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Stories from the front lines

Lessons for transformative ocean science from the Integrated Marine Biosphere Research (IMBeR) project

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Abstract

This paper synthesizes the key contributions and lessons learned from Integrated Marine Biosphere Research (IMBeR), a large-scale global research project aimed at fostering ocean sustainability under global change for the benefit of society. The UN Decade of Ocean Science for Sustainable Development has catalyzed a renewed focus on the importance of transforming ocean science. IMBeR's global activity over the past decade has focused on promoting transformative science by generating, mobilizing, and communicating the knowledge needed to support ocean governance. Key contributions from IMBeR participants include quantifying and comparing historic and present structure and functioning of linked ocean and human systems, advancing interdisciplinarity in ocean science, establishing a strong global network that has supported long-term collaboration, capacity building, and career development for participants. In synthesizing IMBeR contributions, we also highlight several challenges identified by the IMBeR community in developing and implementing this global research initiative. These include an uncertain and rapidly changing (and often limited) funding landscape, the reliance on significant additional workload on researchers to catalyze novel science initiatives, and the structural complexity of global networks that can at times impede rapid responses to new questions, opportunities, and overall adaptability. Opportunities for transformative ocean science include developing more resilient and equitable funding models, fostering agile, inclusive, and transdisciplinary collaborations, and strengthening the science–policy interface. This synthesis is intended to help inform and guide large-scale ocean research

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efforts and contribute to ongoing global initiatives to foster transformative science that links people and oceans for healthy and sustainable futures.

Keywords transformative science, UN Ocean Decade, interdisciplinary marine research, global research networks

Introduction

The ocean is central to human well-being, playing a vital role in regulating climate, supporting biodiversity, and sustaining livelihoods for millions of people globally (Nash et al. 2022). However, human–ocean systems are increasingly threatened by pressures acting alone or in synergy, such as climate change, overfishing, habitat degradation, and pollution (e.g. Nash et al. 2017, Malone and Newton 2020, Brodie et al. 2022). Anthropogenic pressures are projected to increase in the future under business-as-usual scenarios (Vargas-Fonseca et al. 2024). With increasing pressures and competing demands on the ocean (Jouffray et al. 2020), transformative changes in ocean systems research and its relationship with policy and governance are essential (Rudolph et al. 2020, Lombard et al. 2023). We define transformative science as the co-creation of knowledge through inter- and trans-disciplinary approaches (Kelly et al. 2019), which when coupled with an effective knowledge exchange strategy (Karcher et al. 2024), can help bridge the gap between policy and practice (see Mauser et al. 2013, Blythe & Cvitanovic, 2020 , Breckwoldt et al. 2021.

Inter- and trans-disciplinary science approaches also sit at the heart of the United Nations Decade of Ocean Science for Sustainable Development (Ocean Decade) (2021–2030) which has the aim of delivering "*the science we need for the ocean we want*'" and emphasizes the importance of transformative ocean science that is co-designed, inclusive, and actionable. The Ocean Decade also calls for greater integration between the natural and social sciences, Indigenous knowledge systems, and policy (UNESCO-IOC 2021), and aligns with science priorities of other global multilateral frameworks, such as the 2030 Agenda for Sustainable Development), the Paris Agreement under the United National Framework for Climate Change), and the Kunming-Montreal Global Biodiversity Framework under the Convention for Biological Diversity). These frameworks underscore the ocean's relevance to global sustainability targets, further reflecting the need for large-scale, interdisciplinary, and policy-oriented science for marine social-ecological systems. Transformative science in this context will significantly advance a comprehensive understanding of human–ocean systems and ocean–climate–biodiversity–society linkages, assist with the development of collaborative strategies and mechanisms to share and mobilize diverse sources and types of knowledges, and build the global networks needed to address cross-scale science and policy challenges.

However, responding to the needs and challenges of transformative science is itself a complex and uncertain endeavor. Kelemen et al. (2021), for example, outline a range of challenges and opportunities associated with "network-of-networks" approaches to science, as well as their relationships to policy and practice. Some of the key challenges inherent in such networked science efforts include, but are not restricted to, limited resource availability, constraints on catalyzing activity in the absence of clear funding models across complicated networks, the challenges of communicating impact from networked efforts, and the often-limited institutional recognition of individual efforts needed to advance large, networked science agendas. These can also generate challenges for early career researchers (ECRs) and limit their involvement in such networks, despite recognition of the critical role that ECRs must play in global sustainability initiatives (Jorgensen et al. 2019, Osiecka et al. 2021, Ferrer et al. 2021, Consentino and Souviron-Priego 2021, Brodie et al. 2022).

There are few blueprints for design and delivery of large-scale global science efforts. Available examples and lessons from anecdotal knowledge and experience point to several elements that increase the likelihood of success (Balvanera et al. 2020, Parry et al. 2020). Key messages highlight the need to incentivize researchers already facing competing demands, and to enhance the network's value by securing additional funding and fostering broader integration through workshops, conferences, and other mechanisms. In this context, Integrated Marine Biosphere Research (IMBeR) (described below) offers a timely and instructive case of how long-term, interdisciplinary, and globally coordinated marine research can: (a) contribute to the goals of the Ocean Decade and related global initiatives, and (b) provide insights and lessons for other major research networks. Notably, we build on several existing efforts to examine and synthesize the impact of IMBeR (see Hoffman et al. 2016, Van Putten et al. 2021, Cvitanovic et al. 2024, Robinson et al. 2025, Zuo et al. 2025), and we draw on key insights from IMBeR's (2016–2020) mid-term review. This synthesis is intended to help inform and guide large-scale ocean research efforts and contribute to ongoing global initiatives to foster transformative science that links people and oceans for healthy and sustainable futures.

Integrated Marine Biosphere Research

IMBER's history traces back to the early 2000s, when it was initially known as OCEANS. The project was initiated by the Ocean Futures Planning Committee of the International Geosphere-Biosphere Programme and the Scientific Committee on Oceanic Research (SCOR) to study the ocean's role in global change. It was renamed Integrated Marine Biogeochemistry and Ecosystem Research—IMBER, in 2005, with a Science Plan focusing on integrating biogeochemistry and ecosystem research for understanding the impacts of global change and the role of the ocean in the Earth System.

From 2005 to 2010, IMBER operated alongside the Global Ocean Ecosystem Dynamics program (GLOBEC). After GLOBEC ended, its Regional Programmes—specifically Climate Impacts on Oceanic Top Predators (CLIOTOP) and Ecosystem Studies of Subarctic and Arctic Seas (ESSAS)—were integrated into IMBER (Barange et al. 2010, Harris 2014). In its initial decade (2005–2015), IMBER concentrated on detailed regional and thematic studies, along with broad comparisons across different marine ecosystems (Hofmann et al. 2015). In 2016, IMBER was renamed to "Integrated Ma-

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Table 1 IMBeRs governance structure (2016–2025).

