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Successful management and mitigation of marine challenges depends on cooperation and knowledge sharing which often occurs across culturally diverse geographic regions. Global ocean science collaboration is therefore essential for developing global solutions. Building effective global research networks that can enable collaboration also need to ensure inter- and transdisciplinary research approaches to tackle complex marine socio-ecological challenges. To understand the contribution of interdisciplinary global research networks to solving these complex challenges, we use the Integrated Marine Biosphere Research (IMBeR) project as a case study. We investigated the diversity and characteristics of 1,827 scientists from 11 global regions who were attendees at different IMBeR global science engagement opportunities since 2009. We also determined the role of social science engagement in natural science based regional programmes (using key informants) and identified the potential for enhanced collaboration in the future. Event attendees were predominantly from western Europe, North America, and East Asia. But overall, in the global network, there was growing participation by females, students and early career researchers, and social scientists,

thus assisting in moving toward interdisciplinarity in IMBeR research. The mainly natural science oriented regional programmes showed mixed success in engaging and collaborating with social scientists. This was mostly attributed to the largely natural science (i.e., biological, physical) goals and agendas of the programmes, and the lack of institutional support and push to initiate connections with social science. Recognising that social science research may not be relevant to all the aims and activities of all regional programmes, all researchers however, recognised the (potential) benefits of interdisciplinarity, which included broadening scientists' understanding and perspectives, developing connections and interlinkages, and making science more useful. Pathways to achieve progress in regional programmes fell into four groups: specific funding, events to come together, within-programme-reflections, and social science champions. Future research programmes should have a strategic plan to be truly interdisciplinary, engaging natural and social sciences, as well as aiding early career professionals to actively engage in such programmes.

Keywords: marine science, research networks, disciplines, global, regional programmes

INTRODUCTION

Ocean and coastal resources are critical for human well-being and prosperity, but are also impacted by increasing anthropogenic pressures that compound natural stresses (Merrie et al., 2014; Inniss et al., 2016). The state of the oceans is changing rapidly due to climate change (e.g., warming temperatures, acidification) and increased use and access (e.g., fishing, transportation, tourism, mining) and the oceans are also a major sink for many forms of pollution (Glavovic, 2016; United Nations, 2017; IPCC, 2019). Decision-makers therefore address multiple environmental threats to the oceans to ensure effective stewardship including conservation, ecosystem-based management, enabling sustainable resource use, and improving consideration of equitable access (Fulton et al., 2014; Stephenson et al., 2019; Allison et al., 2020; Duarte et al., 2020; Friedman et al., 2020; Narita et al., 2020; Österblom et al., 2020).

Addressing these linked socio-ecological challenges effectively (Berkes and Folke, 1998; Colding and Barthel, 2019) requires networking and collaboration that unites sciences and scientists from various disciplines (we focus on social and natural scientists in particular), to understand the problems, develop suitable and equitable solutions, and inform and engage society (Fischer et al., 2011; Ledford, 2015; Viseu, 2015; Crow and Dabars, 2017; McDonald et al., 2018; Schäfer et al., 2020).

In many aspects of ocean science, the natural and social science communities are not traditional partners, and the inter- and transdisciplinary approaches (see **Box 1** for definitions) that are emerging toward achieving future sustainability are relatively new (Norström et al., 2020).

The aim of this research is to investigate the progress and challenges associated with building interdisciplinary global research networks that contribute to resolving complex marine socio-ecological challenges. We use a case-study approach focussed on the Integrated Marine Biosphere Research (IMBeR¹)

project – a global interdisciplinary marine science network (**Box 2**). The 2016–2025 IMBeR Science plan indicates the need for interdisciplinarity between all sciences but particularly between natural and social sciences in ocean research. We focus on interdisciplinarity *between* the social and natural sciences and not on interdisciplinarity *within* the natural or social science disciplines (see **Box 1**). We only explore interdisciplinarity and do not explore trans-disciplinarity which would include the use of non-scientific information.

There are many benefits to interdisciplinary collaboration, including addressing shared questions from diverse angles, generating increased common ground (Bakun, 2010), data-sharing (Hofmann et al., 2009; De Broyer et al., 2014), and support of science diplomacy (Harden-Davies, 2017). A transdisciplinary approach, where non-academic knowledge systems are integrated into social and natural science research, can improve the regional fit of research results and can be used to address socio-ecological challenges. Ultimately, in order to maximise utility and relevance of ocean science, knowledge should be co-produced and integrated across knowledge systems to align new understandings with end-user requirements (Miller and Wyborn, 2020; Norström et al., 2020). The identification of societal needs will ensure that resulting research products are more relevant and meaningful for users (Dannevig et al., 2019).

Interdisciplinary research approaches are championed because of their value (Brondizio et al., 2016; Alexander et al., 2018; Fortunato et al., 2018). Approaches that reach beyond disciplinary and academic boundaries, however, may not be straightforward. For example, institutional organisational structures often do not support the sharing of staff, resources, and intellectual property (Bridle et al., 2013; Blythe and Cvitanovic, 2020). In addition, the communication across disciplines, team building, and integration of research approaches that is required in interdisciplinary endeavours, may take longer than conventional disciplinary approaches. There are also practical difficulties (although these do not exclusively apply to

