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Socio-oceanography: an opportunity to integrate marine social and natural sciences

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Marine natural sciences have been instrumental in helping society understand how ocean systems operate and the threats they face. However, there is a growing realisation that the societal challenges related to the marine environment can only be addressed through more effective integration with all aspects of social sciences. Nevertheless, to date, social sciences remain insufficiently integrated into marine research. Recognising historical weaknesses and drawing on the authors' own experience of interdisciplinary research, albeit writing primarily from a natural marine science perspective, we propose a series of steps to promote integrated marine research inclusive of strong social science. We suggest that changing the perspectives and attitudes of natural scientists is key. The inherent interconnectivity between the ocean and society ensures that nearly everything we do in the marine natural sciences has the potential to influence and, perhaps address, ongoing and future societal challenges. Consequently, a key challenge for natural scientists is to recognise and communicate this in an accessible manner outside their own disciplines. To attempt to address these issues, we introduce the concept of "Socio-oceanography" which we define as an area of research that takes a "whole system" approach to the marine environment. It focuses on the challenges which require advancement of both natural and social science components, especially on those where the feedbacks between social and natural components are beginning to emerge. Here, we discuss its scope, challenges to its effective application and key steps to catalyse interdisciplinary approaches using this concept.

KEYWORDS

interdisciplinary research, socio-oceanography, societal challenges, research funding, marine science

1 Introduction

The ocean is integral for our health, our economies, our climate and our weather. It lies at the core of the food, water, energy and communication security of the planet and holds enormous cultural and spiritual value for many (e.g. Sunde, 2008). Despite this importance, the resources and services provided to human societies by the ocean are under increasing pressure from multiple drivers. Pollution, overfishing, ocean acidification and associated increased hypoxia, and the accelerating impacts of climate change are pushing the ocean – and the wider Earth system – towards a possible sixth mass extinction event (e.g. Cowie et al., 2022). The scale of human impacts is so great, and the changes to the ocean and the whole planet so fast, that the pace of scientific discovery and science-based solutions are not keeping up. Furthermore, there is a growing recognition that the scientific research needed to find solutions for rapidly emerging challenges is fundamentally distinct from traditional single-discipline marine research. It necessitates shaping the objectives and outputs of natural sciences while viewing them through the lens of social sciences. Recognising this challenge, in January 2021, the United Nations declared the Decade of Ocean Science for Sustainable Development (2021-2030) (OD2030, Ryabinin, 2020) (hereafter the Ocean Decade). This decadal program provides impetus for concerted transdisciplinary collaboration to address the urgent need to transform societal relationships with the marine environment. It also opens a new era of ocean science, recognising the breadth and depth of ocean research, moving away from a historical dominance of natural and physical sciences, and with the prospect of major changes in the way the whole ocean research community works together and contributes to sustainable ocean futures, and indeed, sustainable communities. Furthermore, the Ocean Decade is already beginning to refocus the narrative from one of "doom and gloom" around environmental changes towards one of "Ocean optimism" (Koldewey, 2016) that shifts the focus on solutions agenda (e.g. Borja et al., 2022). Key to realising these goals and achieving the desired shift in ocean research and ocean solutions is the recognition that marine research requires fundamental changes in how it is conducted, funded, and communicated across the science-policy-practice interface.