	IMBeR Structure
Scientific Steering Committee (SSC)	IMBeR's main decision-making body. Responsible for providing scientific guidance and overseeing the development, planning and implementation of IMBeR. The committee meets annually and decides upon policy and future research.
International Project Offices (IPOs)	Provide administrative (financial, logistical) support for IMBeR science plan implementation and its SSC activities and facilitate communication knowledge dissemination within and outside the project.
IMBeR Fellows	An additional advisory board, or "wise council," to further strengthen IMBeR's broad and interdisciplinary approach.
National Contacts	Participants involved in IMBeR relevant work around the world, appointed to ensure broad international participation, link national researchers and raise the profile of IMBeR nationally organized activities to the international community.
Regional Programmes	Climate Impacts on Oceanic Top Predators (CLIOTOP) Ecosystem Studies of Subarctic and Arctic Seas (ESSAS) Integrating Climate and Ecosystem Dynamics in the Southern Ocean (ICED) Sustained Indian Ocean Biogeochemistry and Ecosystem Research (SIBER)
Working Groups	Continental Margins working group (CMWG) Human Dimensions Working Group (HDWG) Integrated Ocean Carbon Research IOC-R SOLAS-IMBeR Ocean Acidification (SIOA) Submarine Groundwater Discharge Working Group (SGD-WG)
Interdisciplinary Marine Early Career Network (IMECaN)	Supports early career marine researchers by fostering collaborations through a global networking platform, offering training in areas beyond traditional education, and creating leadership opportunities, particularly for those from developing nations.
Study Groups	A capacity-development initiative that catalyzes collaboration to address emerging research needs. - Indo-Pacific Region: marine biogeochemistry, biodiversity, sustainability study group (IPR) - Ocean Color based Plant species identification and Carbon flux in the Indo-Pacific oceans (OC-PC) - Eutrophication Study Group (ESG)
IMBeR Endorsed Projects	Research initiatives that align with IMBeR's Science Plan, providing visibility within the IMBeR community and fostering collaboration. To obtain endorsement, project leaders submit an application that is reviewed by IMBeR's SSC. Endorsed projects are listed on the IMBeR website to facilitate networking and knowledge exchange.

rine Biosphere Research (IMBeR)" (with a lowercase "e") to emphasize interconnectedness of marine and human systems in its research focus and to evolve in tandem with new science priorities detailed in the Science Plan and Implementation Strategy (2016–2025; Hoffman et al. 2016). This most recent decade is our focus here.

IMBeR has developed into a dynamic, global project and network, comprising Regional Programmes, Working Groups, the Interdisciplinary Marine Early Career Network (IMECaN) since 2016, and International Project Offices (IPOs) based at different institutions and countries over time (in 2025 located in China) (see Table 1). IMBeR follows a collaborative governance model. For example, the main decision-making and management bodies are the Scientific Steering Committee (SSC) working in conjunction with the IPO which leads on coordination and communication activities, as well as budgeting of IMBeR initiatives. However, interactions across IMBeR activities and mechanisms for collaboration include advisory roles and links to national agendas (notably through IMBeR Fellows and National Contacts). Further, the coordination and delivery of IMBeR's global interdisciplinary research agenda is augmented by the members of Regional Programmes, thematic Working Groups, the IMECaN, and IMBeR Endorsed Projects. There is a relatively high degree of independence in how Regional Programmes and Working Groups are run, as each has a specific suite of science objectives aligned with the IMBeR science plan. As discussed below, this decentralized governance model has resulted in both opportunities and challenges.

Since 2016, its mission has been to develop and foster interdisciplinary marine research that contributes to sustainable ocean governance, with a focus on understanding, quantifying, and com-

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paring the structure and functioning of past and present linked ocean–human systems. The project's current Science Plan and Implementation Strategy (2016–2025) outlined a decade-long marine research agenda for IMBeR, centered on three "Grand Challenges" (GCs): (GCI) Understanding past and present ocean variability and change; (GCII) Projecting future scenarios and changes; and (GCIII) Exploring human–ocean interactions and feedback (Hofmann et al. 2016). Each challenge includes key research areas and questions. Additionally, "Innovation Challenges" were developed to target emerging scientific topics with high breakthrough potential within a short time frame, allowing IMBeR to remain responsive to new scientific developments and priorities (Hofmann et al. 2016). As noted above, the Regional Programmes and cross-cutting working groups have played a key role in augmenting and advancing IMBeR's science priorities.

Over the past decade, the IMBeR community has involved >6000 scientists, as well as approximately 1300 ECRs, participating in a wide range of activities. The international SSC provides overall leadership and scientific direction to the IMBeR community (in a manner consistent with the science plan), which is advised further through the involvement of IMBeR Fellows (additional advisory board created in 2022). There are also IMBeR "national contacts" that can help to foster collaboration among scientists conducting IMBeR-relevant research and mobilize knowledge from IMBeR activities (e.g. workshops and conferences). An IPO provides day-to-day administrative support for IMBeR activities and facilitates communication and outreach (Zuo et al. 2025). In terms of funding, IMBeR is a Large-Scale Ocean Research Project under SCOR and a Global Research Network under Future Earth, and both provide international support and periodic review of IMBeR. The current 10-year IMBeR project ended in August 2025, with a new science plan currently under development.

Methods

To undertake this synthesis, the coordinating authors (DP, EKM, MS, DA) identified and conducted semi-structured interviews with 23 current or past members of the IMBeR SSC, key representatives from Regional Programmes and Working Groups, members involved in Grand Challenges and Innovation Challenges, IMECaN representatives, and staff from the IPOs. Initial participant identification was based on IMBeR reports and website content, with additional participants recruited through snowball sampling. The purpose of the interviews was to gather participants' perspectives on IMBeR's most significant contributions over the past decade, the key factors that enabled its successes, the major barriers it faced in achieving its goals, and their views on IMBeR's future role in addressing emerging global challenges and advancing ocean science. Interviewees were subsequently invited to contribute as co-authors of this manuscript. To facilitate the collection of information, the coordinating authors developed a brief interview guide which aimed to encourage reflection and identify key insights from participants' experience. The questions were meant largely as prompts and served as starting points for discussion. Key questions were as follows:

1. What activities have you been involved in or led since you started participating in IMBeR?
2. What impact has resulted from your collaboration and/or role with IMBeR? Can you think of any practical examples of impact?
3. What were the key enabling factors for IMBeR's "successes" in fostering collaboration or generating impactful research or other outcomes?
4. What were the major barriers or challenges faced by IMBeR in achieving its goals? How were they addressed?
5. In the next 10 years, what role do you see for IMBeR in addressing emerging global challenges and supporting ocean science?

