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Editorial: Solving Complex Ocean Challenges Through Interdisciplinary Research: Advances from Early Career Marine Scientists

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Editorial on the Research Topic

Solving Complex Ocean Challenges Through Interdisciplinary Research: Advances from Early Career Marine Scientists

Anthropogenic impacts on the world's coasts and oceans are accelerating at an unprecedented rate, threatening marine biodiversity and ecosystem functioning, and with it the sustainability of the goods and services marine systems provide, with downstream impacts on societal well-being and livelihoods. Embedded within complex social-ecological systems, coasts and oceans are subject to uncertain, unpredictable, and interconnected challenges, to which solutions cannot be developed through single disciplinary approaches. To this end, there has been growing recognition of the need for interdisciplinary and transdisciplinary marine science to push towards sustainable, productive, and healthy coasts and oceans at a time of significant global change (Kelly et al., 2019).

Early Career Researchers (ECRs) are at the forefront of this new research agenda, and this Research Topic showcases the diversity of research undertaken by the next generation of marine

scientists. We received 41 contributions which included first authors from 18 different countries. Themes of contributed papers include: (1) understanding and quantifying the state and variability of marine ecosystems; (2) improving scenarios, predictions, and projections of ocean-human systems at multiple scales; (3) improving and achieving sustainable marine governance; and (4) perspectives on ECRs' role in solving grand ocean challenges (**Figure 1**). The papers in this special issue highlight the wide-reaching and interdisciplinary nature of ECRs in identifying and developing innovative solutions to challenges associated with rapid changes in the world's coastal zones and oceans. We conclude that maximising the contributions of ECRs to interdisciplinary marine research requires the development of impact-based performance metrics (i.e. those that go beyond traditional publication-based metrics), building effective interdisciplinary institutional capacity, promoting diversity, equity, and inclusion, and integrating ECRs into global research efforts. This will help to unlock the full potential of ECRs to aid efforts to safeguard the future of marine environments for all of society and ensure a broader and more inclusive perspective. This is particularly pertinent as we enter the United Nations Decade of Ocean Science for Sustainable Development (2021-2030).

THEME 1: UNDERSTANDING AND QUANTIFYING THE STATE AND VARIABILITY OF MARINE ECOSYSTEMS

Climate change continues to disrupt ecosystem function and human communities globally, threatening biodiversity as well as food supply and economic security (IPCC, 2021). There is a clear need to quantify the current state of marine ecosystems, so as to define a present-day baseline and improve understanding of how ecosystems are responding to climate variability and climate change. This includes considering new forms of knowledge production and accounting for epistemologies when