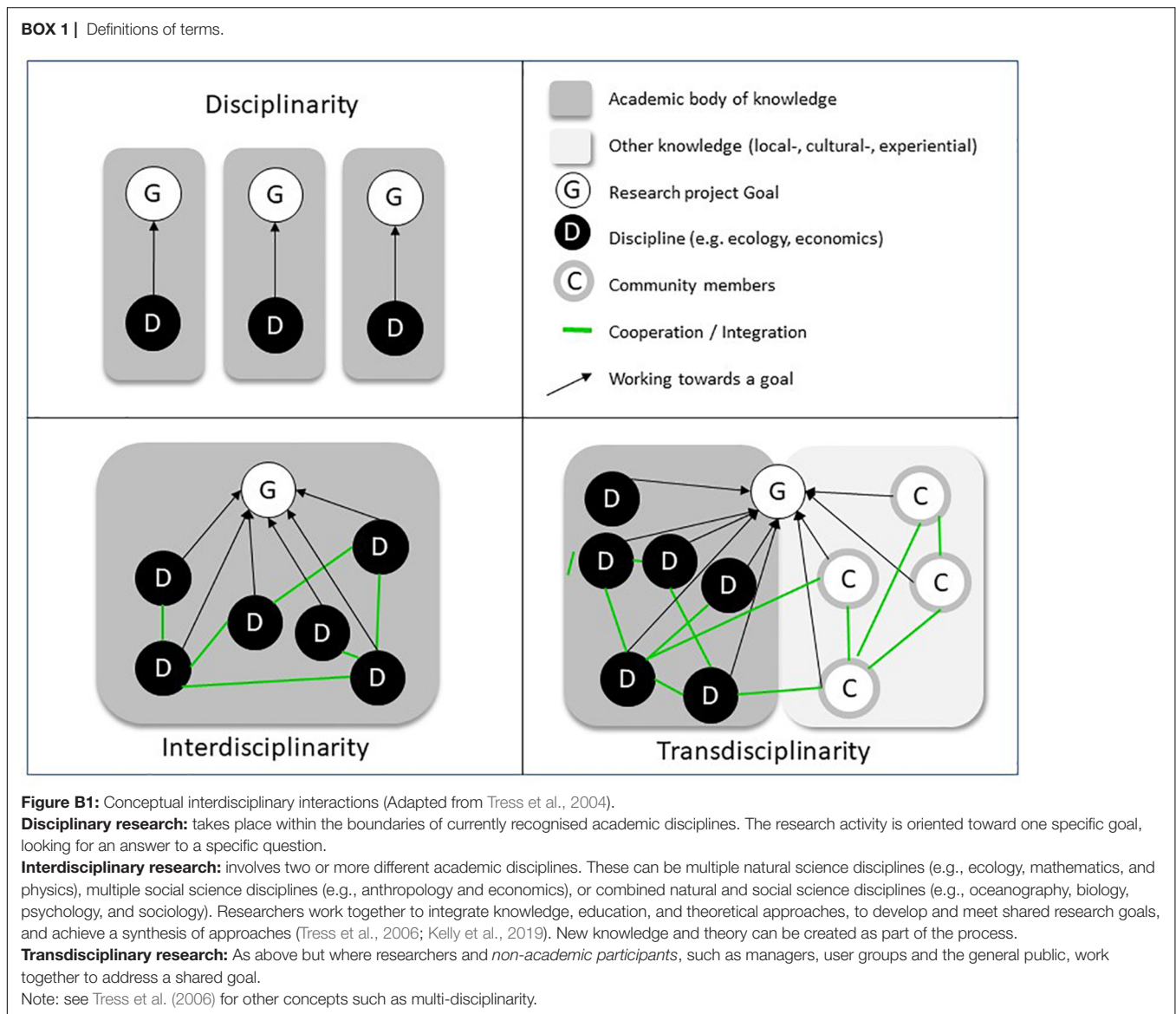
¹ Previously called “Integrated Marine Biogeochemistry and Ecosystem Research” (IMBER) now called “Integrated Marine Biosphere Research” (IMBeR).

interdisciplinary approaches), because diverse scientists bring different paradigms, skills, language and jargon, publishing approaches, and competencies (Fischer et al., 2011; McDonald et al., 2018). As an example, differences in quantitative approaches and knowledge are sometimes notable. Such difficulties are exacerbated when academic and non-academic knowledge systems meet (Cundill et al., 2015, 2019; Koch, 2020). On the whole, diversity is not always encouraged.

Nevertheless, bringing in early career professionals (ECP) from different cultural backgrounds and genders can bring important perspectives and innovation to interdisciplinary projects (Baeseman et al., 2011). Although day to day exposure is more expedient to operationalise interdisciplinarity, bringing researchers and other knowledge holders together (at workshops and conferences) to facilitate diverse collaborations also plays an important role (Lyll, 2019).

Although achieving interdisciplinarity in the marine research realm has been a goal for many decades, joined by transdisciplinary aspirations about 20 years ago, initiatives are often heavily biased to understanding the system through a natural science focus (e.g., climate science, oceanography, biogeochemistry and ecology). True cooperation with the social sciences (i.e., from project inception through to development) based on mutual trust, commitment and support, remains rare (Eigenbrode et al., 2007; Morse et al., 2007; Robinson et al., 2012; Viseu, 2015; Hollowed et al., 2020).

The implementation of an inclusive and integrated approach to knowledge building is important for marine research across a range of spatial scales (Bulkeley, 2005; Charles, 2012); many activities that threaten ocean health occur at local and regional levels, but their impacts are felt nationally and globally



BOX 2 | The Integrated Marine Biosphere Research (IMBeR) project.

Integrated Marine Biogeochemistry and Ecosystem Research (IMBER, or OCEANS as it was initially known) was established in 2002 by the International Geosphere-Biosphere Programme (IGBP) and the Scientific Committee on Oceanic Research (SCOR) in anticipation of the ending of the Joint Global Ocean Flux Study <http://ijgofs.whoi.edu/>. It was also recognised that there was a need for a global marine research project to continue the study of the biological and chemical aspects of the ocean within the context of global change. In 2005, the IMBER project published its Science Plan (IMBER 2005) (Hofmann et al., 2015). A name change occurred in 2016, IMBER became IMBeR (Integrated Marine *Biosphere* Research), together with a new Science Plan and Implementation Strategy reflecting the focus toward the human dimensions of global change and ocean sustainability <http://imber.info/science/imber-science-plan-and-implementation-strategy-spis/>. In addition to being sponsored by SCOR, IMBeR is one of Future Earth Global Research Projects <https://futureearth.org/networks/global-research-projects/> that undertakes research for sustainable development, including interactions between the terrestrial, coastal, and ocean environments.

Initially, IMBeR's project administration was hosted at the European Institute of Marine Studies in Brest, France (2005–2012), and then at the Institute of Marine Research in Bergen, Norway (2012–2020). Since April 2020, project administration has been undertaken by two International Project Offices — one at Dalhousie University in Halifax, Canada, and the other at the East China Normal University in Shanghai, China.

The development and implementation of IMBeR science, in accordance with the Science Plan and Implementation Strategy, is overseen by a Scientific Steering Committee (SSC) — a group of approximately 15 appointed members, who volunteer their time and expertise for a period of between three and six years. The SSC is led by the IMBeR chair. There have been three Chairs of the IMBeR Scientific Steering Committee: Julie Hall (2005–2010) specialises in plankton and microbial foodwebs, Eileen Hofmann (2011–2016) studies physical-biological interactions and physical oceanography, and Carol Robinson (2017–2021) works on the role of marine bacteria, phytoplankton and zooplankton in global carbon cycling., and seeks to achieve geographic, gender, and disciplinary balance.

(United Nations Oceans and Law of the Sea, 1995; United Nations Educational Scientific and Cultural Organization, 2017)². Researchers must collaborate and network with colleagues and other knowledge holders across the globe if a comprehensive integration of (marine) science at disparate spatial scales into collaborative and societally relevant knowledge building is to be achieved (Xavier et al., 2016a; Hobday et al., 2017; Marandino et al., 2020). However, collaborating to address sustainability issues at the global scale can become particularly complicated as a result of political, social, and cultural complexities (Mallin and Barbesgaard, 2020), and regional and local research collaborations have outpaced global collaborations to date (Zuo and Zhao, 2018). Despite this, countries and regions remain intertwined through their use of and reliance on the ocean, and the successful management and mitigation of marine challenges depends on cooperation and knowledge sharing, which often occurs across culturally diverse geographic regions [e.g., regional management of tuna fishing (Sinan and Bailey, 2020), designation of protected areas, addressing illegal, unreported and unregulated fishing (IUU)]. Global ocean science collaboration is therefore essential for developing global solutions.