The interviews were conducted online between March and June 2025 and lasted between 20 and 60 min. Interviews were audio recorded, transcribed and then qualitatively analysed by one of the coordinating authors to identify common themes and points of collective understanding on the factors that supported and constrained IMBeR activities, and general perceptions about how to foster more transformative ocean science.

As part of the synthesis process, the coordinating authors also reviewed key IMBeR documents published between 2016 and 2024, such as the Science Plan and Implementation Strategy of IMBeR, and 10 additional reports, mostly submitted annually to the funding agency SCOR, and available on the IMBeR website (https://imber.info/news/legacy/). Finally, the co-authors of the paper were invited to attend an interactive online session to further discuss and verify the key messages, and to add any examples and perspectives that can inform opportunities for the transformative science envisioned in the UN Decade.

Results and discussion

In the following sections, we synthesize key impacts and enabling factors that have shaped IMBeR's scientific contributions. The key challenges and barriers encountered by this long-term research network are also examined, and selected perspectives on the implications for other large-scale research projects and networks are considered. These results underscore IMBeR's achievements and illustrate the broader potential of global research networks to drive transformative ocean science in alignment with the Ocean Decade, and other global sustainability initiatives.

IMBeR outputs and outcomes

The wide range of activities and initiatives catalyzed through IMBeR's grand challenges research, Regional Programmes and Working Groups, as well as conference and workshop opportunities, ultimately yield valuable scientific outputs and outcomes that would not otherwise have been accomplished in its absence. We highlight in particular the numerous scientific *outputs* (e.g. publications, scientific meetings) associated with IMBeR, and notable *outcomes* of IMBeR activities, such as key science advances and programs, support for unique interdisciplinary research and the capacity to do so, and opportunities for ECRs that shaped the trajectory of their careers.

Attributing specific scientific outcomes to the activities of large-scale research projects and networks is challenging. We have chosen to include activities that were initiated at IMBeR events, that were delivered by researchers active in the IMBeR community, or where acknowledgement to IMBeR was made by researcher leads.

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This is consistent with guidance provided to IMBeR participants on publications. Research networks like IMBeR are typically guided by a common science plan and implementation strategy (see Hofmann et al. 2016). However, IMBeR is also composed of individuals with disparate funding sources principally affiliated with other organizations and/or institutions.

Caveats aside, advances in scientific knowledge and publication outputs have been significant. IMBeR-affiliated researchers have produced >1158 publications from 2016–2024 (Fig. 1), including synthesis papers, books, reports, and special issues that integrated diverse regional insights and complex global perspectives of the ocean and its role in sustainability. The database of publications related to IMBeR since 2016 can be found at https://www.zotero.org/groups/2448334/imber_library_2/library. After 2019, IMBeR usually categorizes publications into Class 1 and Class 2. Class 1 includes those specifically generated through, by, from, or during IMBeR activities (e.g., publications arising from IMBeR conferences and from the activities of Working Groups and Regional Programmes). Class 2 includes publications of topics relevant to the IMBeR Science Plan that benefited from some interaction with IMBeR or its activities, for example by IMBeR symposium attendees, past and present SSC members, Working Group members, Regional Programmes and Endorsed Project members, or national contacts. Although IMBeR made an effort to distinguish between Class 1 and Class 2 publications, this classification was only implemented after 2019. Publications by IMBeR-related members listed above that have no direct link to or benefit from an IMBeR activity and were written as part of the authors' normal scientific work, and that would have occurred irrespective of IMBeR's existence, are no longer logged in the database after 2019.

While it is difficult to attribute these outputs solely to IMBeR, these outputs nevertheless demonstrate the networks' ability to attract and catalyze world-leading, interdisciplinary research across regions and disciplines, reinforcing its role as a platform for scientific collaboration and integration. As well, leading up to the mid-term review period (2016–2020), IMBeR produced >50 peer review papers that were published in journals with impact factors greater than 10, suggesting numerous high-profile contributions on a wide range of themes (IMBeR 2021)).

Publications and citation counts are a direct output indicator, but a key feature of IMBeR success has centered on outcomes related to new partnerships, connections to policy processes, increased diversity and representation (e.g. career stage, geography, and gender) within the IMBeR science community, and the renewal of leadership within the science teams. As stated by one IMBeR researcher, "*it's not just about having more networks, it's about how these networks can continue doing things in terms of new research or action or policy impacts*" (#23).

Another key output metric is IMBeR-led events and conferences (Table 2). For instance, between 2008 and 2025 IMBeR led three Open Science Conferences, six workshops (termed IMBIZOs), eight early career summer schools (termed ClimEco), and supported the creation of IMECaN (an early career research network). In turn, IMECaN held their own workshops and events, such as a science–policy training workshop in Croatia. According to Van Putten et al. (2021), between 2009–2019, 1827 scientists from around the world participated in these events and conferences, contributing to the development of a highly interactive ocean science community. At the third and most recent open science conference (May 2025, Shanghai, China) a further 132 in-person participants from 25 countries and regions and 65 affiliations attended over three days. If we consider online participation, numbers increase to 306 participants from 52 countries and regions and 166 affiliations. Of note, are the outcomes that emerge from these varied activities, such as the capacity to mobilize new knowledge, foster synthesis, and promote collaboration (discussed further below).

A mid-term review of IMBeR (2021)and subsequent annual reports (https://imber.info/annual-reports-to-scor-2002-2025/) have documented a wide range of science outcomes. Of note, many of these outcomes may not have been achieved in the absence of IMBeR support. However, most key outcomes are also tied to individual scientists catalyzing research programs that are funded independently. Table 3 outlines a selection of notable or primary science achievements linked to the "Grand Challenges" within IMBeR. Some of these advances include system-level understanding of the structure and function of marine ecosystems, potential future states of marine ecosystems and biodiversity, and contributions to management processes, climate adaptation and governance, and broader sustainability transitions.

There have also been key contributions to applied or policy-relevant science, including through Regional Programmes and Working Groups that contributed to IMBeR science objectives. For example, the Human Dimensions Working Group led the development of the I-ADApT decision-support tool (Assessment based on Description and responses, and Appraisal for a Typology) as a way to understand vulnerabilities and responses to global change (, Abalansa et al. 2026). Application of the I-ADApT tool has occurred in the context of specific cases (see Khaniya et al. 2025), as well as its uptake as a framework in other applied research projects (e.g. the Vulnerability to Viability Global Partnership for Small-Scale Fisheries; Too Big To Ignore).