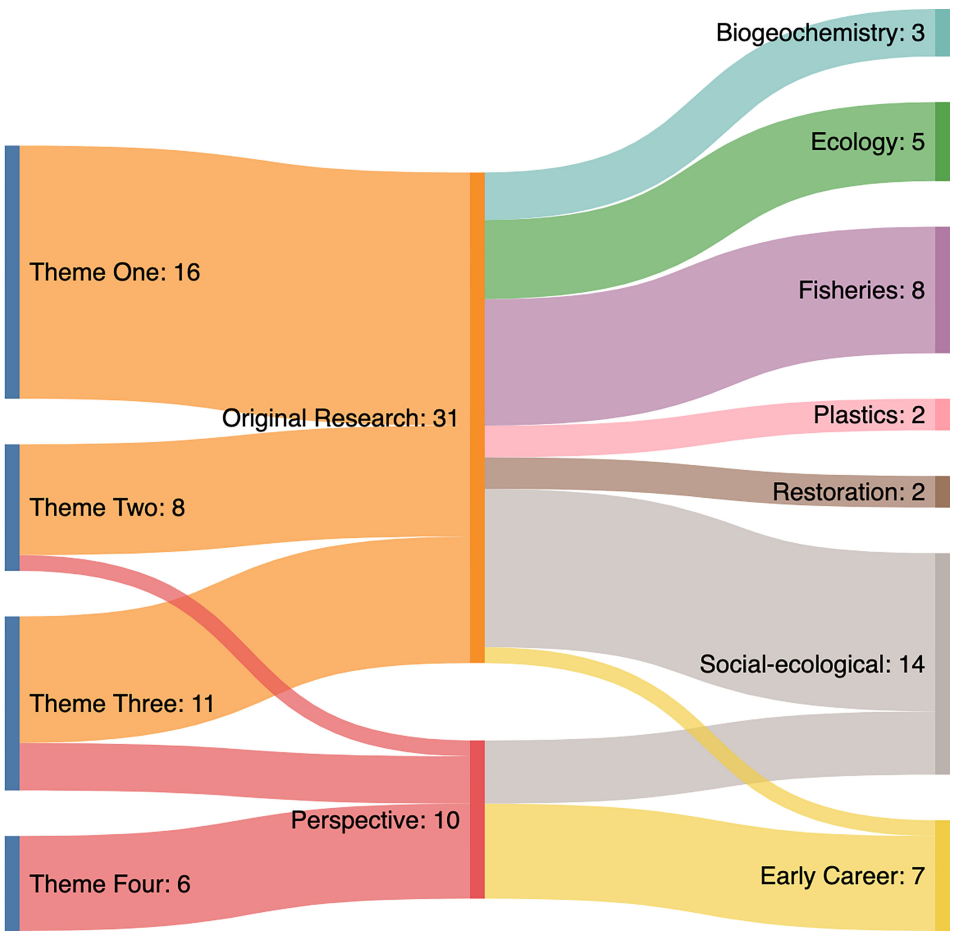

FIGURE 1 | Sankey diagram summarising the 41 articles contributed to this Research Topic (source: http://sankeymatic.com/build/). Diagram shows the distribution of articles across identified themes (left), whether they were an original research article or perspective piece (middle), and the general discipline or topic of the article (right). Numbers represent the number of papers in each category.

conducting integrative marine research (Moon et al.). The first theme to emerge from this Research Topic focused on understanding and quantifying the state and variability of marine ecosystems. Topics ranged across disciplines, from the need for improved marine biosphere observations, over the role of ecosystem services, to the vulnerability of ecosystems to climate extremes and variability.

In situ Observations of Marine Biosphere

In situ observations are necessary to assess changes in ecosystems, and contributions highlighted advances in marine biosphere observation systems. Aniceto et al. demonstrated that ocean gliders can provide effective observing platforms for collecting data on physical and biogeochemical environmental features in conjunction with information on cetacean presence using a coupled hydrophone. Relatedly, bioacoustic surveys are commonly used to estimate and monitor population size of key fish stocks. Wassermann and Johnson highlighted that incorporating individual fish behaviour into acoustic sampling would reduce uncertainty of bioacoustic surveys, and ultimately improve biomass estimates for economically important fisheries. Strategies used to sustainably manage fisheries harvests require information across all life-stages, not just information on population size. Izquierdo et al. used scientific trawl surveys to identify persistent hake nurseries using environmental and spatio-temporal variables and thus produced improved indices to calibrate length-based stock assessment models. Ocean and ecosystem observations are needed across all levels of biological organisation, including at the individual level. Assessing an individual organism's health can be an informative measure to evaluate impacts to specific populations, particularly for threatened species such as cetaceans. Derous et al. synthesised recent developments in cetacean blubber biology to support development of new cetacean health markers that can be used to observe the health of threatened cetacean populations.

Ecosystem Services

As climate change disrupts ecosystem function, the provision of ecosystem services and the well-being of human communities that depend on those services are at risk. Improved efforts to understand and quantify the role of ecosystem services are thus critically needed. For example, Benavides and Robidart highlighted the need to leverage high resolution measurements of dynamic seawater structures to better estimate the contribution of marine microbes (diazotrophs) to N_2 fixation and global nitrogen estimation. Likewise, Jiang et al. examined atmospheric nitrogen variability and its role in driving primary producer growth and subsequent feedback from climate events and coastal human activities. In another example, supporting ecosystem services such as carbon sequestration and carbon storage are vital to climate change mitigation programs, but high spatiotemporal variability in an example seagrass bed cautions against estimations of site-specific carbon stocks using generalised global values (Juma et al.). Changes to ecosystem function and services may require ecological restoration efforts as well, but caution is needed so as to better understand the cultural importance of ecosystem services and to use appropriate indicators that reflect ecosystem value and function more inclusively (Cadier et al.). Pouso et al. proposed an interdisciplinary approach to evaluate changes in cultural ecosystem services in restored systems. Likewise, Prinz et al. conducted stakeholder interviews to assess perceptions around an ecotourism activity that impacts local ecosystem function. While climate change is the major threat facing ecosystems globally, marine plastic pollution has also emerged as an international environmental issue of increasing public concern that threatens provisioning and cultural ecosystem services (Beaumont et al., 2019). Empirical studies that describe microplastic contamination (Barrett et al.) and toxicity (Sarker et al) for marine ecosystems will help to form a baseline for the continued impacts of plastic on coast and ocean health.

