically, encouraging and enabling States to self-identify needs for capacity building, technology and science. Fleshing out critical details, including for the clearinghouse mechanism, requires discussion within the scientific community. Ultimately, capacity building requires a long-term strategy adaptable to changing needs including, but not limited to, science and technology. The UN Decade of Ocean Science for Sustainable Development 2021–2030 offers a unique chance to put such an approach into practice.

AUTHOR CONTRIBUTIONS

HH-D and PS conceived the research, conducted the analysis, and developed the recommendations.

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REFERENCES

Auster, P. J., Gjerde, K., Heupel, E., Watling, L., Grehan, A., and Rogers, A. D. (2010). Definition and detection of vulnerable marine ecosystems on the high seas: problems with the "move-on" rule. *ICES J. Mar. Sci*. 68, 254–264. doi: 10.1093/icesjms/fsq074

Baco, A. R., Etter, R. J., Ribeiro, P. A., Von der Heyden, S., Beerli, P., and Kinlan, B. P. (2016). A synthesis of genetic connectivity in deep-sea fauna and implications for marine reserve design. *Mol. Ecol*. 25, 3276–3298. doi: 10.1111/mec.13689

Baker, K. D., Haedrich, R. L., Snelgrove, P. V., Wareham,V. E., Edinger, E. N., and Gilkinson, K.D. (2012). Small-scale patterns of deep-sea fish distributions and assemblages of the Grand Banks, Newfoundland continental slope. *Deep Sea Res. Part I Oceanogr. Res. Pap*. 65, 171–188. doi: 10.1016/j.dsr.2012.03.012

Bax, N. J., Appeltans, W., Brainard, R., Duffy, J. E., Dunstan, P., Hanich, Q., et al. (2018). Linking capacity development to GOOS monitoring networks to achieve sustained ocean observation. *Front. Mar. Sci*. 5:346. doi: 10.3389/fmars.2018.00346

Bax, N. J., Miloslavich, P., Muller-Karger, F. E., Allain, V., Appeltans, W., Batten, S. D., et al. (2019). A response to scientific and societal needs for marine biological observations. *Front. Mar. Sci*. 6:395. doi: 10.3389/fmars.2019.00395

BBNJ (2019). "Draft text of an agreement under the United Nations Convention on the Law of the Sea on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction," in *Intergovernmental Conference on an International Legally Binding Instrument Under the United Nations Convention on the Law of the Sea on the Conservation and Sustainable Use of Marine Biological Diversity of Areas Beyond National Jurisdiction Third Session* (New York, NY). Available online at: https://undocs.org/a/conf.232/2019/6 (accessed September 5, 2019).

Berkman, P. A. (2010). Biodiversity stewardship in international spaces. *Syst. Biodivers*. 8, 311–320. doi: 10.1080/14772000.2010.512623

Bingham, H., Weatherdon, L., Despot-Belmonte, K., Wetzel, F., and Martin, C. (2017). The biodiversity informatics landscape: elements, connections and opportunities. *Res. Ideas Outcomes* 3:e14059. doi: 10.3897/rio.3.e14059

Broggiato, A., Arnaud-Haond, S., Chiarolla, C., and Greiber, T. (2014). Fair and equitable sharing of benefits from the utilization of marine genetic resources in areas beyond national jurisdiction: bridging the gaps between science and policy. *Mar. Policy* 49, 176–185. doi: 10.1016/j.marpol.2014.02.012

Broggiato, A., Vanagt, T., Lallier, L. E., Jaspars, M., Burton, G., and Muyldermans, D. (2018). Mare geneticum: balancing governance of marine genetic resources in international waters. *Int. J. Mar. Coast. Law* 33, 3–33. doi: 10.1163/15718085-13310030

Chagas, A. M., Prieto-Godino, L. L., Arrenberg, A. B., and Baden, T. (2017). The 100 lab: a 3D-printable open-source platform for fluorescence microscopy, optogenetics, and accurate temperature control during behaviour of zebrafish, drosophila, and caenorhabditis elegans. *PLoS Biol*. 15:e2002702. doi: 10.1371/journal.pbio.2002702

Cicin-Sain, B., Vierros, M., Balgos, M., Maxwell, A., Kurz, M., Farmer, T., et al. (2018). *Policy Brief on Capacity Development as a Key Aspect of a New International Agreement on Marine Biodiversity Beyond National Jurisdiction (BBNJ)*. Washington, DC: Global Ocean Forum. Available online at: https://globaloceanforumdotcom.files.wordpress.com/2018/08/policy-brief-on-bbnj-capacity-development-dec-2018-email-version.pdf (accessed September 20, 2019).