In spite of their paramount importance to addressing the key challenges of sustainable development, the social disciplines remain largely insufficiently and ineffectively integrated into marine research (e.g. van Putten et al., 2021; McKinley et al., 2022). There are multiple challenges for this, well-described in the literature mostly from social science perspective, including divergent epistemologies underpinning knowledge creation in natural and social disciplines (Moon et al., 2021); the lack of commonly accepted definition of transdisciplinary and its concepts and ideas often leading to underestimation of the challenges of transdisciplinary collaboration (Jahn et al., 2012); challenges of career progression for scientists engaging into interdisciplinary research (Kelly et al., 2019); and, insufficient visibility of social marine science research and the need to conduct a global stock take of the marine social sciences (McKinley et al., 2022). Furthermore, the realm of social sciences is vast and multifaceted, and includes more diverse frameworks and methodologies compared to the natural sciences. The disparate array of "social processes" illustrated in Figure 1A underlie a correspondingly wide range of interlinked social science disciplines. In the context of socio-oceanography, it is evident that positivist social sciences (such as economics and psychology) have been more successful when collaborating with the natural sciences, while integrating disciplines that lean towards interpretivism, such as political science, sociology, and cultural anthropology, has proven to be more challenging, though not insurmountable (e.g. the concept of "ethno-oceanography"; Gasalla and Diegues, 2011). In response to these challenges, various solutions have been proposed with the importance of fostering meaningful and effective interdisciplinarity across marine research identified as a pressing priority for advancement of global marine science (McKinley et al., 2022; McKinley et al., 2020). Although there are various ways of defining inter- and transdisciplinary research, here we define interdisciplinary research as involving both natural and social science components, and transdisciplinary research (following Jahn et al., 2012) as research involving non-academic insights and participants (policy-makers, managers, users or, with growing importance, research communicators including artists) and thus relating societal and scientific problems and their communication.

Despite regular and increasing calls for improved inter- and transdisciplinarity (e.g. Cvitanovic et al., 2021) within marine research, it is clear that effective delivery of this remains a challenge. Here, we suggest that one of the key challenges to overcome is the need for natural marine scientists to embrace an inter- and transdisciplinary nature of marine research, one that is inclusive of social sciences, and their critical significance to the societal challenges and their solutions. As a tool to promote this, we introduce the emerging concept of "Socio-oceanography" and, in the following sections of the paper, discuss its potential scope and challenges in supporting the delivery of interdisciplinary 'ocean science for the ocean we want' as set out by the UN Ocean Decade.

2 Socio-oceanography: an emerging concept

2.1 Scope

Socio-oceanography is an emerging area of research that takes a "whole system" approach to the marine environment by explicitly factoring in human dimensions into wider marine research (Figure 1A). It focuses on the challenges which require advancement of both natural and social science components, especially on those where the feedbacks between social and natural components are beginning to emerge.

Similar to the fast-growing research area of marine socio-ecology, which focuses on interacting human and ecological systems (e.g. Refulio-Coronado et al., 2021), socio-oceanography includes both social and natural components and the feedbacks

