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Exposing inequities in deep-sea exploration and research: results of the 2022 Global Deep-Sea Capacity Assessment

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The 2022 Global Deep-Sea Capacity Assessment is a baseline assessment of the technical and human capacity for deep-sea exploration and research in every coastal area with deep ocean worldwide. From 200 to nearly 11,000 meters below sea level, the deep sea encompasses the single largest—and arguably the most critical—biosphere on Earth. Globally, two-thirds of all exclusive economic zones combined have water depths between 2,000 and 6,000 meters, making this a particularly critical depth range to access. This study includes information for 186 countries and territories, analyzed by subregional, regional, and income groups. The data were collected through both an online survey and manual research. We found that globally, 52% of respondents agreed that exploration and research were considered important in their community. A third of respondents agreed they had the in-country technology to conduct deep-sea exploration and research, and half agreed they had in-country deep-sea expertise. Survey results revealed that the most important challenges worldwide are funding, access to vessels, and human capacity. The top three global opportunities for deep-sea exploration and research were training opportunities, less expensive data collection technology, and better data access and analysis tools. This assessment provides the baseline information necessary to strategically develop, equitably implement, and quantitatively measure the impact of deep-sea exploration and research capacity development over the coming years. It is now possible to measure the evolution of deep-sea capacity over the next decade, an important indicator of progress during the UN Decade of Ocean Science for Sustainable Development.

KEYWORDS

marine technology, capacity development, small island developing states, UN Ocean Decade, deep submergence vehicles, deep ocean

1 Introduction

Globally, 82% of all countries and territories have jurisdiction over marine areas with depths greater than 200 meters (Bell et al., 2022b). In addition, expense, inefficiency, and inequitable access to existing tools and resources worldwide make it challenging—and often impossible—to explore, understand, and effectively manage one's exclusive economic zones (EEZs) and marine areas beyond national jurisdiction, resulting in only a tiny fraction of the deep sea being studied and characterized (Bell et al., 2022a; Amon et al., 2022d).

The concept for the Global Deep-Sea Capacity Assessment was sparked by a 2018 pilot project, 'My Deep Sea, My Backyard,' which aimed to provide deep-ocean technology and training for scientists, students, and educators in Kiribati and Trinidad and Tobago, two small island developing states (SIDS) without the capacity to explore and research their EEZs (Amon et al., 2022d). Furthermore, the publication of the 2020 Global Ocean Science Report only included the 45 countries responsible for 82% of ocean science publications from 2010 to 2018—in other words, it only included those countries with the most access to oceanographic resources (IOC-UNESCO, 2020). A more comprehensive and equitable assessment, including *all* coastal areas with deep ocean, was necessary to understand where humankind stands today.

At the same time, the imminent United Nations Decade of Ocean Science for Sustainable Development (UN Ocean Decade) and the recently adopted agreement on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction (United Nations, 2023a; United Nations, 2023b; the "BBNJ Agreement") included capacity building and the transfer of marine technology as major priorities (Ryabinin et al., 2019; Harden-Davies et al., 2022a; Harden-Davies et al., 2022b; United Nations, 2023a). Additionally, deep-sea exploitation—often without management underpinned by robust science—is rapidly emerging (e.g., Ramirez-Llodra et al., 2011; Amon et al., 2022c; Levin et al., 2023). Thus, the Ocean Discovery League convened a global team to address this challenge via the first Global Deep-Sea Capacity Assessment (Bell et al., 2022b). This assessment aimed to enable ocean stakeholders to strategically develop, equitably implement, and quantitatively measure the progress of deep-sea exploration and research capacity development throughout the UN Ocean Decade and beyond.

2 About the capacity assessment

The 2022 Global Deep-Sea Capacity Assessment is a baseline assessment of the technical and human capacity for deep-sea exploration and research in every coastal area with deep ocean worldwide (Figure 1; Bell et al., 2022b). It was released on September 15, 2022, and includes survey and/or research data for 186 geographical areas, or GeoAreas.[1]

2.1 The survey

Data collected from a 42-question online survey[2] conducted between February and December 2021 formed the foundation of the assessment. The survey included a combination of quantitative and qualitative questions. Respondents took the survey for one GeoArea at a time and as many GeoAreas as they felt qualified to represent. To increase participation in the survey, it was available in English, French, Portuguese, and Spanish, and the team sent personalized invitations to marine professionals in underrepresented GeoAreas.