To enable global science collaboration, large-scale (global) research networks, such as the 19 different Global Research Projects¹ that underpin *Future Earth* have been created. These global projects (here also referred to as global networks) all have a different focus (i.e., marine, mountains, atmosphere, land) but most have similar aims: to support, coordinate and foster world-wide scientific research and provide a hub for this global scientific research (through synthesising and promoting). The use of an interdisciplinary approach to promote new science to address global issues is central to achieving the aims of the global networks (as for example stated by, Analysis, Integration, and Modeling of the Earth System (AIMES) <https://aimesproject.org/Global Mountain>

Biodiversity Assessment (GMBA) GBRMPA Integrated Land Ecosystem-Atmosphere Processes Study (iLEAPS). The networks all aim to facilitate communication and dialogue between scientists, and also between scientists, policy makers, and stakeholders. The global networks also promote science leadership and build capacity of Early Career Scientists (ensuring developing countries also benefit). The creation of opportunities for scientists to link up, communicate, and build capacity through events and conferences is central to all global programmes.

The expansion of these global networks is, however, outpacing knowledge on how to effectively build them (Hennemann et al., 2012). For instance, we have only started to understand how these networks can incorporate local and regional science information in order to successfully address global challenges (Gerhardinger et al., 2018), and importantly, whether their aim of interdisciplinarity is being achieved at the regional *and* global level. Learning from the experiences of global networks developed thus far will provide opportunities to improve and create successful practices for existing and future initiatives (van der Hel, 2016). In an effort to identify and better understand what has worked or not thus far, particularly in achieving interdisciplinarity in global research networks, we evaluate IMBeR as a global network case study. There are some differences between IMBeR and other global networks, such as the focus on the marine environment and the associated role of the Regional Programmes (as explained elsewhere). But as highlighted above there are many similarities in the stated aim to implement an interdisciplinary approach to scientific research, to create opportunities to connect scientists and others by means of conferences and events, and to be inclusive toward ECRs and developing countries. The lessons learned from our case study will therefore be applicable to other global networks.

We therefore aim to explore interdisciplinary practice using the case study of IMBeR. We explore this topic by bringing together expert insights and event attendance data analysis. The event attendance data helps understand (1) how opportunities for inclusive engagement (in terms of discipline, career stage, and geographic spread) at the whole-of-project (global) level

²See also the International Geosphere-Biosphere Programme (IGBP, <http://www.igbp.net/>) an international research initiative from 1987–2015 to coordinate research on global- and regional-scale interactions between the Earth's biological, chemical and physical processes and their interactions with human systems. Global Ocean Ecosystem Dynamics (GLOBEC) and IMBER were both marine research projects of IGBP, set up to complement their land and atmosphere projects.

through events and conferences have developed over time; and the expert insights help (2) identify opportunities for enhanced interdisciplinary collaboration within global networks. We argue there is an urgent need to improve the sharing, integration, and application of interdisciplinary ocean science (United Nations, 2017) and outline effective ways through which this might be achieved.

Study: IMBeR

There are currently approximately 4,400 registered members in the global IMBeR science network (see **Box 2**). IMBeR science is predominantly undertaken by four Regional Programmes, four Working Groups, and an interdisciplinary Early Career Network (**Table 1**).³ The first IMBeR Science Plan (2005–2015) dedicated one of its four themes to the human dimension, namely, Responses of Society.⁴ The importance of including humans as both drivers and recipients of change, together with an interdisciplinary approach to marine science were specifically highlighted in 2010. Since then, IMBeR has evolved from being a mostly natural science project, to one where inter- and transdisciplinarity are actively promoted (Bundy et al., 2016). The 2016–2025 IMBeR Science plan specifically states that “collaborative, disciplinary, interdisciplinary, transdisciplinary and integrated research that addresses key ocean science issues generated by and/or impacting society is required to provide evidence-based knowledge and guidance” (Hofmann et al., 2016, p. i).

Methods

Using the IMBeR global science network as a case study, we investigated several data sources to explore our two aims:

1. IMBeR records of attendance at events and conferences provided insight into opportunities for natural and social scientists (at various career stages and from different geographic origins) to come together and collaborate to address interdisciplinary marine issues.
2. Experts provided qualitative insights into the social and natural science interactions and interdisciplinary collaborations within Regional Programmes through key informant interviews. The key informants are co-authors and in contributing to this paper they refined any insights.

IMBeR Event Attendance Data

IMBeR organises three different types of events⁵: Open Science Conferences (OSCs) held at five-year intervals that provide

³As part of the IMBER-GLOBEC merger in 2010, ESSAS and CLIOTOP, moved to IMBER. The ICED science plan (2008), is a joint GLOBEC-IMBER document that defined the programme that became the ICED Regional Programme under IMBER/IMBeR. SIBER was initiated by IMBER at the request of Indian Ocean researchers who wished to continue the work undertaken during JGOFS.

⁴The four themes were; 1. Interactions between biogeochemical cycles and marine food webs, 2. Sensitivity to global change, 3. Feedbacks to the Earth system and 4. Responses of society.

⁵A fourth event is held bi-annually (China-Japan-Korea (CJK) symposiums) for which no records were available.

a platform to deliver an update of the pertinent science and research direction; biennial IMBIZOs⁶ consisting of three concurrent, but interacting workshops that address current research topics and facilitate interdisciplinary research (informed by the IMBeR Science Plan); and biennial Climate and Ecosystems Summer Schools (“ClimEco”) for marine early career professionals led by interdisciplinary scientists with a focus on different topics relating to global change and human and ocean systems. To address the first aim of this paper, we investigated the diversity of participants attending IMBeR events, by considering their demographic information, career stage (students, early career researcher⁷, or researcher), gender, nationality, and country of residence. The disciplines for all attendees were self-reported as part of the conference registration process. Where disciplinary information was missing, a web-search was undertaken. Data was available for events held between 2009 and 2019 (two open science conferences, five IMBIZOs and four ClimEco Summer Schools) and are provided in the **supplementary materials** (deidentified).

Key Informant (Expert) Survey

Eighteen scientific researchers currently leading and/or collaborating within the IMBeR Regional Programmes were approached (hereafter, “key informants”). The key informants were identified by the IMBeR International Project Office and via recommendations from the Regional Programme Chairs [i.e., snowball sampling (Goodman, 1961)] and were selected based on four criteria:

1. They had a range of experience working in research teams (though not necessarily interdisciplinary teams);
2. They held senior positions in their research organisation (i.e., senior manager, professor, principal research scientist);
3. They had a (current or past) history of engagement with IMBeR and were associated with the Regional Programmes; and
4. They represented a range of research backgrounds and geographical locations.

A qualitative questionnaire was implemented (**Appendix A**) to elicit information on the key informants’ experiences and perceptions of interdisciplinary collaboration between natural and social scientists within the Regional Programmes and/or IMBeR more broadly. The open-ended questions (that did not have a word limit) specifically focussed on key informants’ past engagement and their views on the value of social science engagement. They were asked to identify factors that could enable or hinder future engagement with the social sciences. Responses to the survey were analysed using the qualitative data analysis software (NVIVO 12, QSR International). A content analysis was applied to the survey responses, a technique where

⁶IMBIZO is the Zulu word for “a gathering.”