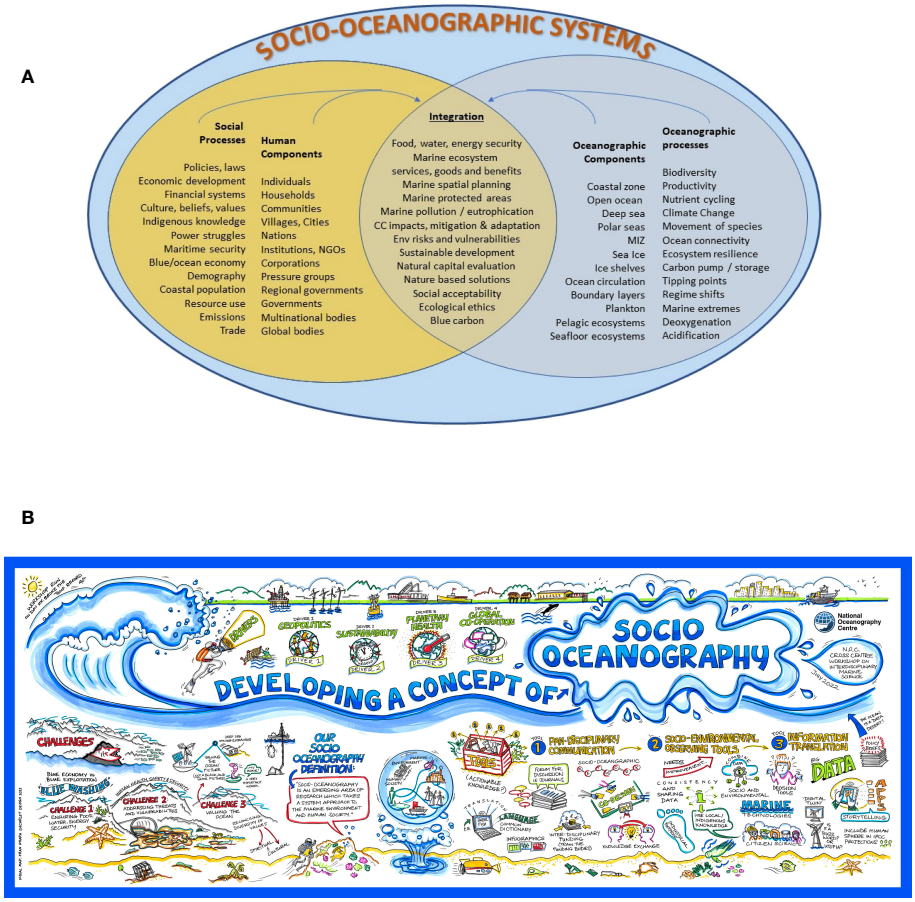

FIGURE 1
(A) Schematic representation of socio-oceanographic systems: process, components and integration challenges (adapted from the original schematics of Finzsch, 2017). MIZ, Marginal Ice Zoe; CC, Climate Change. **(B)** Developing a concept of socio-oceanography: graphical notes of a conceptualisation.

between them. However, the range of problems is broader than in the field of socio-ecology, and includes situations where the living components of marine ecosystems do not necessarily take the centre stage of its environmental components. Socio-oceanography considers the entirety of the natural ocean and marine systems, addressing physical, chemical and biological aspects that impact and interact with society at levels that can be more fundamental or basic than that of ecosystem-level interactions.

Examples of socio-oceanographic problems span the entire breadth of the ocean. Changes in the intensity and loci of marine hazards due to climate-scale variability and trends require communication and engagement with coastal communities to ensure disaster response and/or adaptation strategies are effective. Marine hazards also affect subsea telecoms cables (Clare et al., 2022) and their social and economic significance. Marine construction is expanding (Bugnot et al., 2021) and impacts on physical and chemical characteristics of the marine environment, marine ecosystems and habitats, and on many aspects of coastal human relationships with the ocean as a place of belonging, of work, of inspiration, and of connection. Marine and terrestrial biological species are being redistributed due to climate change impacts, which could influence economies and societies and feedback on the climate, changing the pace of climate change itself (Pecl et al., 2017). New shipping routes are emerging as a result of Arctic sea-ice loss (Aksenov et al., 2017) and emissions from increasing Arctic shipping feedback on the regional and global climate (e.g. Stephenson et al., 2018). Ocean based carbon dioxide removal involves complex feedbacks between the proposed interventions, climate response, ecological impacts, public acceptability, unintended consequences and responsible and equitable governance (Lebling et al., 2022). The list of questions above has the potential to be expanded further into more challenging areas of integrating marine and interpretive social sciences. Such integration holds great promise in addressing equity challenges and making a critical contribution to truly sustainable development. These areas may encompass examining the influence of power structures in shaping oceanographic knowledge, incorporating knowledge from indigenous communities, and exploring the intrinsic value of biodiversity. However, examples of fully integrated studies within these domains remain relatively scarce, as the challenges associated with integration are particularly pronounced.

The rapidly escalating climate and biodiversity crises and accelerating development of the blue economy, driven by – and also exacerbated by – the steady growth of human societies

and economies impels a sense of urgency for socio-oceanography. Its timely expansion and development as a concept is critical in order that the challenges facing the global ocean are successfully – and practically – addressed.