Researchers affiliated with Regional Programmes and Working Groups, such as ICED (Integrating Climate and Ecosystem Dynamics), ESSAS (Ecosystem Studies of Subarctic and Arctic Seas), SIOA (SOLAS-IMBeR Ocean Acidification Working Group), and CLIOTOP (Climate Impacts on Oceanic Top Predators), have contributed diverse policy-oriented ocean–climate science outputs, fostered the development of new tools, methodologies and datasets (Table 3), and strengthened the science–policy interface within their respective fields of activity. For instance, the ESSAS initiative Resilience and Adaptive Capacity of Arctic Marine Ecosystems (RACArctic), supported by the Belmont Forum, included stakeholder meetings convened in Japan, Alaska and Norway with fishing and food supply companies, fishers' associations, regional fisheries management council and government representatives and representatives of coastal communities. Among other examples, the SOLAS-IMBeR Ocean Acidification Working Group collaborates with the Ocean Acidification International Reference User Group (OA-iRUG) whose objective is to share scientific findings with non-scientific audiences and science end-users, particularly policy- and decision-makers. Interdisciplinary *ad hoc* groups like the Marine Ecosystem-based Management Progress Evaluation Group were also catalyzed through IMBeR science networks (Haugen et al. 2024), with management insights and implications for related partners (e.g. International Council for the Exploration of the Sea).

Notably, it is the global reach and organizational structure of IMBeR that: (1) creates a crucially needed bridging organization for

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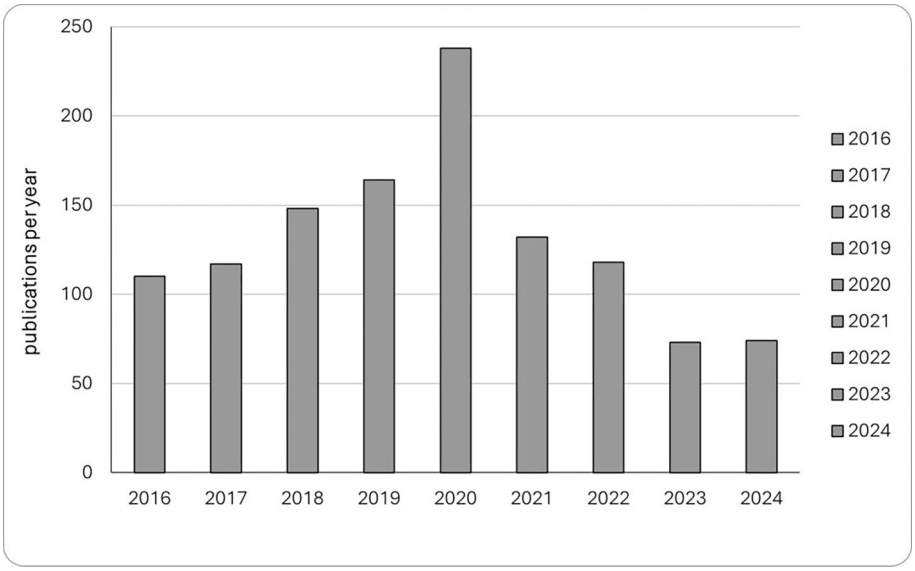

Figure 1 IMBeR-attributed publications per year from 2016–2024. (Source: https://imber.info/science/publications/).

these activities; and (2) helps to catalyze further initiatives linked to policy needs. For instance, the Marine Ecosystem Assessment for the Southern Ocean (MEASO), launched in 2018, is an innovative, policy-focused effort that plays a central role within the IMBeR Integrating Climate and Ecosystem Dynamics in the Southern Ocean (ICED) Regional Program (see Constable et al. 2023). As noted above, science advances have fed into a range of other, externally driven policy facing processes, including for example, those related to IPCC, IPBES, and World Ocean Assessment initiatives.

Another IMBeR outcome has been its success in bridging natural and social sciences and significantly advancing conditions for multidisciplinary and interdisciplinary understanding and collaboration, although more work is still to be done in this space (Van Putten et al. 2021). A growing appreciation of the importance of interdisciplinary approaches, and a better integration of social dimensions into ocean research has been a core "narrative" of IMBeR's success during the decadal science plan. Recent science guidance from the International Science Council (Kaiser and Gluckman 2023) and national granting councils highlight the important foregrounding role of IMBeR in this regard. As mentioned by a natural scientist: "*I think one of the personal impacts is my better appreciation of interdisciplinary science and being able to interact with social scientists more than I think I would have been able to do […] I really benefited from being in an environment where there were other scientists and other colleagues who were also working in this interdisciplinary space*" (#3).

IMBIZO events and the Future Oceans meetings (in 2019, 2025) have provided spaces where interdisciplinary collaborations are intellectually supported, and opportunities for more transdisciplinary research examined. Publications and long-term research agendas that spanned ecological, economic, and societal considerations have been important outcomes of IMBeR activities and include topical synthesis efforts (Bundy et al. 2017, Stephenson et al. 2021). IMBIZOs are recognized for catalyzing new areas of study, often being the first meetings on emerging themes and fostering research communities. As well, the assessment conducted by Van Putten et al. (2021) over a decade of IMBER/IMBeR events (2009–2019) shows that while Future Oceans, IMBIZOs, and Summer Schools were still attended predominantly by natural scientists, the number of attendees identifying as social scientists or combined natural and social scientists increased over time. As mentioned by a past SSC chair,

> *"[During] the first couple of IMBIZOs, the topics at the time were revolutionary in some sense because it was putting together somebody who measured bacterial respiration in the tropical ocean with somebody who was interested in food webs and then someone else who was interested in fisheries on the coastal area. And those are communities that don't interact. And IMBeR provided the space that allowed those communities to get together and talk to each other. And I think that is the long-term legacy" (#6).*

Another significant outcome of IMBeR has been the establishment of a robust global network for early career researchers (IMECaN) that has been essential for sustained collaboration and capacity building. As of 2025, IMECaN includes 1243 members from 101 countries across all populated continents, with >40% of its members being women (Palacios-Abrantes et al. 2025). Members range from students to professors, entrepreneurs, NGO and government representatives, engaging in diverse topics including marine ecology, fisheries, climate change, ocean governance, and marine biotechnology (Palacios-Abrantes et al. 2025). IMECaN has supported not only research, but also synthesis efforts (Brodie et al. 2022), professional development, and interdisciplinary dialogue (Brodie et al. 2021, Pennino et al. 2021, Kaikkonen et al. 2024, Kaikkonen et al. 2025). For instance, IMECaN played a pivotal role in connecting ECRs with senior scholars, supporting mentoring relationships that promoted intergenerational and international dialogues around the globe, and providing training to help ECRs engage more effectively with policy processes in their home countries.

> *"When IMECaN was established and then started doing their workshops and having more input into what the summer*

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Table 2 IMBeR-led events and conferences from 2016 to 2025.