2.2 The research

A team of eight researchers did manual research on the inhabited GeoAreas in their region with >1% deep sea area within their EEZ. All researchers used the same protocol[3] to identify current and prospective in-country capacity and capacity dependent on foreign partners and capabilities. The researchers' personal and contextual knowledge supported the research and allowed them to consult with professionals in their networks. Online research was conducted mainly in English, French, and

1 https://deepseacapacity.oceandiscoveryleague.org/pub/2022-data-collection.

2 https://deepseacapacity.oceandiscoveryleague.org/pub/2022-survey.

3 https://deepseacapacity.oceandiscoveryleague.org/pub/2022-research-protocols.

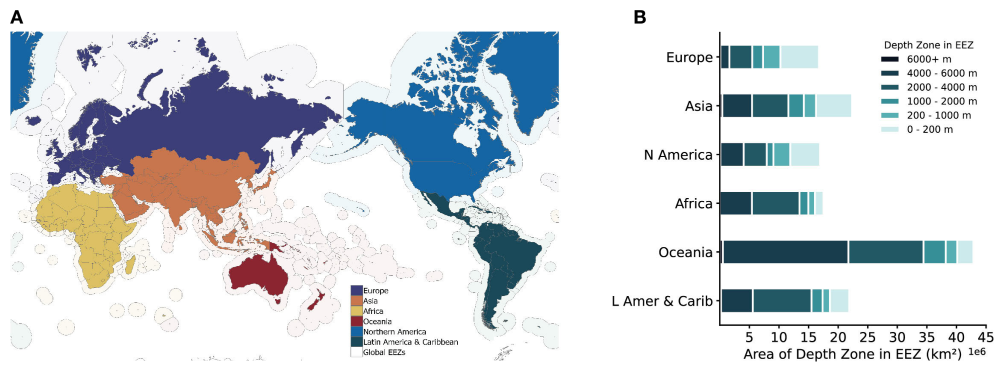

FIGURE 1
Where is the deep sea globally? **(A)** A global map illustrates of the regions included in the assessment: Europe, Northern America, Africa, Asia, Oceania, and Latin America & the Caribbean; **(B)** Area of each depth zone for all EEZs claimed in each region of the world (Bell et al., 2022b).

Spanish, but also in Arabic, Bengali, Georgian, Indonesian, Persian, and Vietnamese when needed.

2.3 The analysis

The assessment includes survey and/or research data for 186 GeoAreas: both survey and research data for 119 GeoAreas, research data only for 62 GeoArea, and survey data only for five GeoAreas[4,5]. Each GeoArea was categorized by region, subregion, SIDS, income group, and EEZ depths and areas (VLIZ, 2019; GEBCO, 2021; ESRI, 2022; UNSD, 2022; World Bank, 2022). The assessment data were analyzed and presented (1) globally[6], (2) by region[7,8,9,10,11] and (3) by SIDS/Non-SIDS and economic groups[12].

We calculated two sets of indices from these data: the Deep-Sea Capacity Status Parameters (SPs) and the Deep-Sea Capacity Indices (DSC Indices)[13]. The Status Parameters were based on survey respondents' level of agreement that they (1) have in-country deep-sea expertise, (2) have in-country deep-sea tools, and (3) that deep-sea exploration and research are considered important in their GeoArea (Figures 2A, B).

Research data documented the presence of organizations, industries, vessels, deep submergence vehicles (DSVs), sensors, and data analysis tools in each GeoArea, and survey responses identified respondents' access to and satisfaction with vessels, DSVs, sensors, and data tools in each subregion or economic group. With these data, we calculated three DSC Indices to compare locations regarding the presence of, access to, and satisfaction with each of the various capacities.

3 Key findings of the 2022 Global Deep-sea Capacity Assessment

3.1 Many who consider deep-sea exploration and research important do not have deep-sea tools and technologies

Survey respondents for several geographic and/or economic groups of GeoAreas indicated that deep-sea exploration and research was considered important in their location but did not have access to the tools and technology needed. Specifically, respondents for geographic subregions like Southeastern Asia, Western Africa, and Melanesia agreed that deep-sea exploration and research were considered important in their GeoArea, but disagreed there were in-country deep-sea tools and technology (Figure 2A). Similarly, respondents for lower-middle income

4 https://deepseacapacity.oceandiscoveryleague.org/pub/2022-global-tables/#global-data-sources.