⁷Early career researcher was defined as less than eight years after completion of their Ph.D. or masters degree. Note that early career professionals include students, whilst early career researcher is restricted to those who have completed a Ph.D. or Master degree.

TABLE 1 | IMBeR Regional Programmes and Working Groups and their aims.

Regional Programme	Acronym	Aim
Integrating Climate and Ecosystem Dynamics in the Southern Ocean	ICED	better understand integrated circumpolar dynamics of climate and ecosystems in the Southern Ocean to support sustainable management approaches (Murphy et al., 2008)
Sustained Indian Ocean Biogeochemical and Ecological Research	SIBER	understand biogeochemical cycles and their interactions with marine ecosystem dynamics in the Indian Ocean (Hood et al., 2011, 2016)
Ecosystem Studies of Subarctic and Arctic Seas	ESSAS	quantify and predict the impact of climate change on the productivity and sustainability of Subarctic and Arctic marine ecosystems (Drinkwater et al., 2012)
Climate Impacts on Top Oceanic Predators	CLIOTOP	worldwide perspective of open ocean ecosystems and interactions of top predators (Lehodey and Maury, 2010; Hobday et al., 2017)
Continental Margins working group	CMWG	address global, regional, local, and human pressures interactively affecting continental margin biogeochemical cycles, marine food webs, and society
Human Dimensions Working Group	HDWG	understand interactions between human and ocean systems, recognising that humans not only influence ocean systems, but also depend on ocean systems for goods and service (Guilloteau et al., 2018)
Integrated Ocean Carbon Research Working Group	IOC-R	better understand and quantify the ocean carbon cycle in light of the rapid changes that are currently occurring and will occur in the near future
SOLAS-IMBeR Ocean Acidification Working Group	SIOA	coordination of international research efforts and synthesis activities in ocean acidification
Interdisciplinary Marine Early Career Network	IMECaN	Provide a networking, training, and leadership platform to develop collaborations, foster international networks, and offer opportunities to marine early career professionals.

Note that in this perspective we focus mainly on the Regional Programmes.

narratives are systematically coded according to themes and the relationships among those themes (see also Kelly et al., 2019; **Table 1B** and **Appendix B**). The themes were largely structured from the design of the questionnaire survey (i.e., questions on *past engagement with social scientists*, *perceptions of social scientists*, *value of engagement*, etc.). The results were continually verified against the raw data from which they were derived. Collective author reflection⁸ (by those that designed the survey and the key informants that provided responses to the survey) on the themes resulting from the analysis further verified the relevance and value of the results (see also Kelly et al., 2019).

RESULTS

IMBeR Events and Attendance

A total of 1,827 scientists from 11 global regions were involved in the 11 IMBeR events (OSCs, IMBIZOs and Summer Schools) convened by IMBeR since 2009. Attendees predominantly resided in western Europe, North America, and East Asia (Peoples Republic of China (including Taiwan), South Korea, and Japan (**Figure 1**). Across all events, 46%

of participants were female, and 21% of participants attended more than one event.

There were also regional differences in the career level of attendees (**Figure 2**). Proportions of early career researchers from North America, East Asia, Europe, Australia, and New Zealand were all below 50%. However, almost three quarters of all student and early career attendees (503 out of a total of 691) were from these regions.

Over time, the proportion of early career researchers and students attending IMBeR events has also increased to around 40% of the total (**Figure 3**), each growing to around 20% in 2019 (note: only IMBIZO and OSC events are shown, as the ClimEco Summer Schools are attended exclusively by students and early career researchers).

Records of the disciplinary backgrounds of attendees were only available for the ClimEco Summer School events (consisting of students and early career researchers). While these events are still attended predominantly by natural scientists, the number of attendees identifying as social scientists or combined natural and social scientists has increased over time (**Figure 4**).

Across all IMBeR events, females were underrepresented in five of the global regions (assuming a sex ration of 1:1); and likewise, males were underrepresented in five regions. Over time, the proportion of female attendees has increased and has been higher than that for male attendees since 2015. ClimEco Summer Schools were attended by more females (55%) than males, and females represented 71% of European attendees (see **supplementary materials** for de-identified data). The gender balance was close to 1:1 at the OSCs (51% male), but was less equal at the IMBIZOs (39% female, 61% male).

⁸Because the respondents were also co-authors no ethics approval was needed for the survey (see for instance also Norström, A. V., Cvitanovic, C., Löf, M. F., West, S., Wyborn, C., Balvanera, P., Bednarek, A. T., Bennett, E. M., Biggs, R., De Bremond, A., Campbell, B. M., Canadell, J. G., Carpenter, S. R., Folke, C., Fulton, E. A., Gaffney, O., Gelcich, S., Jouffray, J.-B., Leach, M., Le Tissier, M., Martín-López, B., Louder, E., Loutre, M.-F., Meadow, A. M., Nagendra, H., Payne, D., Peterson, G. D., Reyers, B., Scholes, R., Speranza, C. I., Spierenburg, M., Stafford-Smith, M., Tengö, M., Van Der Hel, S., Van Putten, I. and Österblom, H. (2020), "Principles for knowledge co-production in sustainability research," *Nature Sustainability* Vol. 3, pp. 182–190.