Cybulski, J. S., Clements, J., and Prakash, M. (2014). Foldscope: origami-based paper microscope. *PLoS ONE* 9:e98781. doi: 10.1371/journal.pone.0098781

Danovaro, R., Aguzzi, J., Fanelli, E., Billett, D., Gjerde, K., Jamieson, A., et al. (2017). An ecosystem-based deep-ocean strategy. *Science* 355, 452–454. doi: 10.1126/science.aah7178

Danovaro, R., Gambi, C., Dell'Anno, A., Corinaldesi, C., Fraschetti, S., Vanreusel, A., et al. (2008). Exponential decline of deep-sea ecosystem functioning linked to benthic biodiversity loss. *Curr. Biol*. 18, 1–8. doi: 10.1016/j.cub.2007.11.056

Danovaro, R., Snelgrove, P. V., and Tyler, P. (2014). Challenging the paradigms of deep-sea ecology. *Trends Ecol. Evol*. 29, 465–475. doi: 10.1016/j.tree.2014.06.002

Drazen, J. C., and Sutton, T. T. (2017). Dining in the deep: the feeding ecology of deep-sea fishes. *Annu. Rev. Mar. Sci*. 9, 337–366. doi: 10.1146/annurev-marine-010816-060543

Dunn, D. C., HarrisonA.-L., Curtice, C., DeLand, S., Donnelly, B., Fujioka, E., et al. (2019). The importance of migratory connectivity for global ocean policy. *Proc. R. Soc. B*. 286:20191472. doi: 10.1098/rspb.2019.1472

Dunn, D. C., Jablonicky, C., Crespo, G. O., McCauley, D. J., Kroodsma, D. A., Boerder, K., et al. (2018). Empowering high seas governance with satellite vessel tracking data. *Fish Fish.* 19, 729–739. doi: 10.1111/faf.12285

Harden-Davies, H., and Gjerde, K. (2019). Building scientific and technological capacity: a role for benefit sharing in the conservation and sustainable use of marine biodiversity beyond national jurisdiction. *Ocean Year Book* 33, 377–400. doi: 10.1163/9789004395633_015

Harden-Davies, H. R. (2017). Research for regions: strengthening marine technology transfer for Pacific Island countries and biodiversity beyond national jurisdiction. *Int. J. Mar. Coast. Law* 32, 797–822. doi: 10.1163/15718085-13204023

Holland, G., and Pugh, D. (eds.). (2010). *Troubled Waters: Ocean Science and Governance*. Cambridge, MA: Cambridge University Press.

Hsiao, K. C. (1991). A fast and simple procedure for sequencing double stranded DNA with sequenase. *Nucleic Acids Res.* 19:p.2787. doi: 10.1093/nar/19.10.2787

IISD (2019). *Summary of the Third Session of the Intergovernmental Conference (IGC) on the Conservation and Sustainable Use of Marine Biodiversity of Areas Beyond National Jurisdiction:19-30 August 2019*, *Vol. 25*. Available online at: http://enb.iisd.org/oceans/bbnj/igc3/ (accessed September 20, 2019).

Intergovernmental Oceanographic Commission (IOC) (2019). *Reports of Governing and Major Subsidiary Bodies: International Oceanographic Data and Information Exchange: 25th Session of IODE, Tokyo.* Thirtieth Session of the Assembly. Paris: UNESCO.

IOC (2005). *IOC Criteria and Guidelines on the Transfer of Marine Technology*. Paris: UNESCO.