5 https://deepseacapacity.oceandiscoveryleague.org/data.

6 https://deepseacapacity.oceandiscoveryleague.org/pub/2022-global-regions-summary.

7 https://deepseacapacity.oceandiscoveryleague.org/pub/2022-africa-summary.

8 https://deepseacapacity.oceandiscoveryleague.org/pub/2022-americas-summary.

9 https://deepseacapacity.oceandiscoveryleague.org/pub/2022-asia-summary.

10 https://deepseacapacity.oceandiscoveryleague.org/pub/2022-europe-summary.

11 https://deepseacapacity.oceandiscoveryleague.org/pub/2022-oceania-summary.

12 https://deepseacapacity.oceandiscoveryleague.org/pub/2022-sids-summary.

13 https://deepseacapacity.oceandiscoveryleague.org/pub/2022-data-collection.

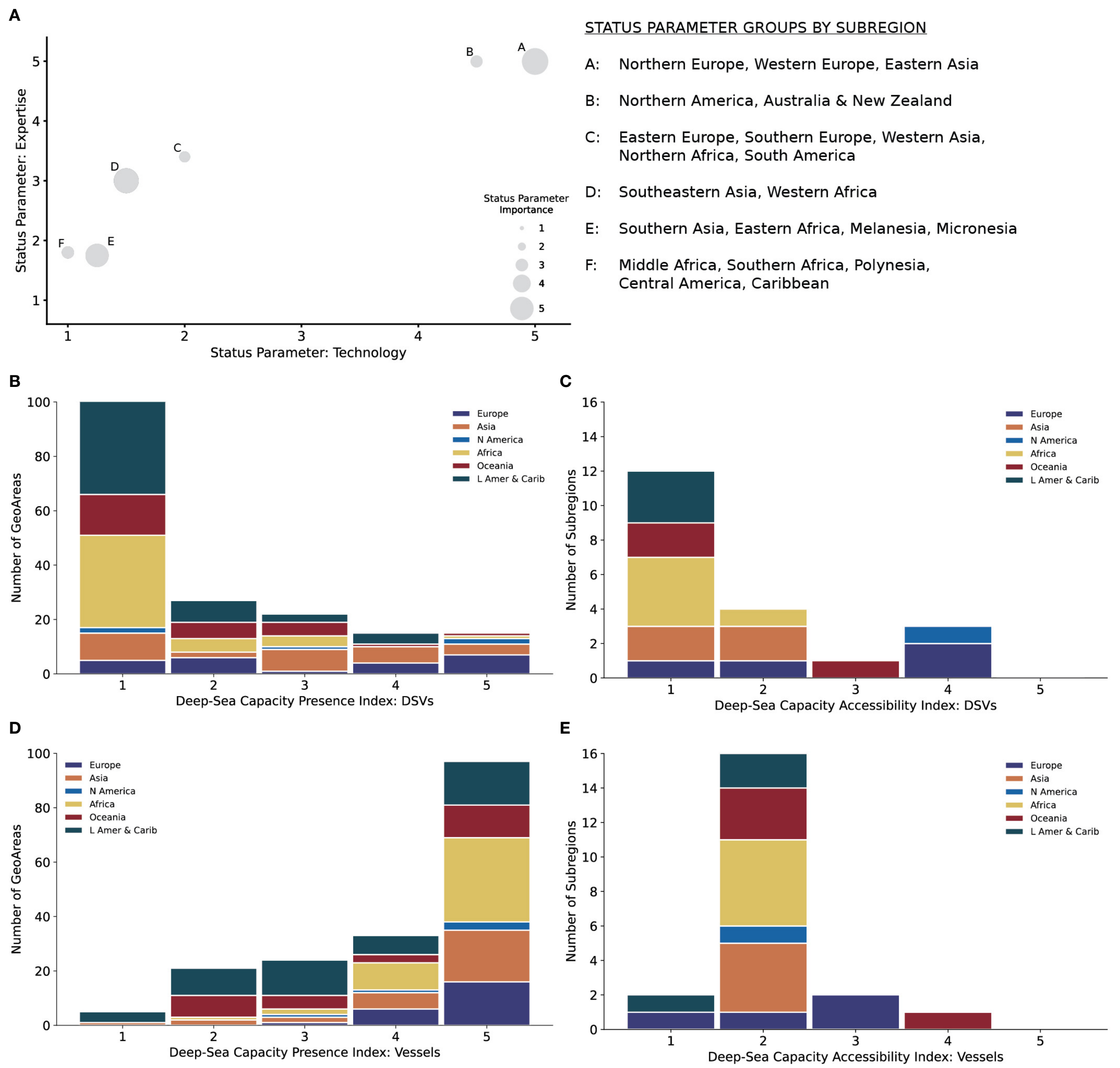

FIGURE 2
(A) Three Status Parameters (SPs) were calculated to compare respondents' perceptions of the existence of in-country deep-sea technology (x-axis) and expertise (y-axis) in their GeoArea, and whether deep-sea exploration and research is considered important in their GeoArea (bubble size). The SPs were calculated for each subregion of the world and can be used to compare similarities between locations. **(B)** Number of GeoAreas worldwide with each DSV Deep-Sea Capacity Presence Index. High DSV DSCPIs indicate higher diversity of vessel types present in each GeoArea. DSVs were the technical capacity with the lowest presence worldwide. **(C)** Number of subregions worldwide with each DSV Deep-Sea Capacity Accessibility Index. High DSV DSCAIs indicate higher respondent-reported access to vessels in their GeoArea. DSVs were the technical capacity to which respondents had the lowest access worldwide. **(D)** Number of GeoAreas worldwide with each Vessel Deep-Sea Capacity Presence Index. High Vessel DSCPIs indicate higher diversity of vessel types present in each GeoArea. Vessels were the technical capacity with the most extensive presence worldwide. **(E)** Number of subregions worldwide with each Vessel Deep-Sea Capacity Accessibility Index. High Vessel DSCAIs indicate higher respondent-reported access to vessels in their GeoArea. Vessels were the technical capacity to which respondents had the second-lowest access. (Bell et al., 2022b).