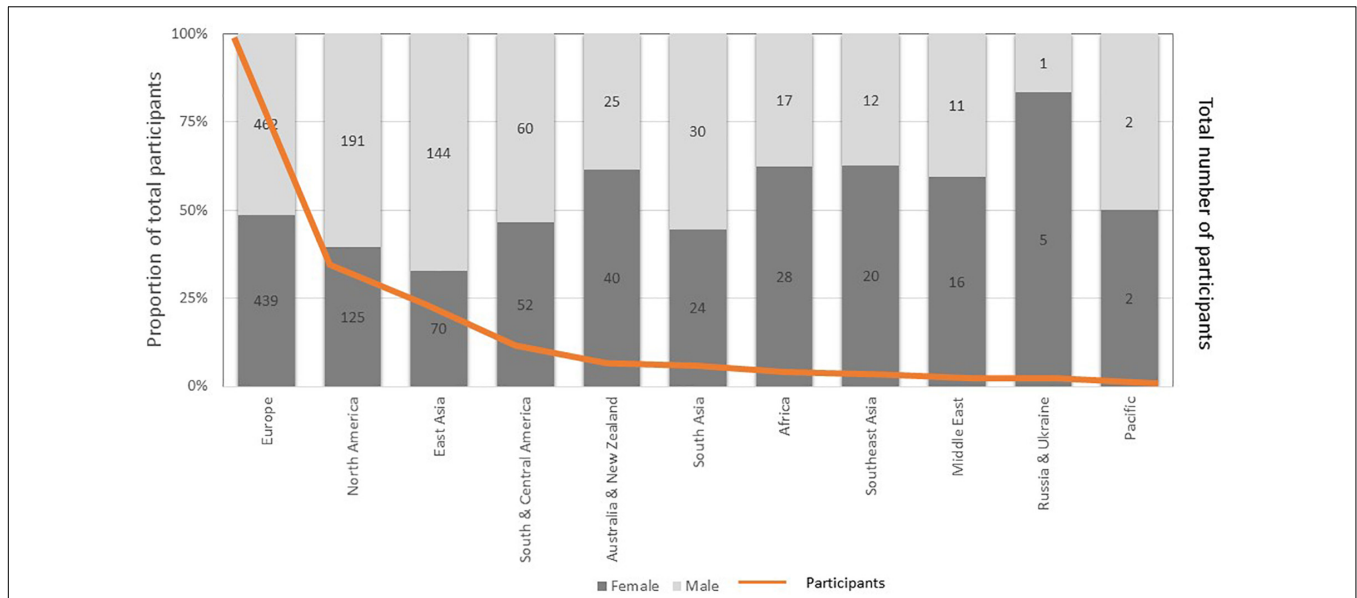


FIGURE 1 | Regional origin of attendees at IMBeR events (the Open Science Conferences, IMBIZOs, and ClimEcos) by gender as a proportion of total (actual numbers are provided inside the bars).

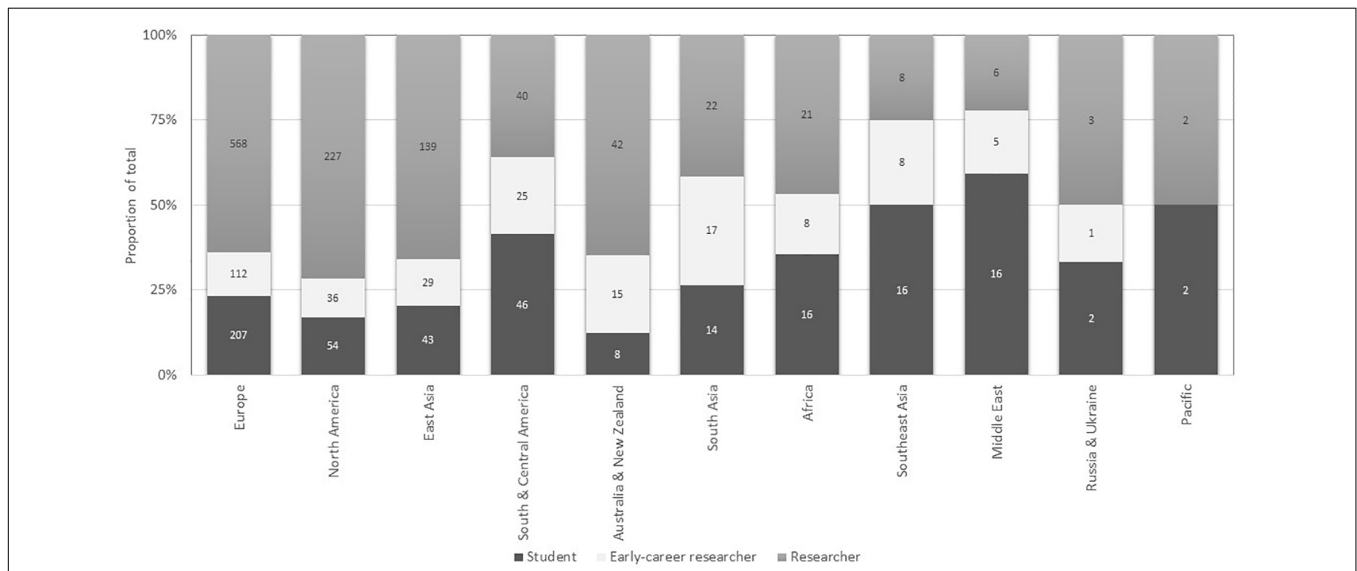


FIGURE 2 | Regional origin of attendees at IMBeR events (the Open Science Conferences and IMBIZOs) by career level as proportion of total (actual numbers are provided inside the bars). ClimEcos not shown as they are targeted at students and early career researchers.

Key Informant Survey Results

The 18 key informants represented all four IMBeR Regional Programmes and included members of IMBeR’s Scientific Steering Committee (Tables 1C, 2C, 3C, Appendix C). They were predominately located in western countries (i.e., United States, Australia, New Zealand, United Kingdom, Spain, Germany, Portugal, Canada, Norway) and generally had expertise in natural sciences (ecology, oceanography, marine biogeochemistry, fisheries science, etc.), although some also highlighted more social-focussed expertise (i.e., marine

policy, human use of marine resources, social-ecological systems, etc.). Only one key informant identified themselves as interdisciplinary. On average, these key informants have been involved in IMBeR for 10.2 years (median 10 years). Key informants were all senior scientists or professors. The key themes derived from the qualitative analysis were largely derived from the structure of the questionnaire survey (i.e., *past engagement with social scientists, perceptions of social scientists, value of engagement*, etc.). These themes are described below, and interviewee quotations (de-identified using codes)

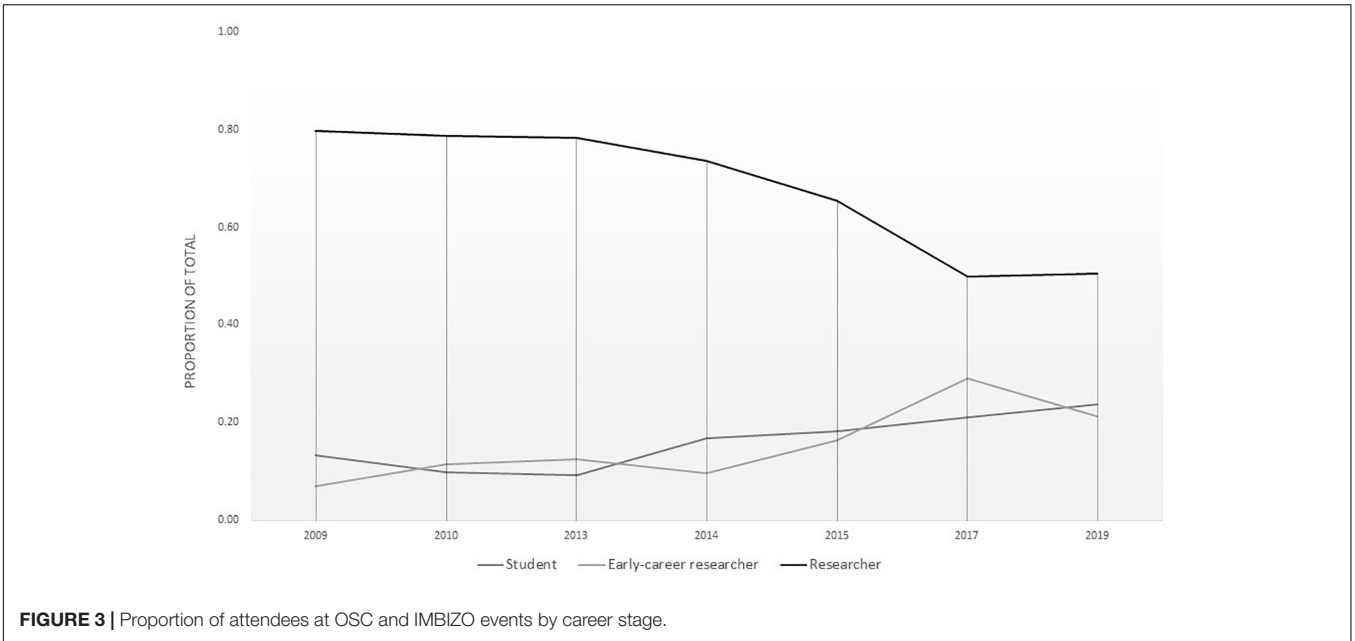


FIGURE 3 | Proportion of attendees at OSC and IMBIZO events by career stage.