Climate Variability and Change

Extreme climate events, such as marine heatwaves, are interacting with longer-term climate change and leading to unprecedented environmental conditions globally (Gruber et al., 2021; IPCC, 2021; Oliver et al., 2021). Fogarty et al. explored how Australian state fisheries agencies are incorporating climate variability and climate change into their management plans, and how funded research is accounting for climate change locally. They conclude that there is a need for increasing climate research in Australia to assure the preparedness of fisheries management in the changing world. Building on this call for increasing climate research in fisheries, Champion et al. assessed variation in predicted rates of climate-driven redistributions among four recreationally important coastal-pelagic fishes from an ocean warming hotspot. They demonstrate variation in the sensitivity of multiple coastal-pelagic fishes to climate change and highlight changing fishing opportunities off eastern Australia. There are increasing calls to better consider the role and impact of climate variability and extreme climate events on ecosystem function and human communities. Blaisdell et al. addressed this need by using a so-called "stress-scape" framework to compare environmental conditions during marine heatwaves and the impacts on Pacific cod. The framework applies the fundamentals of dynamic seascape classification, where they discovered stress-scapes were able to capture unique marine heatwave and non-heatwave classes, and effectively resolved five dynamic stress-scapes in the coastal Gulf of Alaska ecosystem.

THEME 2: IMPROVING SCENARIOS, PREDICTIONS AND PROJECTIONS OF FUTURE OCEAN-HUMAN SYSTEMS AT MULTIPLE SCALES

The importance of improving modelling scenarios, predictions and projections at multiple scales was one of the themes that emerged from the articles in this Research Topic, and highlighted that the accuracy of these approaches is key to preparing and adapting to change. For instance, Franco et al. showed how deep warming hotspots of the southwest South Atlantic Ocean extend

in the water column, particularly in the mid-water and bottom layers, where species of different ecological and economic importance inhabit. Their findings aimed to draw the attention of stakeholders and decision-makers to develop better management approaches for marine biota in the context of climate change. Tonelli et al. used a suite of Earth System Model projections to indicate a loss of bacterial and archaeal diversity in surface waters of the Southern Ocean, with potentially large negative implications for key biogeochemical processes, such as carbon, nitrogen, and sulphur cycling. Levine et al. studied the water-column response to major storms using a simplified data mining technique and concluded that establishing a community of practice for early career scientists in oceanography can enhance their skills, promote collaborations and potentially create meaningful scientific innovations.

Saldívar-Lucio et al. discussed the importance of identifying climate risks and responses at the local level and how psycho-social factors and local attributes might operate and enhance climate resilience. The importance of spatial scales was highlighted by Magel et al., who assessed risk as a combination of exposure, where Dungeness crab reliance and social vulnerability indices demonstrated that communities along the US west coast showed different degrees of susceptibility to a decline in catch. In a similar focus on spatiotemporal resolution, Lawson et al. demonstrated the sensitivity of bioenergetic models to spatial, temporal, and ontogenetic variability in predator diets. Other studies identified how interdisciplinary approaches can help improve adaptive capacity and strengthen management. For instance, Gammage and Jarre describe how using scenario-based approaches (i.e structured decision-making tools) in a research process with marginalised stakeholders can enhance adaptive capacity at the local level. Quintana et al. examined how a short-term, inclusive and adaptive area-based conservation model can help achieve both social and ecological objectives given that area design is ecologically sound and supported by integrated social-ecological theory.

THEME 3: IMPROVING AND ACHIEVING SUSTAINABLE MARINE GOVERNANCE

Marine governance is critical to ensuring biodiversity conservation and the sustainable use of coastal and marine resources. In the context of fisheries, Mackay et al. examined evidence for the possible connection between illegal, unreported, and unregulated (IUU) fishing and organised crime, and the links among illegal fishing and other crimes with the aim to protect those working in the marine fisheries industry and to support the sustainability of global fisheries. Relatedly, Mackay et al. explored what psycho-social characteristics of individuals were associated with the responses to management incentives in recreational fisheries, and identified that ecological values and personality types were important factors for certain compliance groups. Understanding the behavioural characteristics of fisheries compliance will help to progress innovative fisheries management.