SIDS, such as Cabo Verde, Haiti, and Papua New Guinea, also agreed that deep-sea exploration and research were considered important in their GeoArea, but disagreed they had in-country deep-sea tools and technologies. More deep-sea tools are needed in locations where they are currently unavailable, particularly those that recognize the importance of deep-sea exploration and research.

3.2 In many places, there is expertise but not technology

In every subregion, respondents indicated that the presence of in-country individuals with deep-sea expertise exceeded the availability of deep-sea tools (Figure 2A). The locations with the highest ratios of in-country deep-sea expertise to technologies were in subregions such as Eastern Europe, South America, and Western Africa. When comparing economic groups of GeoAreas, respondents for high-income, upper-middle income, and lower-middle income SIDS had the highest ratios of in-country expertise to technologies. As such, more access to vessels, deep submergence vehicles, sensors, and data analysis tools could activate available expertise to conduct locally-led deep-sea exploration and research.

3.3 More deep submergence vehicles are needed globally

Deep submergence vehicles (DSVs) were the technical capacity with the lowest presence, access, and satisfaction worldwide. While some DSVs exist worldwide, the majority are concentrated in Europe, Northern America, and Asia (Figure 2B). Most respondents for Africa, Oceania, and Latin America & the Caribbean reported having no access to DSVs (Figure 2C), and half of the DSVs within those regions could not operate deeper than 200 meters, limiting researchers to shallow waters. Nearly two-thirds of respondents for SIDS reported that they had no access to DSVs. In addition, respondents were generally dissatisfied with the DSVs available to them and were least satisfied with DSV cost and availability. Globally, 71% of respondents reported that increased DSV access would have a high impact or be transformative for their work. Greater access to affordable and user-friendly deep submergence technologies capable of operating beyond 200 meters could have a transformative impact on a global scale.