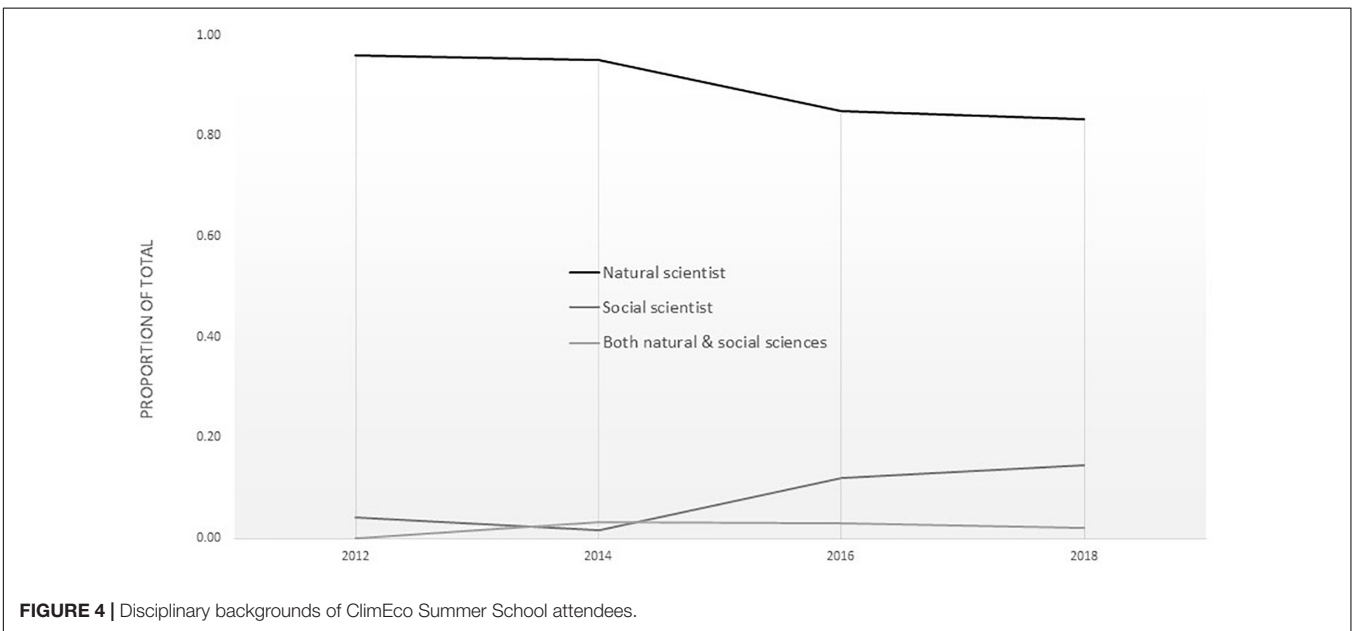


FIGURE 4 | Disciplinary backgrounds of ClimEco Summer School attendees.

are used to elucidate and describe the themes in context. The interviewee quotations used below are intended to be descriptive, and not representative, of scientific researchers working within IMBeR.

Past Engagement With Social Scientists

Key respondents indicated that, in most Regional Programmes, interactions with researchers from the social sciences were largely initiated at natural science meetings. The focus of these science meetings centred largely around natural science agendas. However, key informants identified that past engagement with social scientists had achieved mixed

success overall (9 positive responses out of 17). One informant reflected that:

“The (current) [IMBeR] structure makes it difficult to link to any one of the Regional Programmes” (Key Informant #18 – IMBeR SSC).

Where there has been limited or no engagement, this is largely reflective of (i) the dominance of natural science (i.e., biological, physical) goals and agenda of the programmes, and (ii) the lack of support from the institutions the researchers worked at to initiate connections with the social sciences. Despite this, our thematic analysis (using NVivo) found that all key informants recognised

the (potential) benefits of working with social scientists, including developing connections and interlinkages, broadening their respective understanding and perspectives, and making science more useful for end-users. For example, key informants noted:

“Engaging with social scientists [...] has given me a much better appreciation of the consequences of climate change on marine resource dependent communities” (Key Informant #6 ESSAS);

“Through discussion with (social scientists) I learned the formats in which our science can be useful to them” (Key Informant #7 ESSAS);

“The diversity of disciplines means you get a much more holistic understanding of the different aspects of marine science” (Key Informant #17 SSC).

The key respondents perceived several challenges to connecting with/engaging social scientists within their Regional Programmes, including: programme research priorities; access to funding and other resources; cross-disciplinary communication; limited opportunity to engage; and scientists’ interest (i.e., personal research interest and also programme focus). For example:

“The interactions were not well facilitated” (Key Informant #1 CLIOTOP);

“The challenge is to envision integrative cross-disciplinary projects and get them funded” (Key Informant #5, CLIOTOP);

“Keeping people engaged and finding time and space for scientists to come together (is difficult)” (Key Informant #4 CLIOTOP).

Perceptions of the Value of Social Science Engagement in IMBeR’s Regional Programmes

All key informants across the programmes had positive perceptions of the (potential) added value of social science contributions. However, they highlighted that social science research would not be relevant to all the aims and activities of the Regional Programmes. They emphasised that creating opportunities for fruitful engagement with social scientists is necessary to co-create relevant and useful questions and that there needs to be much more work in this regard across all parts of IMBeR. Furthermore, they held diverse views of how social scientists might help to address the programme challenges:

“Setting the context/management of the marine environment is actually management of humans” (Key Informant #5 CLIOTOP);

“(Social scientists are needed for) engaging stakeholders, evaluating social and legal institutions and regulations, translation at disciplinary boundaries, participation in co-production” (Key Informant #13 ICED).

Some uncertainties were also expressed.

“The main role for social scientists is not particularly clear” (Key Informant #15 SIBER).

Again, all key informants agreed on the need to co-develop research questions and agendas with social scientists and provided suggestions for refining or creating new programme challenges that could accommodate the interests and capacities

of social scientists (see section “Enabling Engagement With Social Scientists”).