IOC (2008). *Practices of States in the Fields of Marine Scientific Research and Transfer of Marine Technology: An Update of the 2005 Analysis of Member State Responses to Questionnaire No. 3, UN Doc. IOC/ABE-LOS VIII/8*. UNESCO-IOC.

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

IOC (2017b). *Ad hoc Report of the Intergovernmental Oceanographic Commission (IOC) of UNESCO to the 4th Session of the Preparatory Committee on Marine Biological Diversity of Areas Beyond National Jurisdiction (BBNJ Prepcom) (New York, 10–21 July 2017), IOC Strategy on Activities in Relation to Capacity Development and Transfer of Marine Technology.* Paris: UNESCO.

Konar, B., Iken, K., Pohle, G., Miloslavich, P., Cruz-Motta, J. J., Benedetti-Cecch, L., et al. (2010) "Surveying nearshore biodiversity," in *Life in the World's Oceans: Diversity, Distribution and Abundance,* ed A. McIntyre (Oxford: Wiley-Blackwell). doi: 10.1002/9781444325508.ch2

Levin, L. A., Bett, B. J., Gates, A. R., Heimbach, P., Howe, B. M., Janssen, F., et al. (2019). Global observing needs in the deep ocean. *Front. Mar. Sci.* 6:241. doi: 10.3389/fmars.2019.00241

Levin, L. A., and Le Bris, N. (2015). The deep ocean under climate change. *Science* 350, 766–768. doi: 10.1126/science.aad0126

Long, R. (2007). "Marine Science capacity building and technology transfer: Rights and duties go hand in hand under the 1982 UNCLOS," in *Law Science and Ocean Management,* eds M. H. Nordquist, R. J. Long, T. H. Heidar, and J. N. Moore (Martinus Nijhoff), 308–309. doi: 10.1163/ej.9789004162556.i-0.80

Long, R., Rodriguez Chaves, M. (2015). Anatomy of a new international instrument for marine biodiversity beyond national jurisdiction: first impressions of the preparatory process. *Environ. Liabil. Law Policy Practice* 6, 213–229.

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

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

Mora, C., Tittensor, D. P., Adl, S., Simpson, A. G., and Worm, B. (2011). How many species are there on earth and in the ocean? *PLoS Biol.* 9:e1001127. doi: 10.1371/journal.pbio.1001127

Muller-Karger, F. E., Miloslavich, P., Bax, N. J., Simmons, S., Costello, M. J., 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. *Front. Mar. Sci.* 5:211. doi: 10.3389/fmars.2018.00211

Organisation for Economic Cooperation and Development (OECD) (2012). *Meeting Global Challenges Through Better Governance: International Cooperation in Science, Technology and Innovation*. Paris: OECD Publishing.

Pearlman, J., Bushnell, M., Coppola, L., Karstensen, J., Buttigieg, P. L., Pearlman, F., et al. (2019). Evolving and sustaining ocean best practices and standards for the next decade. *Front. Mar. Sci.* 6:277. doi: 10.3389/fmars.2019.00277

Rabone, M., Harden-Davies, H., Collins, J. E., Zajderman, S., Appeltans, W., Droege, G., et al. (2019). Access to marine genetic resources (MGR): raising awareness of best-practice through a new agreement for biodiversity beyond national jurisdiction (BBNJ). *Front. Mar. Sci.* 6:520. doi: 10.3389/fmars.2019.00520

Ramirez-Llodra, E., Brandt, A., Danovaro, R., De Mol, B., Escobar, E., German, C., et al. (2010). Deep, diverse and definitely different: unique attributes of the world's largest ecosystem. *Biogeosciences* 7, 2851–2899. doi: 10.5194/bg-7-2851-2010

Rogers, A., Sumaila, U., Hussain, S., and Baulcomb, C. (2014). *The High Seas and Us: Understanding the Value of High Seas Ecosystems*. Oxford: Global Ocean Commission.

Royal Society (2011). *Knowledge, Networks and Nations: Global Scientific Collaboration in the 21st Century*. London: Royal Society.