2.2 Key challenges/themes of socio-oceanography

There are multiple ways in which the key themes of socio-oceanography can be organised. Here, we suggest the following (overlapping) broad challenges which can guide further horizon scanning exercises (e.g. Wisz et al., 2020; McKinley et al., 2022) to establish and prioritise the key research questions:

2.2.1 Challenge 1: ensuring food, water, energy and communication security

The sustainable and equitable exploitation of the ocean holds enormous potential to contribute innovative solutions for some of the biggest societal challenges, such as ensuring food, energy, and communication security. These challenges are complex and approaches to their understanding and solutions require system thinking in socio-oceanographic framework. For instance, there are suggestions that seafood representing 17% of food being currently produced, has the potential to increase by 36–74% by 2050 if harvested sustainably (Costello et al., 2020). This notion has faced challenges as an "aquaculture over-optimism" (Sumaila et al., 2022), highlighting concerns about equity by drawing attention to the devastating socio-economic costs that low-income coastal states may bear if the full potential is pursued. The ocean is also the world's largest untapped source of renewable energy, with off-shore wind energy currently being the fastest growing Green Energy sector in the UK (Energy Trends UK, 2022) potentially becoming the number one source of power generation in Europe by 2042, scaling up from 20 GW today to 450 GW by 2050 (WindEurope, 2019). However, maritime transportation, which constitutes the largest energy consumer within the blue economy, is also accountable for a staggering 2-3% of global anthropogenic carbon emissions (Jaramillo et al., 2022). Further, the deep-sea mining of seafloor minerals containing critical metals represents a potentially key resource for the technology infrastructure needed to enable the renewable energy transition (Hein et al., 2020) and the net zero agenda, although its sustainability is under debate (e.g. Hallgren and Hansson, 2021).

With nearly four billion people facing severe water scarcity (Mekonnen and Hoekstra, 2016), water security is increasingly recognised as one of the largest global risks in terms of potential impacts on society (World Economic Forum, 2015). At the coastal interface, water security issues are strongly influenced by interactions with the ocean. The combination of reduced river flow, water table drop and sea-level rise leads to increased salt water intrusion in estuaries and groundwater. Increased frequency and height of extreme sea level events, caused by storm surges and long-term sea level rise, can cause overtopping of freshwater coastal reservoirs. Periodic intense storms also bring sea-water inland, affecting soil salinity and productivity. Groundwater extraction can also lead to subsidence, increasing relative to sea-level rise around coastal megacities and exacerbating the water security issues (e.g. Cao et al., 2021).

The global ocean is host to more than 1.3 million km of in-service telecommunication cables that cross the seabed, underpinning the internet and >99% of global data transfer (Carter et al., 2009). These subsea communications links are considered critical infrastructure by many governments, and provide crucial services to remote, developing island states, allowing access to the internet, e-finance, telemedicine and remote education. However, subsea cables and their landing stations can be damaged by marine natural hazards, such as storm surges, waves, cyclones, floods, submarine landslides and ice scour, as well as long-term sea level rise at the coast. At the same time, cables can be damaged by human activities at sea, ranging from accidental to intentional causes with profound socio-economic impact, such as recent instances of cable breaks that cut off the Shetland Islands from mainland Scotland in 2022 (e.g. Clare et al., 2022).

2.2.2 Challenge 2: addressing threats and vulnerabilities

At the core of this challenge is vulnerability of socio-oceanographic systems to a range of threats such as e.g. extreme climate events (e.g. marine heatwaves), climatic and social tipping points (e.g. reaching a hypothesised irreversible loss of the Arctic sea ice or negative social tipping points resulting from mounting poverty, Tàbara et al., 2022), political changes and instabilities (e.g. resulting in reversal of green policies), management decisions (e.g. land use change), technological advances (e.g. deep sea mining, carbon dioxide removal), pollution disasters (e.g. oil spills). The concept of vulnerability has been evolving for nearly a century (e.g. Carr, 1932; Lahsen and Ribot, 2022) with modern approaches advocating systems thinking (Bevacqua et al., 2018), integrating natural and social sciences and examining complex socio-oceanographic systems using a theoretical framework which include (e.g. IPCC, 2022): i) the exposure to the environment (e.g. ocean warming, sea level rise), ii) the sensitivity of the economy to changes in a resource as a result of this environmental exposure (e.g. economic or nutritional dependence of the population on a resource), and iii) the adaptive capacity of the region to respond and recover (e.g. governance, literacy, availability of alternative incomes). Nevertheless, the adoption of integrated approaches, particularly in the context of climate change risks, remains uncommon. Both natural (e.g., Sutton, 2019) and social science (e.g., Lahsen and Ribot, 2022) perspectives have emphasized the need for improved incorporation of socio-economic and political factors into risk assessments. Socio-Oceanography as a framework should not only strengthen the bridge between characteristics of changing natural environment, ecosystems and society but also capture the feedbacks between these system components.