3.4 Non-research assets could be available for deep ocean research

Non-research assets such as commercial vessels or data analysis tools could be used for deep-sea research. For example, while vessels were the technical capacity with the most extensive presence worldwide (Figure 2D), respondents had the second-lowest access (Figure 2E). The most abundant types of vessels found worldwide were fishing and recreational vessels. The most accessible vessel types globally were research vessels, but only in Europe, Northern America, and Asia. Respondents for Africa, Latin America & the Caribbean, and Oceania reported the most access to fishing vessels. Approximately one-third of respondents for these regions reported no access to vessels. Overall, 66% of respondents reported that increased access to vessels would have a high impact or be transformative for their work. New strategies for using non-research assets for research could open up significant opportunities for collecting and analyzing deep-sea data.

3.5 Funding is the top challenge

Increased funding and lower-cost technical and training solutions are key to increasing access to the deep sea globally. Survey respondents identified funding as the greatest challenge regardless of region, geographic group, or income group. In Europe and Northern America, vessel access was the second biggest challenge, followed by DSV access. In Asia and Latin America & the Caribbean, access to vessels and human capacity were equally ranked as the second biggest challenge. Human capacity was the second biggest challenge in Africa and Oceania, followed by access to vessels in Africa and DSVs in Oceania. For SIDS, human capacity was the second-biggest challenge, nearly equal to funding.

3.6 Prioritizing deep-sea exploration is essential

No matter the self-assessed level of in-country expertise and technology, respondents for several subregions thought their communities did not consider deep-sea exploration and research important (Figure 2A, Groups B, C, and F). Below are two excerpts from survey participants' responses on why the prioritization of deep-sea exploration and research would be beneficial for their communities:

"Additional at-sea opportunities for our youth would open jobs at diverse coastal institutions that currently do not engage in oceanographic and deep-sea research or education."– Respondent for Mexico, Central America

"Tonga is one of those countries that gives licenses for exploration in its EEZ. So for all we know from the contracting company, they can give any erroneous data, and we have no way of validating them. Tonga would benefit from an ROV."–Respondent for Tonga, Polynesia

Progress in prioritizing deep-sea exploration could be beneficial in securing long-term support for increased access to tools and training where they are most needed. In addition, a discussion about *why* deep-sea exploration and research are not considered important is also crucial so that stronger cases can be made to prioritize it.

3.7 Tailored strategies are needed for each location

Shallow-water vehicles and sensors are less expensive to manufacture and operate than those needed for deeper waters. A better understanding of the environmental requirements in each location can help ensure the greatest return on technological investments (Figure 1B). For example, over 90% of EEZs in Central America, Eastern Europe, Northern Africa, Northern Europe, and Western Asia are less than 4,000 m in depth. Accessible technologies reaching 4,000 m will unlock the vast majority of EEZs in these subregions. Furthermore, eleven out of twenty-one subregions worldwide have a maximum depth of 6,000 m; deep-sea technology capable of reaching 6,000 m would unlock access to all EEZs within these subregions. Understanding each location's operational needs could help create suitable deep-ocean technologies and strategies.

3.8 Detailed research and inclusion matter

While capacity development and technology transfer have received significant attention in recent years, there is still a need for a comprehensive understanding of global deep-sea technical and human capacity. As of January 2021, the 2020 Global Ocean Science Report was the closest analog but only included the 45 countries responsible for the majority of ocean-science publications from 2010 to 2018 (IOC-UNESCO, 2020). This lack of inclusive global information likely inhibited success. With limited baseline information about deep-sea capacity in most countries worldwide, measuring progress over the UN Ocean Decade would prove challenging, if not impossible.

With more information and perspectives gathered on deep-sea capacity than ever before, the results of this assessment were more nuanced than expected. Reaching out to people in locations often under-resourced and overlooked in many global studies created a community and a sense of inclusion but was also valuable in many other ways. Now that the deep-sea capacity gaps have been documented, it will be possible to strategically develop, equitably implement, and quantitatively measure the progress of deep-sea exploration and research capacity development.

3.9 SIDS and non-SIDS have different priorities for exploration & research

Respondents for SIDS and non-SIDS GeoAreas had different perspectives on the most important deep-sea issues in their GeoAreas. For example, climate change was important for lower-middle and upper-middle income SIDS but was not highlighted as a main issue by non-SIDS GeoAreas. Basic science was an important issue for all five non-SIDS income groups, often the most important one, while it was only highlighted by the non-classified SIDS group. Respondents for non-SIDS GeoAreas appeared to have a greater desire to explore "for the science." In contrast, respondents for SIDS prioritized their subsistence and the protection of their marine environments and communities.