Event	Description	Years	Location
IMBIZOs	IMBIZO, meaning "a gathering" in Zulu, are biennial IMBeR meetings designed to address current research topics, foster transdisciplinary collaboration, and identify future research needs. These combine workshops, plenary presentations, poster sessions, and discussion groups to integrate knowledge and highlight key questions for the IMBeR community.	2017 2021	*USA* *online*
ClimEco Summer Schools	International programs for early career marine researchers, organized by IMBeR and IMECaN. They combine lectures, workshops, and collaborative projects to enhance understanding of ocean science, climate change, and ecosystem management, while fostering interdisciplinary skills, networking, and collaboration among emerging marine professionals.	2016 2018 2021 2023	*Brazil* *Indonesia* *online* *Slovenia*
Future Oceans	The IMBeR Open Science Conferences—Future Oceans series bring together marine scientists, early career researchers, and policy stakeholders to review recent advances in ocean science, assess emerging challenges, and identify future research priorities. They provide a platform for interdisciplinary collaboration, knowledge exchange, and strategic planning to guide global marine research and support sustainable ocean management.	2019 2025	*France* *China*
IMECaN events	IMECaN Capacity Building Workshop: How to operate effectively at the science–policy–society interface	2018	*Croatia*
	Marine Spatial Planning Workshop: Balancing social, economic, cultural, and ecological objectives	2020	*online*
	IMECaN Workshop: Fostering Diversity, Equity and Inclusion into Interdisciplinary Marine Research	2022	*online*
	IMECaN Workshop: Ensuring meaningful engagement of early-career researchers in scientific collaborations	2024	*online*
	IMECaN Event: The future of early-career networks in interdisciplinary and transdisciplinary ocean science	2025	*France*
Regional programmes, Working Groups workshops and others	ESSAS Annual Science Meeting 2016	2016	*Japan*
	The 7th China-Japan-Korea IMBeR Symposium: Variability in biogeochemical cycles and ecosystem dynamics in the marginal seas of the Northwest Pacific	2016	*Korea*
	ESSAS Annual Science Meeting 2018	2018	*Alaska*
	The 8th China-Japan-Korea IMBeR Symposium and Training Course: Marine biogeochemical sciences for the sustainability of the West Pacific biosphere	2018	*China*
	Continental Margins Working Group Workshop 2018: Ecosystem-social interactions in marginal seas	2018	*China*
	4th CLIOTOP Symposium: Oceanic biodiversity under climate change: shifts in natural and human systems	2018	*China*
	Doctoral Forum—Experiencing China—Dialogue on the Maritime Silk Road	2019	*China*
	Continental Margins Working Group Workshop 2019: Ocean health and sustainability in Chinese marginal seas	2019	*China*
	ESSAS Annual Science Meeting 2021	2021	*online*
	IMBeR West Pacific Symposium: Changing West Pacific Ocean: Science and Sustainability	2021	*online*
	ESSAS Annual Science Meeting 2022	2022	*USA*
	Chinese Marginal Seas Case Study 2022 Annual Meeting	2022	*online*
	Workshop: Expanding EO data usage to address climatic changes in the marine biosphere of the northwest Pacific and Indo-Pacific regional seas (EO-WPI) project	2023	*online*
	Chinese Marginal Seas Case Study 2023 Annual Meeting	2023	*online*
	International Training Workshop on the Carbon Sequestration Estimate and Capacity Building of Coastal Blue Carbon Ecosystems in Maritime Silk Road Countries	2024	*China*

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Table 3 Selected Science Achievements, Examples and Outputs from IMBeR Grand Challenges Source: IMBeR, 2021; IMBeR Annual Reports, 2016–2024.

Grand Challenge	Selected Achievements
GC I Understanding and quantifying the state and variability of marine ecosystems	• Analysis of the impacts of climate change on Southern Ocean ecosystems, such as decreased summer sea ice extent in the Weddell Sea (Murphy et al. 2016, Cavanagh et al. 2017,Turner, 2020). • Examination of the role of krill and mesopelagic fish in Southern Ocean ecosystem structure and functioning, including carbon cycling (Manno et al. 2020, Belcher et al. 2020). • Special Issue providing the first circumpolar interdisciplinary assessment of Southern Ocean ecosystem status and trends. This first Marine Ecosystem Assessment for the Southern Ocean (MEASO) has been a core activity of Integrating Climate and Ecosystem Dynamics in the Southern Ocean (Constable et al. 2023). • Assessing stressors-combined effects of coastal "eutrophication" caused by anthropogenic nutrient inputs (cultural eutrophication) (Malone and Newton 2020). • Analysis of tuna diet and isotope data to show long-term global shifts in marine ecosystem structure and carbon cycling (Duffy et al. 2017, Pethybridge et al. 2018, Lorrain et al. 2020).
GC II Improving scenarios, predictions and projections of future ocean–human systems at multiple scales	• Providing the first assessment of CMIP6 models of projected changes in marine ecosystem drivers in response to different Shared Socioeconomic Pathways (SSPs) (Kwiatkowski et al. 2020). • Assessing the impacts of climate change and the development of future projections for regional ecosystems (Cavanagh et al. 2017, Murphy et al. 2017, Veytia et al. 2020). • Developing scenarios for the future of marine social-ecological systems, integrating an explicit representation of human activities and their drivers in oceanic socio-ecological models (Boschetti et al. 2020) and developing quantitative foresighting methods (Hobday et al. 2020). • Development of a policy-focused Marine Ecosystem Assessment of the Southern Ocean (MEASO) that aims to provide a quantitative assessment of the status and trends of Southern Ocean ecosystems to enable managers to achieve consensus in adapting their management strategies (Press 2021, Cavanagh et al. 2021).
GC III Improving and achieving sustainable ocean governance	Developing policy and legal perspectives on adaptation in transboundary fishery systems (Koubrak and VanderZwaag 2020). Designing a "quilt of sustainable ocean governance" to compare the relative strengths and weaknesses of a range of governance concepts and provide practitioners with "best practices" (Stephenson et al. 2021). Developing new governance perspectives on fisheries transitions in the context of ocean change and other drivers, and includes collaboration and participation in the Third World Ocean Assessment (Armitage et al.in press).

schools were going to address, I saw a complete change in the scope of what was being addressed [in IMBeR] that we would never naturally have talked about, and things that the early careers felt were most important to do and most important to them. And it was really good" (#12).

ClimEco Summer Schools, IMECaN-led workshops, and ECR targeted events at conferences combined training and networking opportunities, but they were especially recognized for their lasting legacy of consolidating a sense of shared identity and fostering professional relationships that continued well beyond the events themselves. IMBeR's commitment to ECR engagement not only supported research but also advanced career development and fostered regional initiatives that may not have flourished without its ability to connect people and sustain collaboration over time. For example, IMBeR regularly included an ECR keynote speaker at its Future Oceans conferences and offered multiple workshops and activities beyond the ClimEco schools. A recent assessment by Cvitanovic et al. (2024) underscores this impact, noting that over a 16-year period, eight ClimEco Summer Schools were held across six countries, bringing together 445 ECRs from 68 nations. As one interviewee remarked:

"It offered something to everyone. Whereas no matter what you worked on, IMBeR would give you a home […] and I think for me, that's really important because again, particularly through

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the early career research, we had to focus on the Global South. We had to focus on early career women research. It's like we were trying to create opportunities. And I think there's a lot of humility across IMBeR to kind of create a safe space" (#4).