2.2.3 Challenge 3: valuing the ocean

From an economic perspective, the ocean provides a broad range of resources and natural services while political perspective recognises a set of individual and collective rights and duties. However, the value of the ocean is far more diverse and encompasses the richness of people's relationship with nature, providing socio-cultural benefits that are perhaps less tangible than the narrow set of values on which political and economic decisions have historically been based (IPBES, 2022). For the ocean to continue to meet diverse and divergent (and often directly competing) human needs, it is critical that it is properly and holistically valued. This requires stepping away from traditional economic valuation of oceans, such as the percentage of national Gross Domestic Product (GDP) attributed to marine industry production. A country could exhaust its mineral resources and fish their waters to extinction, but GDP would only reflect the positive monetary contribution the extraction and sale of those resources would generate (Banerjee et al., 2020). This approach fails to acknowledge the potential loss of economic, and indeed other non-economic, benefits in the long term by ignoring the cost of depletion and degradation of natural capital (Fenichel et al., 2020).

Introducing a System of Environmental-Economic Accounting (SEEA) framework could be considered a first step towards including biodiversity indicators into national economic accounts (King et al., 2021). The application of SEEA to ocean environments has, however, been limited due to challenges of classification of ocean ecosystems, and their associated benefits, across large and dynamic spatial scales. The Global Ocean Accounts Partnership (GOAP, 2022) was formed to respond to this challenge aiming to bring together social, environmental and economic statistics relating to oceans. This experimental effort to valuing the ocean can only succeed if it employs interdisciplinary socio-oceanographic approaches enabling us to "understand and appreciate the place of Nature's services in our economies, including the services that are usually overlooked" (Dasgupta, 2021, p78). In a broader context, the goal of Socio-Oceanography is not to directly challenge existing frameworks but rather to enhance whole system thinking within them. From the standpoint of marine natural sciences, the main challenge lies in addressing the inherent incompatibility between current natural science methods and outputs with these frameworks. Successfully overcoming this challenge requires a community of natural scientists to become aware of, engage with, apply and disseminate successful examples of evaluation frameworks, such as those offered by IPBES or GOAP.

2.3 Drivers of socio-oceanographic systems

System drivers represent key external factors (demographic, economic, sociopolitical, cultural and religious, scientific and technological, and physical and biological; Millennium Ecosystem Assessment, 2005), which influence the trajectory of whole systems, as well as the strength of the feedback between the system's natural and social components. It should be recognised that the system drives may vary depending on the geographical scale, location and context of the system in question. Here, we presented a set of drivers as an illustrative example, specifically addressing planetary-scale challenges (Figure 1B).