Ortega-Cisneros et al. urged the inclusion of climate change and adaptation approaches into relevant fisheries management documents in South Africa, since the inclusion of both approaches is limited for the marine aquaculture and fisheries sector. In the aquaculture sector, Selim at al. examined ways to ensure equitable development, so that the most marginalised coastal communities impacted by increasing salinity are able to benefit from new livelihoods that are adapted to climate change.

This topic also highlights the relevance of introducing significant changes in management tools to those which facilitate participatory modes of governance, which can also serve genuine knowledge co-production (Breckwoldt et al.), avoid exclusionary processes in underrepresented groups, and recognise the access, rights, and cultural values of marine social-ecological communities, with the aim to promote social equity and ecological conservation (Muhl et al.; Okafor-Yarwood et al.; Pennino et al.). Uffman-Kirsch et al. further argues that public participation in marine-based decision-making can offer legitimacy to governance decisions, whilst also bolstering marine actors to use and sustain their social licence. This is further evidenced by Cvitanovic et al. who found visitors to a marine World Heritage Area had a limited understanding of the rules and regulations in place to support its management. They highlight future considerations for managers when developing visitor-focused communication and engagement strategies.

THEME 4: PERSPECTIVES ON THE ROLE OF EARLY CAREER RESEARCHERS IN SOLVING OCEAN CHALLENGES

The fourth theme to emerge from this special issue highlights perspectives on the role of ECRs in solving contemporary coastal and ocean challenges. Contributed papers highlight the unique challenges faced by marine ECRs, many of which have been exacerbated by the COVID-19 pandemic (Pardo et al.). These include the availability of paid work within the marine biology and conservation market (Osiecka et al.), and the need for ECRs to understand and employ interdisciplinary research approaches and develop a broader set of skills beyond those traditionally taught as part of ECR training. Cosentino and Souviron-Priego discuss the expectations placed on ECRs to have a wide range of skills beyond their focal research discipline, particularly in relation to communication and collaboration across disciplines. In addition to scientific endeavours, papers within this Research Topic highlight that ECRs are increasingly working to navigate the science-policy interface to ensure that the outcomes of their research have real world tangible impacts. For example, Ferrer et al. describe their view of participating in the UN climate negotiations as ECRs, summarising the key themes of the negotiations and encouraging other young scientists to familiarise themselves with the negotiation processes to facilitate ECR representation.

In highlighting the challenges faced by ECRs, contributed papers also identify opportunities, actions and solutions to overcome these barriers. Wilson et al. reflect on the

experiences of graduate students who successfully completed the NSF-funded Research Traineeship Program in the USA and discuss the importance of developing relationships to overcome disciplinary differences. Building on this, Deininger et al. suggest that senior researchers are key enablers for the success of ECRs. For example, senior researchers can include ECRs in their long-term funding and project planning, expose them to their research networks, and implement steps to share experimental knowledge both within and amongst institutions.

CONCLUSION

The papers in this Research Topic highlight the wide-reaching and interdisciplinary nature of ECRs in identifying and developing innovative solutions to successfully navigate marine sustainability challenges. Supporting ECRs to undertake successful interdisciplinary research necessitates institutional reform and support (Kelly et al., 2019). Measures to achieve these goals include the development of impact-based performance metrics (i.e. those that go beyond traditional measures of academic performance to acknowledge the broader set of activities that comprise interdisciplinary research practice), building effective interdisciplinary institutional capacity including the support of female leadership (as identified and outlined in Blythe and Cvitanovic), and promoting inclusive metrics of success to dismantle a discriminatory reward system in science and improve diversity, equity and inclusion across all scientific spaces (Brodie et al., 2021; Davies et al., 2021). Similarly, global research networks such as the Integrated Marine Biosphere Research Project (IMBeR), and in particular its ECR network the Interdisciplinary Marine Early Career Network (IMECaN), of which all the authors are members of, can help to strengthen global research networks and provide important pathways to help ECRs to undertake collaborative interdisciplinary research (Hobday et al., 2020; van Putten et al., 2021) Through these, and other steps, we can unlock the full potential of ECRs to become the future ocean leaders that are needed both now as we enter the UN Ocean Decade, and into the future, to safeguard the future of global marine environments for all of society and nature.

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SB, CC, AF, JL, SM, KO-C, MP, SS, and NV were topic editors for the Research Topic. All authors contributed to the review and synthesis of articles, as well as writing and editing of the manuscript. All authors contributed to the article and approved the submitted version.

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