3.10 Training is a critical opportunity

Respondents from different income groups looked forward to seeing different capacity developments in their GeoArea. Training opportunities, for example, were the most exciting for all low, middle, and non-classified income groups of GeoAreas.

"Having the technology is important, but even more important is building capacity and long-term technical training for staff to be able to use these tools, not just to have them."–Respondent for Iraq, Western Asia

Respondents for high-income SIDS and non-SIDS GeoAreas considered less expensive data collection technologies the most exciting opportunity, with training opportunities a close second for high-income SIDS.

4 Toward an equitable deep-sea future

The global inequities in present-day deep-sea exploration and research highlighted by the 2022 Global Deep-Sea Capacity Assessment are deeply problematic (Bell et al., 2022b), presenting significant challenges and opportunities for improvement. They result in exploration, research, and conservation agendas dominated and shaped by those from high-resource countries or regions, which often goes hand-in-hand with parachute science, the norm in deep-sea research (de Vos, 2020; Stefanoudis et al., 2021; Amon et al., 2022d; Bell et al., 2022a; Harden-Davies et al., 2022b). These inequities limit humankind's ability to explore the deep ocean from a scientific perspective, resulting in a rate of research that is too slow to understand and mitigate the pressures we are already placing on this fragile environment. They prevent many nations and regions from advancing sustainable ocean-based economies and ocean-science evidence-based policies that would create jobs, support livelihoods, and promote an equitable deep-sea future for generations to come. They exclude individuals from being inspired by the deep ocean's aesthetic, spiritual, emotional, and historical value so they may become its custodians. Decolonization and equity are at the heart of protecting the wonder and health of the ocean (Bennett et al., 2021; Trisos et al., 2021).

But these inequities present opportunities for transformative change. This capacity assessment is one tool to galvanize action. It sits amidst growing awareness and calls for more equitable research and conservation, where partnerships facilitating change are genuine, durable, equitable, sustainable, and responsive to locally-identified needs (Miloslavich et al., 2018; Woodall et al., 2021; Amon et al., 2022d; Harden-Davies et al., 2022b; Sink et al., 2023; Lopes et al., in prep). From the outset of a project, these partnerships should also be co-designed, co-developed, and co-implemented through meaningful engagement and information-sharing to build a shared understanding of the objectives, aims, and desired outcomes. Sufficient time and resources must be allocated to establish effective, long-term relationships based on mutual trust and respect. These should also be accountable, inclusive, and transparent, with periodic monitoring and evaluation.

Change is already occurring. To date, 2,750 unique users from 112 countries and territories have accessed the report. Examples from this assessment were used to inform countries' and regional groups' positions on capacity building and the transfer of marine technology at the recent negotiations on the BBNJ Agreement (Amon et al., 2022a; Harden-Davies et al., 2022c; United Nations, 2023b; Lopes et al., in prep). There are also emerging technological advancements to help close the gaps in access to tools, training, and infrastructure for deep-sea exploration and research, especially in the many countries where expertise exists. These include less expensive data collection technologies such as low-cost, easy-to-use deep-sea data collection systems (Phillips et al., 2019; Dominguez-Carrió et al., 2021; Amon et al., 2022d; Bell et al., 2022a; Novy et al., 2022), as well as better data access and analysis tools (Katija et al., 2022).

All sectors, from marine scientists and engineers to business leaders, philanthropists, and governments, have a role in transforming and supporting multi-pronged approaches to increasing truly global deep-sea exploration and research efforts. Given the centering of the blue economy with a growing focus on the deep ocean and high seas (Jouffray et al., 2020; Amon et al., 2022b), as well as the continued onset of climate change and associated interventions (IPCC, 2019; Cooley et al., 2022; Levin et al., 2023), a sustainable and equitable global ocean future will certainly depend on it.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: https://deepseacapacity.oceandiscoveryleague.org/data.

Author contributions

KB, MQ, SP, and AH conceived and designed the study. KB, MQ, DA, and SP drafted the article. All authors executed the study, revised the article critically, gave final approval of the submitted version, and agree to be accountable for all aspects of the work.

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Conflict of interest

Author TC was employed by the company Large Marine Vertebrates Research Institute Philippines Inc.

The remaining 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.

Publisher's note

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