- **Global system health** , including the realised greenhouse gas emissions pathway, the resulting impacts and the changed state of terrestrial, atmospheric, cryosphere and oceanic systems and interactions between them (IPCC, 2022); other direct anthropogenic factors such as land use change, agricultural practices including fishing, and industrialisation of the ocean (Smith, 2000); and, as the Coronavirus pandemic so clearly demonstrated, the state of the global human health impacting the environment (e.g. Braga et al., 2022).
- **Sustainability agenda**, which aims to profoundly change how social and environmental components of the coupled socio-oceanographic system interact. Under this agenda, a sustainable blue economy, if implemented via innovative policies, practices, collaborations, and personal choices can promise: "20% of the carbon emission reductions needed to achieve the Paris climate agreement's warming limit of 1.5 ° C above pre-industrial levels; 40 times more renewable energy than was generated in 2018; 6 times more sustainable seafood; 12 million jobs; and US$15.5 trillion in net economic benefits" (Lubchenco et al., 2020).
- **Geopolitics** can profoundly affect socio-oceanographic systems as well as the way we study them. Numerous examples include such acute cases as risks and security implications of the newly opening Arctic sea routes (e.g., Melia et al., 2017), issues of maritime security in the Horn of Africa and their routes in degradation of marine ecosystems as a result of IUU fishing and toxic waste dumping (Sumaila and Bawumia, 2014), "Mackerel wars" resulting from lack of cooperation on transboundary fish stock management (e.g. Østhagen et al., 2020) or racial inequalities in the fisheries labour and its significance for the fisheries and the blue economy (Clark, 2022). Geopolitics may also drive ocean exploration for resource sovereignty claims and additional resource extraction activities to reduce dependency on other states and ensure security of supply for minerals (Carver et al., 2019).
- **Global cooperation**. 61% of the global oceans exist beyond national EEZ's (exclusive economic zones), referred to as Areas Beyond National Jurisdiction (ABNJ's). Maintaining marine biodiversity in these regions is the focus of recently completed intergovernmental negotiations within the framework of the ABNJ treaty, under the UN Convention on the Law Of the Sea (UNCLOS). Successful adoption of the ABNJ treaty and subsequent implementation are dependent on approaches that can effectively combine scientific understanding with the social dimensions of managing the global commons (Dunn et al., 2017; Popova et al., 2019).

3 Key barriers to socio-oceanographic approaches and pathways to addressing them

In essence, interdisciplinary marine research and challenge-led integrated marine science are not novel, and numerous programs and initiatives have been previously attempted, with many proving successful. However, it is worth considering why these approaches have not gained more widespread adoption. In this section, we examine the cultural and institutional aspects of the scientific community, funding bodies, and publishing norms which we view as barriers and changes to which in our opinion are required to foster a broader proliferation of these ideas.

3.1 Towards a change of perspective

Historically, a significant barrier to the development of socio-oceanography has been the prioritising of "Blue Sky" or fundamental research over applied or practical research, although this may differ between the countries and funding bodies. This distinction, largely borne out of intellectual stereotyping widely shared across many sciences, is reinforced by funding streams and scientific publications/societies that separate "pure" and applied research (e.g. Singh, 2022). Challenging this unhelpful distinction, together with the associated rhetoric, is necessary and fostering opportunities for research experience of working across disciplines is critical. From the authors' experience, networks involving social and natural scientists are most successful when they are output-oriented and present opportunities to work together in producing a common output (e.g. academic publications, policy briefings, communications material or practical recommendations for regulatory or governing bodies). Opportunities for such cross-discipline activities vary in frequency and accessibility across international research environments. Among such recent opportunities are the USA National Science Foundation's (NSF) the Dynamics of Integrated Socio-Environmental Systems (DISES) program (e.g. NSF, 2020), presenting a challenging example where the focus of research were systems with two-way linkages (or feedbacks) between their natural and social components rather than a one way influence of natural system on human system or vice versa; the UK's Global Challenges Research Fund (GCRF) tackling global challenges via interdisciplinary research (Grieve and Mitchell, 2020); Australian funding of the Centre for Marine Socioecology, Blythe and Cvitanovic, 2020), and Long-Term Socio-Ecological Research Platforms (LTSER) established in Europe in 2007 (Dick et al., 2018). Palmer (2018) suggests that if interdisciplinary leaders co-organise, they can exert a powerful mechanism to promote and expand such cross-discipline working through engagement with/lobbying funding agencies. International activities such as the UN Ocean Decade, as well as the UN Decade of Ecosystem Restoration and the UN's seventeen Sustainable Development Goals present opportunities for establishing high-profile UN-endorsed networks on socio-oceanography that may fulfil this role.