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

Sandwell, D. T., Müller, R. D., Smith, W. H., Garcia, E., and Francis, R. (2014). New global marine gravity model from CryoSat-2 and Jason-1 reveals buried tectonic structure. *Science* 346, 65–7. doi: 10.1126/science.1258213

Scholin, C., Doucette, G., Jensen, S., Roman, B., Pargett, D., Preston, C., et al. (2009). Remote detection of marine microbes, small invertebrates, harmful algae, and biotoxins using the Environmental Sample Processor (ESP). *Oceanography* 22, 158–167. doi: 10.5670/oceanog.2009.46

Snelgrove, P. V. R. (2010). *Discoveries of the Census of Marine Life: Making Ocean Life Count*. Cambridge, MA: Cambridge University Press.

Snelgrove, P. V. R. (2016). An ocean of discovery: biodiversity beyond the census of marine life. *Planta Med.* 82, 790–799. doi: 10.1055/s-0042-103934

Stall, S., Yarmey, L., Cutcher-Gershenfeld, J., Hanson, B., Lernhert, K., Nosek, B., et al. (2019). Make scientific data FAIR'. *Nature* 570, 27–29. doi: 10.1038/d41586-019-01720-7

UN (1982). "Resolution on the Development of National Marine Science, Technology and Ocean Service Infrastructures", *Adopted by the Conference at the 182nd meeting on 30 April 1982. Third United Nations Conference on the Law of the Sea 1973–1982* (Concluded at Montego Bay, Jamaica on 10 December 1982. A/CONF.62/120).

UN (2015). *United Nations General Assembly, Resolution Adopted by the General Assembly, 'Transforming Our World: the 2030 Agenda for Sustainable Development'*. GA Res 70/1, 70th sess, Agenda Items 15 and 116, A/RES/70/1.

UNGA (2017a). *United Nations General Assembly Resolution 72/249. Resolution Adopted by the General Assembly. International Legally Binding Instrument Under the United Nations Convention on the Law of the Sea on the Conservation and Sustainable Use of Marine Biological Diversity of Areas Beyond National Jurisdiction*. 72nd sess, Agenda Item 77. UN doc A/RES/72/249.

UNGA (2017b). *United Nations General Assembly Resolution 72/73. Resolution Adopted by the General Assembly. Oceans and the Law of the Sea.* 72 sess. Agenda Item 77(a). UN doc A/RES/72/73.

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

Vierod, A. D., Guinotte, J. M., and Davies, A. J. (2014). Predicting the distribution of vulnerable marine ecosystems in the deep sea using presence-background models. *Deep Sea Res. Part II Top. Stud. Oceanogr.* 99, 6–18. doi: 10.1016/j.dsr2.2013.06.010

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.* 1:6. doi: 10.3389/fmars.2014.00006

Webb, T. J., Berghe, E. V., and O'Dor, R. (2010) Biodiversity's big wet secret: the global distribution of marine biological records reveals chronic under-exploration of the deep pelagic ocean. *PLoS ONE* 5:e10223. doi: 10.1371/journal.pone.0010223

Wilkinson, M. D., Dumontier, M., Aalbersberg, I. J., Appleton, G., Axton, M., Baak, A., et al. (2016) The FAIR guiding principles for scientific data management and stewardship. *Sci. Data* 3:160018. doi: 10.1038/sdata.2016.18

Woodall, L., Andradi-Brown, D., Brierley, A., Clark, M., Connelly, D., Hall, R., et al. (2018). A multidisciplinary approach for generating globally consistent data on mesophotic, deep-pelagic, and bathyal biological communities. *Oceanography* 31, 76–89. doi: 10.5670/oceanog.2018.301

Wright, G., Cremers, K., Rochette, J., Clark, N., Dunn, D., Gjerde, K. M., et al. (2019). *High Hopes for the High Seas: Beyond the Package Deal Towards an Ambitious Treaty*. IDDRI, Issue Brief, N°01/19.

Wright, G., Rochette, J., Gjerde, K., and Seeger, I. (2018). *The Long and Winding Road: Negotiating a Treaty for the Conservation and sustaInable Use of Marine Biodiversity in Areas Beyond National Jurisdiction*. IDDRI, Studies N°08/18, 82.

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