Enabling Engagement With Social Scientists

Around one third of the key informants who were natural scientists did not have any experience working with social science disciplines. Their experiential knowledge, therefore, could not inform their views on the role or potential for collaboration with social scientists within the Regional Programmes they contributed to. The remaining key informants identified several potential roles for social scientists within the Regional Programmes. These roles pertained to addressing management and policy questions, questions around legality of activities, sectoral interactions, and conservation policy development. It was, however, not clear to key informants how social scientists might address these questions (i.e., the methods to go about it). Nor was it clear how social scientists might engage with the Regional Programmes in practice (i.e., logistically) to address these questions. In particular, there seemed to be some misunderstanding on what the contribution and capacity of social science is, or could be, for the Regional Programmes. For example, several informants thought that the role of social scientists was associated with communication, rather than science:

“Social scientists can utilise natural scientific information and can transform it into something that is more relevant to public needs” (Key Informant #7 ESSAS);

“(It could) relate science and education and outreach” (Key Informant #12 ICED).

Key informants believed that social science-led projects and activities were needed within the Regional Programmes, and that this could be best enabled by IMBeR workshops, conferences, and Summer Schools (and potentially, other new IMBeR events) and Regional Programme events. One informant highlighted interdisciplinary training for ECPs (e.g., via IMECaN) as an opportunity that could help enable future collaborations across disciplines:

“Organise interdisciplinary workshops and conferences” (Key Informant #19 SSC).

Even though opportunities currently do exist to interact with social scientists at IMBeR events, there was a perception amongst key informants that the opportunity to engage with social scientists, and, importantly, to better understand their research interests and capacities, was currently limited. Anticipated barriers to potential future collaborations between social and natural sciences in the Regional Programmes included lack of access to funding, and the institutional barriers to conducting interdisciplinary research:

“There is no substantial funding to generate wide interest” (Key Informant #1 CLIOTOP);

“A lack of common language and understanding” (Key Informant #19 SSC);

“IMBeR’s limited budget makes it difficult” (Key Informant #12 ICED);

“The different experiences, processes, and perspectives that are brought from the natural and social sciences – it takes a lot of effort” (Key Informant #8 ICED).

Key informants highlighted several pathways to address these barriers and support (greater) future social science engagement within the Regional Programmes. These pathways fell into four groups: specific funding, events, within-programme evaluation processes, and social science champions. At a global research level, more than half of key informants highlighted the need for funding that could enable collaboration and dedicated funding opportunities for projects with social and natural scientist collaborations to address specific IMBeR objectives.

Workshops and conferences were seen as crucial for facilitating collaboration. The need to create opportunities for specific information exchange through IMBeR events was emphasised, as was a role for IMBeR's Human Dimensions Working Group in providing training materials (e.g., short workshops/presentations) on aspects of “social science for natural scientists” (while the inverse, that natural scientists provide such material for the social scientists was not mentioned). Key informants suggested creating a database of social scientists, that could identify individual researchers potentially willing to become involved with addressing identified regional issues (but see for instance Mckinley et al., 2020).⁹ Overall, facilitating engagement across all Regional Programmes, to share experiences of collaborating across disciplines, was highlighted as a worthwhile exercise. Key informants did not mention the role of ECPs in achieving interdisciplinarity and collaboration.

DISCUSSION

Global networks are increasingly recognised as an effective mechanism for developing interdisciplinary research approaches and projects for developing solutions to the grand challenges facing coasts and oceans. The aim of facilitating communication and dialogue between diverse scientists and build capacity through events and conferences is central to building global networks. Our study, focussing on IMBeR as a case study, showed that attendance of social scientists at events over the past 10 years has increased. At the same time IMBeR successfully achieved increased diversity by improving the gender balance (to almost 1:1 across all events) and spread of career stages (growing to a 40% early career researcher and student participation). Face-to-face interactions at events between different disciplines are essential to encourage research collaborations, such as evidenced in special issues¹⁰. This reflects the active role IMBeR has taken

⁹<https://www.marsosci.net/>

¹⁰see <https://www.frontiersin.org/research-topics/11540/solving-complex-ocean-challenges-through-interdisciplinary-research-advances-from-early-career-marine-and-hobday>, A. J., Arrizabalaga, H., Evans, K., Scales, K. L., Senina, I. and Weng, K. C. (2017), “International collaboration and comparative research on ocean top predators under CLIOTOP,” Deep Sea Research Part II: Topical Studies in Oceanography Vol. 140, pp. 1–8. and collaborative papers Van Putten, I., Boschetti, F., Ling, S. and Richards, S. A. (2019), “Perceptions of system-identity and regime shift for marine ecosystems,” ICES Journal of Marine Science Vol. 76, pp. 1736–1747.

to prioritise representation across gender, career stages, scientific disciplines, and countries.

Our study also highlighted regions where representation of gender and career stage were not equal, and in future, focussed efforts to resolve under-representation within these regions is needed. For example, researchers from developed countries were more represented at IMBeR events than those from developing nations. And whilst the gender balance is more equal at an ECP level than at senior researcher levels, women are least well represented among attendees from East Asia and North America. North America was also predominantly represented by senior researchers and had the lowest proportion of students and ECPs. Our comprehensive examination of the IMBeR global network revealed that improvements are still needed to better leverage the disciplinary, professional, age, gender and geographic diversity of its members to further build capacity and facilitate interdisciplinary collaboration at global levels.

The most rapid change observed within IMBeR and its Research Programmes was participation from IMBeR ECPs. The inclusion of diverse ECPs (i.e., hailing from different cultures, regions, genders) in interdisciplinary projects can bring important perspectives which might not otherwise be acknowledged (Hofstra et al., 2020). Efforts that can provide inclusive and resultingly, productive environments welcoming all ECPs are expected to diversify scientific collaborations and drive more innovative research.

Despite the many (potential) benefits of interdisciplinary collaboration for addressing global and regional science questions, including data sharing and gaining common ground (Harden-Davies, 2017), there is currently no smooth-running conduit for developing social and natural science collaborations (and interdisciplinary approaches) between regional and global-scale research programmes. However, efforts to achieve such collaboration are emerging and improving including; the IMBeR ESSAS programme which created its own Human Dimensions Working Group; the CLIOTOP programme which provides data and outputs to Regional Fisheries Management Organisations (e.g., Lehodey et al., 2015) and the Intergovernmental Panel on Climate Change and the Intergovernmental Panel on Biodiversity and Ecosystem Services (e.g., Maury et al., 2017); and ongoing scientific contributions to the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) (Cavanagh et al., 2021) through the ICED programme (Murphy et al., 2008). Experiences of collaboration between social and natural sciences and the implementation of interdisciplinary approaches are thus not absent at Regional Programme levels (see for instance Evans et al., 2020) but neither are they ubiquitous.

This is contrary to findings stating that local and regional research questions are applied research questions which are well suited to interdisciplinary approaches and projects (Saint-Paul and Schneider, 2010). As a result, even though the IMBeR network has enabled an increased exposure of natural and social scientists to each other, and promoted collaboration on a global level, several potential reasons for a lag at some of the Regional Programme level activities were identified.