3.2 Making the funding model ready for interdisciplinary sciences

Although research funding opportunities that integrate natural and social sciences are beginning to emerge (e.g. Palmer, 2018, and, for instance, the UKRI funded Sustainable Management of UK Marine Resources (SMMR) programme), funding models still largely favour single discipline funding (e.g. van Putten et al., 2021). Furthermore, there is evidence that interdisciplinary research has lower funding success (e.g. Bromham et al., 2016). There is an understandable mistrust about the routine use of proposal review processes that effectively operate "behind closed doors" with concerns that the evaluation panel may lack knowledge of all disciplines involved or understanding of challenges and tensions of coupling specific disciplines. With the low success rate of research proposals encompassing multiple disciplines, and often a lack of clear guidelines on how the interdisciplinarity is being accessed, the risk (or opportunity cost) of putting together a trans-disciplinary proposal (especially where co-design is involved) is often perceived as being too high as these require up-front unfunded investment. Addressing these issues, for instance via sandpit models for proposal development and evaluation, a multiple stage co-design process, and/or fast-feedback modes (with non-academic stakeholders where appropriate), will significantly assist the facilitation of interdisciplinary science. Where available (e.g. where formal processes are in place to instigate or guide funding calls, e.g. NERC, 2022), researchers should influence funding agencies to create programmes where socio-oceanography can be a clearly-funded objective rather than a "lip-service" add-on to proposals.

The dominant economic system of recent decades, with its emphasis on free markets, low trade barriers and limited regulation has created a situation where private foundations and high net worth individuals have become prominent funders of research focused on environmental conservation and sustainability. In 2020 an estimated $1.2 billion of philanthropic funds were focused on marine conservation (CEA Consulting, 2021), which has since been dwarfed by the $5 billion 'Protecting our planet challenge' supported by a coalition of philanthropists (e.g. Beer, 2022). Gruby et al. (2021) suggest that attention needs to be given to these actors, whose influence is akin to an ecological keystone species, highlighting that the rapid growth of philanthropic research funding has had a "…profound and disproportionate influence on conservation agendas, research, organizations, networks, policy, and the local societies affected by these interventions." The sheer volume of funding and the influence of these actors highlight that this is an interdisciplinary funding route that cannot be ignored and that research agendas in the "frontier" space of socio-oceanography targeting philanthropic funding needs to be set and challenges of working with ocean philanthropy understood and acknowledged (Gruby et al., 2021). Such challenges may encompass, but are not limited to, the following: the emergence of biases driven by the interests or agendas of the funders; the narrowing of research scope and priority areas; a lack of transparency and compromised publication quality due to non-disclosure agreements or

constraints on research publications; an uneven distribution of funding leading to a decline in research areas with less commercial appeal or immediate societal impact; potential conflicts of interest arising when funders have a vested interest in research outcomes; the prioritization of accountability to funders over accountability to communities in conservation and sustainability research (Crosman et al., 2021); and the potential erosion of research credibility resulting from the aforementioned challenges.

3.3 Improve organisational cultures and develop interdisciplinary teams rather than individuals

There is a growing realisation that we need to look beyond growing the capacity of individual scientists engaging with an interdisciplinary research, and instead towards developing institutional capacity to conduct interdisciplinary projects (Blythe and Cvitanovic, 2020), focusing on developing teams rather than individuals. In a review of successes and failures of incorporating marine social sciences into the Integrated Marine Biosphere Research Project (IMBeR), van Putten et al. (2021) highlighted a lack of institutional support and incentives to engage with social sciences as one of the key challenges resulting in somewhat mixed success of the integration. Looking into particular aspects of organisational cultures that enable inter- and transdisciplinary research and using the Centre for Marine Socioecology in Australia as an example, Blythe and Cvitanovic (2020) suggested a range of key principles underpinning successful interdisciplinary organisation, from supporting female leadership to cultivating a visible brand. Although more studies on such "institutional enablers" are needed, spanning various nations and funding models, it is becoming clear that individual scientists raised in conventional natural/socioeconomic silos are not ready to take PI roles without a strong institutional support.