IMBeR has strengthened researchers' careers by enabling access to funding opportunities, publications, and international networks and collaborations. ECRs have clearly benefited from leadership opportunities, participation in SSCs, and greater exposure to interdisciplinary science, and this has helped increase their visibility and productivity (see Kaikkonen et al. 2024), as highlighted by the same interviewee:

"I joined IMBeR as a really early career researcher, so for me personally it led to stronger networks, diversified networks, and global networks. Through those networks, we wrote papers together. So, it increased my academic productivity. It increased my funding success. It got me invited to different meetings, different workshops, different things. So, there were these personal benefits, which I see as a career accelerator" (#4).

Another participant that first engaged IMBeR as an ECR also spoke of the longer-term impacts of ECR participation, noting in particular how their experiences shaped their own approach to research partnerships later in their career:

"My entry into IMBeR…has influenced how [I] run a global partnership. We learned to be open to different ways of doing interdisciplinary work and we learned how to effectively cross science boundaries" (#23).

Enabling factors for IMBeR's successes

A key interest in this synthesis has been to identify some of the enabling factors that have led to successful initiatives or outcomes within IMBeR. Recognition of these enabling factors can potentially inform ongoing or new global research projects and networks and further build an evidence base for better practice (Parry et al. 2020, Kelemen et al. 2024). Three main themes emerged in this regard: strong community engagement, effective and inclusive leadership (across different levels), and robust structural and governance foundations of IMBeR.

A high level of group motivation and engagement consistently energized the network, fostering collaboration and shared purpose. The diversity of the community, bringing together researchers from different backgrounds and disciplines, enriched discussions, and expanded perspectives.

"Leadership skills, for example, to get people motivated and engaged in it is important. You need to enjoy it. Some people are quite happy in their own space and working with their own region and institute. And that's great. And then there's those that thrive on, I guess, value adding to their research and connecting to other scientists. I think that's an enabler when you've got those people in the room that are willing to give additional time and convince their organization that that time is worthwhile. And working late at night" (#22).

In part, the motivation and engagement within IMBeR reflects a general recognition of the "value-added" of being part of a large global research network. As one long-standing member of IMBeR summarized, being part of the research community can help individual researchers "…*articulate their contributions (e.g. to the Grand Challenges), to find a meaningful role (e.g. in a working group, the SSC), to connect to a global knowledge hub, and to provide opportunities to connect research to global challenges*" (#23).

Additionally, IMBeR's long-term reputation and the credibility of affiliated scholars helped attract participants and maintain engagement over time. Annual in-person meetings and events were considered essential for relationship-building (and friendships) that created a positive momentum for long-term engagement. Many IMBeR participants—especially those in organizational roles like Working Groups or Regional Programmes—have stayed active for a decade or more. This level of engagement is especially important in research networks that depend on volunteer time and resource contributions. As one interviewee emphasized, such enduring involvement is often underpinned by interpersonal connections and shared values developed through international collaboration:

"[…] and friendship, I think, is another enabling factor. They've become not just really good colleagues… There are similar, like-minded people working on, you know, similar problems. We discuss institutional sorts of issues, and you realize that we're all going through similar things. This type of relationship building is possible when you collaborate in this international sphere"(#22).

Effective and inclusive leadership with interdisciplinary vision and skills have emerged from participants as a critical feature of the success of IMBeR over the longer term. While the value of leadership does not come as a surprise, there are elements of effective leadership in a global research network that become particularly important, including: (1) the ability to communicate clearly in the context of different institutional practices and expectations (particularly in an interdisciplinary ocean science space); and (2) the capacity to coordinate activities, motivate teams, and facilitate international collaboration given diverse geographies, time zones, languages, and funding differences. As also noted by an expert:

"It has to be a person who is already multidisciplinary, or who has a sufficiently broad background. If it is a person who is very specialized in one thing, it doesn't work. Because IMBeR is more than one thing, isn't it? It is a project that relates to fishing, aspects of eutrophication, biogeochemical cycles, and other things. And therefore, the person has to be someone who has a vision and an appropriate background. Then it has to be a person who does not have problems dealing with various cultures" (#1)

There were numerous examples cited of the importance of individuals doing a lot of work "behind the scenes" and significant work not visible to those outside the network and highlighting the importance of people with an innate capacity to bring people together and feel part of something bigger. This includes, in particular, some individuals who have served in leadership roles within the IPO, whose caring, compassionate, and passionate engagement has been critical in sustaining participation, cohesion, and a strong sense of community across the network. As noted by one individual that has been involved in diverse roles and reflecting on their interactions, "…*you seldom meet people who are not excited or not friendly within IMBeR…and you see how you can value people at a [different] career stage, life stage, age stage, and work with engaged people, excited people*" (#23).

Individuals such as the chairs of the steering committee, IMBeR staff from IPOs, Regional Programmes, Working Groups, and IME-

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CaN have frequently been recognized for their contributions to IMBeR, over and above the regular institutional roles that they may have. According to many people that have been involved, and consistent with outcomes from the mid-term review survey, a safe and trusting environment, shaped by humility and a bottom-up philosophy, has encouraged open dialogue and experimentation within IMBeR. These features of leadership have also helped IMBeR to remain at the forefront of scientific transitions, as mentioned:

> *"IMBeR is unique because it has had a very long-term reputation for almost 20 years, every time at a tipping point, IMBeR follows or is leading the transition in the scientific community" (#8).*

Several structural factors, such as governance and funding further enabled success within IMBeR. The IMBeR governance model has revealed itself to be overall a positive foundation. This governance model has included the transition of the International Project Offices (IPOs) to different parts of the world, spreading ownership and inclusivity. The IPOs have provided essential administrative, logistical, and coordination support, working to ensure more effective operation of meetings, communications, and partnerships.

The necessity and importance of a well-supported IPO revealed itself to be a distinct factor in the ability of IMBeR to function effectively. For example, a time of transition of all IPO functions to the office in Shanghai involved a period of adjustment, while the emergence of an organization to backstop and ensure support to the IPO (in this case East China Normal University) provided timely resources needed to help navigate unexpected turbulence post-COVID. In this regard, consistent operational funding and support from SCOR and Future Earth offered stability and resources to sustain activities. As funding opportunities become less certain, and opportunities for stability diminish, the value of even small levels of baseline funding become increasingly evident.