Firstly, the Regional Programmes were largely established with aims that focussed around natural sciences (with the exception of

CLIOTOP). Many of the programmes had their scientific plans focussed on achieving these aims in place before they became part of IMBeR. Given the specific science objectives of each of the Regional Programmes and, in association, the geographic focus of most (e.g., SIBER in the Indian Ocean, ICED in the Antarctic, ESSAS in sub-Antarctic regions), they contribute to IMBeR's overall goals in varying ways, and not all contribute to all of the goals IMBeR sets out in its most recent science plan. As IMBeR has updated its science plan through time (with input from the chairs of the Regional Programmes), the Regional Programmes have reshaped their activities somewhat to align their priorities with those of IMBeR. There is recognition that Regional Programmes could benefit, particularly in contributing to IMBeR's science plan, by developing their programme aims and focus to include more social science perspectives. A key lesson from this is that Regional Programme aims and objectives are best developed in parallel with those of the global project whilst recognising that the Regional Programmes may exist beyond the timeframes of global projects (i.e., global projects change or cease to exist), which is a lesson for IMBeR and other global networks.

Secondly, general research funding is limited and studies have shown that the probability of funding decreases with the level of interdisciplinarity (Bromham et al., 2016). The "paradox of interdisciplinarity" where this type of research is encouraged by policy makers but less likely to be funded (Bromham et al., 2016), is exacerbated by the decrease in funding available for integration and communication activities in the IMBeR Regional Programmes. The Regional Programmes are now essentially funded by the researcher's institutions or research funds. Consequently, potential new members (including different disciplines, ECPs and less well represented countries) may be limited in their ability to participate and contribute to this research. This potentially reduces project participant diversity and (potentially) delays social and natural science collaborations (Blythe and Cvitanovic, 2020). This potential barrier to inclusion was highlighted by a virtual workshop held in August 2020 by IMECaN, where no limits to attendance, free admittance (assuming access to internet), and no requirement to travel likely contributed to the majority (66%) of participants coming from developing nations. Active engagement by Regional Programmes' members and IMBeR in accessing funds, and in doing so increasing funding available for activities, could have real benefits in terms of accessibility (through physical travel or prioritising funded work) for new and existing members, particularly from countries and regions currently underrepresented within IMBeR events (e.g., **Figures 1, 2**). Increasing accessibility to new members will help to promote diversity and support scientific innovation.

The need for collaboration and integration of natural and social sciences (Pannell et al., 2019) was recognised by most researchers in Regional Programmes who stated that they were eager to work together to learn and develop approaches.¹¹

However, the survey responses revealed a lack of awareness and understanding among some of the natural scientists of social science disciplines, methods, and approaches. For instance, some key informants believed that social scientists are responsible for the communication of project outputs (e.g., to policy-makers or the public), whereas science communication has its own specialised field and is a discipline in itself (Kaiser et al., 2010; Xavier et al., 2016b). Such misperceptions could place unrealistic expectations by natural scientists on those social scientists engaged in global marine science projects, with an end result of missed opportunities.

An important consideration for the development and implementation of global networks is to ensure that natural scientists gain a deeper understanding of the capacity and scope of the broad field of social sciences, and vice versa (Ledford, 2015). We highlight the importance of social science champions at the regional level to achieve this. But we also highlight the role of for example joint natural science-social science workshops (such as exemplified by ClimEco Summer Schools). Indeed, our results show similar levels of social scientist representation in Summer Schools and within IMECaN (~20–30%). Increasing mutual comprehension of different disciplines through such networks and activities are likely to help resolve misperceptions and ultimately facilitate interdisciplinary collaboration. We recommend that IMBeR continues to offer activities to attract social scientists, targeting an equal representation of the different disciplines in the future.

Although bringing social and natural scientists together by providing adequate resources to support engagement (i.e., funding, events, and training) was identified as central to facilitating collaboration - it is not enough. There is a clear role and benefit of expanding engagement from a high diversity of disciplines to expedite and promote effective and sustainability-focussed collaboration between the natural and the social sciences. The results of this case study further revealed that participants at ECP events represented greater diversity (i.e., geographic region and gender) which is a necessary component of interdisciplinarity (Blythe and Cvitanovic, 2020). Yet, much more work is needed to embed ECPs within IMBeR's institutional structures (for instance as members of Working Groups and Regional Programmes) if this diversity is to facilitate research to resolve the grand and complex challenges facing the oceans and the societal well-being associated with them. We suggest that early-career training and capacity building should play a central role in large global programmes, not just by creating peer-to-peer networks but also by preparing future leaders through vertical integration and exposure to existing and trusted inter- and transdisciplinary scientific networks with senior scientists. In doing so, ECPs will acquire the necessary skills to actually collaborate and integrate across scientific disciplines and other knowledge systems (Roy et al., 2013).

¹¹In general reflection, a shortcoming of the informant survey was that respondents represented low geographic diversity (i.e., respondents were from mainly western countries). Because of this bias, we were not able to assess if the

submissions from respondents were completely representative of views on the integration of natural and social sciences in the Regional Programmes, and future studies should investigate any geographical variation in views.

Training in social science methods for natural scientists and vice versa is, of course, the role of Universities (with support from funding agencies). In such interdisciplinary programmes, students learn how to communicate in the language of the “other” discipline. IMBeR and other programmes could capitalise on that through efforts to recruit student participants from such programmes into Working Groups and Regional Programmes.

We recognise that in this study we provide some useful insights into exposure by natural and social scientists, but we could not explore in detail how IMBeR specifically has facilitated interdisciplinary collaborations. One overarching sentiment is that there is still a need to bring disciplines together to work collaboratively to address large-scale interdisciplinary marine challenges. This means that there is a need for IMBeR to keep evolving and perhaps increase the speed to push the evolution of the co-development of interdisciplinary research. Continuous renewal in combination with self-reflection is a key strength (Wilson, 2009) that will influence IMBeR's impact in achieving such co-development.

CONCLUSION

There are clear benefits of social and natural scientists engaging and collaborating in a meaningful way and using interdisciplinary approaches to solve specific marine science problems that occur locally, regionally, and globally. Moreover, bringing researchers and other knowledge holders with different perspectives and expertise together at events or conferences to facilitate diverse collaborations is a precursor for interdisciplinary research to be operationalised. There are several pathways to reduce barriers across disciplines and support future social science engagement within natural science Regional Programmes, such as specific funding, events, within-programme reflections, and programme social science champions. Thus, opportunities to interact and

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build networks between natural and social scientists, that can lead to such diverse collaborations, are key to providing interdisciplinary solutions from local to global marine issues. Global networks, such as IMBeR, have the potential to play an important role in making this vision of fostering inclusive and comprehensive knowledge-building relationships and supporting the integration of natural and social science a reality.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

IP, EM, and RC contributed to conception of the study. IP, RC, LM, JX, CC, MD-C, AB, and JM-T contributed to the design of the survey instrument. IP and RK analysed the data. IP, RK, and RC wrote the first draft of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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SUPPLEMENTARY MATERIAL

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