3.4 Publication modes remain single-sciences oriented: a shift towards interdisciplinarity is needed

Although interdisciplinary manuscripts are welcome in many journals, special issue collections dedicated to inter- or trans-disciplinary projects or programmes that would welcome both underpinning natural, social science and cross-disciplinary papers remain relatively rare. This can present a challenge for natural scientists working in such projects, as they often need to publish their results with all necessary details as a single discipline-based paper first, ahead of incorporating the research outcomes into a broader interdisciplinary publication (ESPA, 2018). However, as methods and experimental design may have been dictated by a project's interdisciplinary objectives rather than the need to advance natural science objectives, such publications can fall short of the expected standards of novelty. Consequently, interdisciplinary, project-focused journal special issues can help with promoting such interdisciplinary research. Further, they can also help to alleviate the difficulties of peer-review of inter-disciplinary papers which can result in the reduction of quality in such publications (e.g. Pautasso and Pautasso, 2010). In this context, we recommend that academic publishers at the border of natural and social disciplines consider supporting novel interdisciplinary publication categories to serve this new and developing niche.

3.5 The need to develop new tools and concepts to support communication and collaboration between academic and non-academic actors

In inter- and transdisciplinary studies, traditional peer-reviewed research papers are not the only – or even the best – mode of communication or way of fostering collaboration. A much broader range of peer-reviewed material is required to ensure outputs are communicated in an accessible way to all relevant audiences, using for example, infographics, graphical notes (e.g. Figure 1B), interactive debates, and video material. Further, the extent of the behavioural, policy and social shifts required necessitates collaboration with diverse media such as theatre, arts, music, and film to reach communities and individuals across cultural and language boundaries (e.g. Jung et al., 2022). Noting that transdisciplinarity is an evolving concept, Strand et al. (2022) urge the movement towards a mode of knowledge production "that recognises a multitude of knowledges, knowledge production methods, and knowledge outputs". In particular, urging early career researchers involved into transdisciplinary research to include and cite other sources/knowledge outputs in research, such as oral stories, fiction, poetry, songs, and art, as well as policy briefs and non-academic reports. However, diversifying research communication methods presents a challenge for researchers in both natural and social sciences as career recognition and academic measures of success typically focuses on publication industry research metrics such as the H-factor (e.g. Singh, 2022). Consequently, there is an urgent need for academic publishing to provide illustrative examples of its openness to more inclusive content, as well as action from the research community to open a dialogue with executive editors and publishers about the need for these novel publication categories.

4 Conclusions

The United Nations Ocean Decade provides an opportunity and momentum to transform the perspectives not only of marine natural scientists but also their funders, governing bodies, communicators and the wider media. To realise the ocean's potential role as part of the solutions agenda, all of these actors need to embrace the inter-disciplinary nature of marine science that is required for the delivery of sustainable ocean futures. This paper calls for a decisive action by natural scientists in particular to expand their collaborative boundaries, develop and strengthen

their narratives of contribution to solution agendas, and offers the concept of "socio-oceanography" as a viable framework to facilitate this. Within this framework, a "whole system" approach to the marine environment would explicitly factor in human dimension and focus on the challenges which require advancement of both natural and social science components recognising the feedbacks between social and natural components.

Author contributions

EP was the lead author and responsible for overall development and integration of the concept and the manuscript. All authors made important contributions to the development of the concept of socio-oceanography and the content of the paper during a manuscript conception workshop (either in person or remotely) and subsequent discussions of the manuscript.

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Conflict of interest

Author FO'H is employed by Scarlet Design International, Ltd, Cardiff, UK.

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Publisher's note

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