Challenges and barriers

The enabling conditions for success in IMBeR have not always been present, and indeed, some were never fully established. Instabilities, funding insecurity, uncertainties and points of conflict have at times constrained the implementation of the IMBeR science plan and have created barriers to impact. Many engagement-related difficulties were connected to the COVID-19 pandemic (Hobday et al. 2020), which affected participation, communication, and the continuity of activities. In addition to pandemic-related disruptions, however, maintaining consistent involvement has sometimes proved challenging because of time constraints, reflecting the natural difficulty of sustaining motivation over time in voluntary-based research initiatives and networks.

While the pandemic created major disruptions, it also brought unexpected opportunities for some (although not all) research programs within IMBeR. As one expert noted:

> *"There was a silver lining and that silver lining was that almost all of the funding agencies that had awarded grants that had to be "cancelled" weren't cancelled. They were just postponed. So, what happened is that when we came out of the pandemic in 2022, it was like a coiled spring. Because all these countries had just postponed their cruises and then everybody went right back into the water and research activity. So, we had an incredible resurgence of activity. We're still riding that wave right now" (#16).*

Also challenging have been the changes and substitutions of individuals that did not have pre-existing relationships, and therefore, reflected a loss of personal and professional contacts and loss of IMBeR institutional knowledge. As noted, the loss of one of the IPOs also created a significant barrier that had to be navigated. Unsurprisingly, funding challenges emerged as a common area of concern, including situations where limited resources constrained specific actions, or in circumstances where there was a need to reconcile funders' different priorities in terms of research interests or varying approaches to interdisciplinarity. As mentioned by a senior scholar,

> *I think it has got more difficult for the community to do these types of international programmes over time. And that related to the way in which they were funded and supported by the different national groups. Not all nations and groups of nations necessarily see this type of programme and international activity as the best way to get the best science out for them. And so, some nations will focus more on their own work and their own projects, whereas other nations will work more on some of these international things (#7).*

The absence of a comprehensive fundraising strategy contributed to uncertainty about how to secure and manage financial support effectively across the network, and especially with regard to the autonomous nature of Regional Programmes and Working Groups. For some participants, writing grants for a "second" organization was also a conflict with their primary employer. An outcome of such circumstances is that significant effort is required to write proposals and secure resources for activities such as in-person meetings, and this detracts from a focus on securing resources for science-related initiatives. As one example, many diverse funding sources (or in-kind institutional contributions) are required to run open science conferences and IMBIZO workshops, and that demands significant time and energy from organizers, over and above the science programming.

Two factors that have enabled success were also revealed to be a source of some challenges within IMBeR as well. First, leadership changes inevitably affect the continuity of activities, especially those tied to the grand challenges and innovation challenges. Transitions between leaders and differences in management approaches occasionally lead to coordination and collective efforts difficulties. Second, despite the essential benefits of the interdisciplinary focus of IMBeR, integrating diverse disciplines has proven complex in practice and constrained efforts, for example, to better align activities across the Grand Challenges and Innovation Challenges. For instance, there have been unrealized opportunities for greater alignment across the Human Dimensions Working Group and Grand Challenge III due in part to transitions in the individuals involved, gaps in activity and a need to address more direct priorities or expectations for action within the science plan. A similar message that also emerged from experts was the opportunity for greater interaction among IMBeR's Regional Programmes, and specifically in ways that would align with contributions to IMBeR grand challenge themes.

Interdisciplinary barriers are not unique to IMBeR (e.g. Alexander et al. 2018). Integrating methods, terminologies, and priori-

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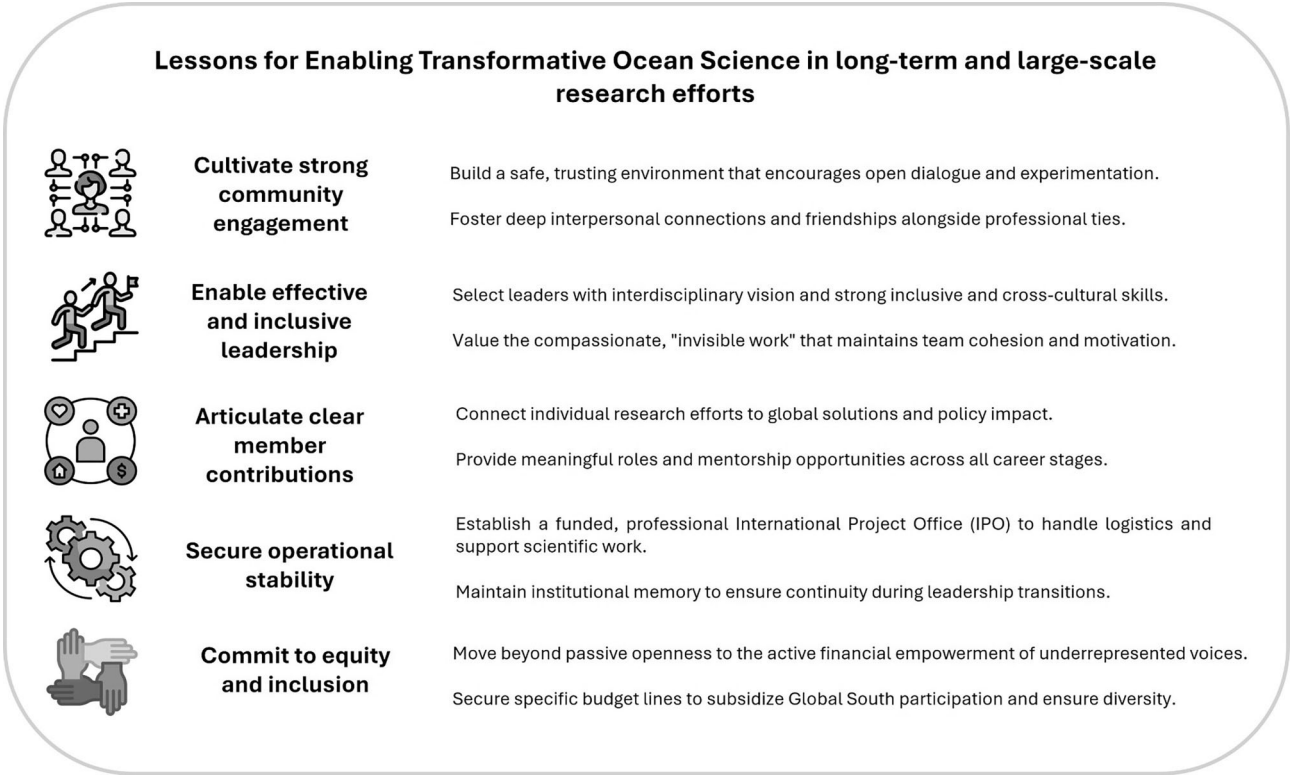

Figure 2 Key lessons from IMBeR's experience over the past decade for advancing transformative ocean science and supporting the effective implementation of other large-scale research initiatives.

ties occasionally creates obstacles to collaboration, and as a result, requires ongoing efforts to build mutual understanding and appreciation across disciplines. Engaging social scientists early on in some of the science processes has been recognized as a key to legitimacy in this regard (van Putten et al. 2021). There have been ongoing efforts to amplify this work, including a number of panel sessions at IMBeR's Future Oceans 2 conference in Brest, France (2019). This is a stated aim for IMBeR's IMBIZO initiatives as well, which are specifically designed to bridge disciplines and approaches. Still, the level of effort and interest in catalyzing or sustaining interdisciplinary efforts is linked more to individuals than to institutional expectations or requirements tied to other incentive factors (e.g. funding).

Finally, while certain structural arrangements associated with IMBeR have enabled positive outcomes, there are some elements of the IMBeR structure that have been less ideal. For instance, the emergence of parallel international ocean initiatives (outside of IMBeR) created overlaps and uncertainty about IMBeR's positioning and relevance. As noted above, Regional Programmes and IPOs have been very productive, yet they often had their own activities that were not always closely aligned with the IMBeR's global priorities (including Grand Challenges which were core to the IMBeR science plan). In addition, ensuring inclusion and broad participation across the ocean community has remained a challenge despite significant progress, particularly for researchers from the Global South. As one interviewee noted, "*IMBeR is still dominated by Western scientists and the Global North. There wasn't enough money to empower the Global South or to non-English speaking participants to be really engaged with it*" (#2). Many researchers may encounter financial, bureaucratic, and institutional barriers that can limit their full engagement in large-scale international projects. Addressing these barriers is critical to achieving a genuinely inclusive and equitable research network.

Navigating the future

Over the last 10 years, IMBeR has shown that integrating diverse knowledge systems, nurturing new generations of researchers, and building international networks can generate knowledge and partnerships that make a tangible difference for the ocean. Fig. 2 summarizes some of the main lessons for transformative ocean science based on experiences over the past decade and offers some key insights for the effective implementation of other large-scale research initiatives. For example, the strong focus on supporting in-person activities and ECRs across disciplinary silos has emerged as a stand-out feature; however, this is an ongoing and evolving process. Some of these changes may involve a stronger solutions-oriented focus to knowledge generation (i.e. information and tools to support communities and governments in the context of mitigation, adaptation and nature repair), co-developing conventional science with local and Indigenous knowledge systems into practical outputs and equitable outcomes (Mills et al. 2022), and defining a clearer niche within the crowded landscape of current international ocean programmes. Previous IMBeR efforts to concentrate on a small set of priorities may be warranted to facilitate more rapid responses and policy advice on emerging ocean challenges. For example, the Ac-

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tion Plan for the Ocean has emerged as a solutions-focused initiative and may help shape frameworks for ocean-related risk-based decision-making (see Murphy et al. 2021). IMBeR will need to evolve to remain relevant and impactful by leading on key research areas, while also complementing other ocean science research projects.

Similarly, strengthening efforts at the knowledge–policy interface is recognized as a key priority for the future (e.g. by improving connections with organizations like the Intergovernmental Oceanographic Commission of UNESCO). Like other global research networks, IMBeR has often been a "supply-side" generator of ocean science. To be clear, IMBeR activities have involved numerous points of interaction with policy makers and decision-making organizations (national and multi-lateral) that shape the science, yet the development of science outcomes in direct response to the needs of the policy community occurs through relationships, rather than by structured "design." Greater attention to co-development of research questions and developing synthesis outcomes to address emergent policy challenges is a direction that requires more consideration. There are examples of this already, however, and the experience of Regional Programmes and Working Groups generating societal impacts is noteworthy, and a model to follow in the future. Continuing to build more inclusive approaches that amplify perspectives from the Global South and underrepresented regions will also foster transdisciplinary collaborations that blend diverse knowledge systems and address policy needs.

Despite the success, there have been and will continue to be challenges that impede the progress of large-scale ocean research projects and networks, including IMBeR. Efforts to build strategic science plans must be done in tandem with a broad-based and sustainable economic foundation, built on shared partnerships and clear attention to the science–policy interface. There is greater recognition that large-scale research networks are or can serve as "boundary organizations" to link scientists (along with policy makers, communities, and other actors across jurisdictions). Such "organizations" catalyze information sharing and enhance the credibility and legitimacy of science outputs (see Cash et al. 2003, Huitema and Turnhout 2009, Crona and Parker 2012). However, the conditions in which these positive outcomes can be achieved do not exist *a priori*, and the manner in which large-scale research projects are structured and governed will have a significant influence

In this regard, IMBeR exemplifies how long-term, international research networks can sustain collaboration, continuity, and innovation in global ocean science, while also nurturing an interdisciplinary community that bridges natural and social sciences. As the UN Ocean Decade advances, IMBeR's experience demonstrates the critical importance of maintaining durable, inclusive, and adaptive scientific communities capable of addressing complex and evolving marine sustainability challenges. At the same time, the growing recognition of Indigenous and local knowledge systems is challenging long-standing assumptions about the primacy of science and evidence-informed decision-making in the global ocean agenda. Embracing such plurality of knowledge is central to transdisciplinary research and offers IMBeR and similar networks an opportunity to deepen their societal relevance and legitimacy.

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Author contribution

Prado, D. (conceptualization, investigation, formal analysis, validation, Writing – original draft) Muhl, E-K. (conceptualization, investigation, Writing – review & editing), Strand, M. (investigation, writing – review & editing), Armitage, D. (conceptualization, funding acquisition, investigation, validation, Writing – original draft), Bednaršek, N. (conceptualization, Writing – review & editing), Brodie, S. (Writing – review & editing), Cvitanovic, C. (Writing – review & editing), Claydon, J.A.B. (Writing – review & editing), Dupont, S. (Writing – review & editing), Evans, K. (Writing – review & editing), Hobday, A.J. (Writing – review & editing), Hofmann, E.E. (Writing – review & editing), Hood, R. (Writing – review & editing), Kaikkonen, L. (Writing – review & editing), Liu, D. (conceptualization, Funding Acquisition, Writing – review & editing), Melbourne-Thomas, J. (Writing – review & editing), Mueter, F. (Writing – review & editing), Murphy, E.J. (Writing – review & editing), Nayak, P.K. (Writing – review & editing), Newton, A. (Writing – review & editing), Pethybridge, H. (Writing – review & editing), Robinson, C. (Writing – review & editing), Selim, S.A. (Writing – review & editing), Trebilco, R. (conceptualization, Writing – review & editing), Trimble, M. (Writing – review & editing), Zuo, F. (conceptualization, Funding Acquisition, Writing – review & editing)

Conflict of interest

Authors declare no conflict of interest.

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Data availability

Data available on request.

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