Developing capacity for transdisciplinary studies of changing ocean systems

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Climate change is one of the greatest challenges facing humanity today. Addressing such global challenges requires large-scale collective actions, but such actions are hindered by the complexity and scale of the problem, and the uncertainty in the long-term benefit of short-term actions (Jagers et al. 2019). Besides climate change, socio-ecological systems also face the cumulative pressures associated with resource needs, technology development, industrial expansion, and area conflicts. In marine systems, this has been called the Blue Acceleration (Jouffray et al. 2019) and will be referred to as 'socio-ecological pressures' in the remainder of this paper. These socio-ecological pressures reduce our ability to reach the UN Sustainable Development Goals and the challenges of the UN Ocean Decade, and require a transdisciplinary approach –integrating knowledge within a shared conceptual framework. For example, achieving sustainable growth must integrate ecological, socio-economic, and governance perspectives on a larger scale by considering ecological impacts, ecosystem carrying capacities, economic trade-offs, social acceptability, and policy realities. This requires Capacity Development whereby actors unite to bridge disciplinary boundaries to meet challenges of complex systems.

We have considerable knowledge from various disciplines, monitoring, field and laboratory experiments, and modelling projections, and have developed mitigation and adaptation plans with national and international legislation. Yet, what is needed now is building and sharing techniques to expand and integrate work across disciplines and scales to generate meaningful solutions for entire societies. The purpose of this position paper is to identify the main challenges to achieving a transdisciplinary research approach for studying marine socio-ecological systems. We then introduce case studies that successfully combine and integrate insights from different disciplines to achieve a transformative system perspective. These examples of successful Capacity Development and Capacity Sharing strategies can serve as models for securing more sustainable socio-ecological systems.

Challenges and examples of capacity building and sharing for transdisciplinary action

Uniting natural and social science approaches to address ocean-change impacts on socio-ecological systems has major challenges falling into three classes: system complexity, spatial scales, and cultural differences among disciplines. These need to be recognized and solutions for each must be developed and shared to achieve sustainable transformation (Figure 1).

Case study 1: Complex Systems and Emerging Properties

Ecological systems are dynamic networks of organisms interacting with each other and the environment. Environmental parameters determine which organisms can be present (e.g. biogeographical provinces), and how organisms influence each other through predation, facilitation, or competitive hierarchies. Further, ecosystems and societies are complex systems that are characterized by emergent properties resulting from interactions among system components that are not easily predictable from knowing the structure of the system. Examples include ecosystem services, or socio-cultural organization around a shared resource. Socio-ecological pressures are already producing novel conditions, including combinations of drivers/stressors, species, and area-use conflicts not experienced previously. This complicates projections of impact both of natural systems and their interactions with human societies.

To address these challenges, underlying properties common across socio-ecological systems can be identified, suggesting that some emergent properties can be modelled. In addition, some studies show that transdisciplinary science in complex systems is possible where e.g. ecological impacts, societal perspectives, and industrial decision-making can be bridged (Ponce Oliva et al. 2019). Here, a common goal among natural scientists, social scientists, and the aquaculture industry to adapt to ocean acidification led to new solutions for product development based on consumer preferences and willingness to pay. Such innovative studies within and across economic sectors and stakeholder communities are examples of Capacity Building and provide insight into how we can adapt to existing pressures and improve sustainable ocean stewardship.

Case study 2: Bridging relevant spatial and temporal scale

The second challenge involves scale. There is often a mismatch in the spatial or temporal scales over which environmental drivers act, the scales of scientific studies, and those scales pertinent to human societies and governance regimes (Dirnböck et al. 2013). This presents considerable challenges in selecting the scope of a study where practical requirements must balance the need for information that can be actionable and relevant. Efforts are needed to secure adequate methods to bridge different scales of study and use. Gladstone-Gallagher et al (2019) showed that modelling and statistical integration of expert opinion and decision scenarios with empirical data collected at local scales can help address problems at the ecosystem scale. In another study, Beauchesne et al. (2020) used geospatial analysis spatial patterns of multiple ecological and socio-economic drivers in the St. Lawrence estuarine system to identify areas of high overlap in stressor levels in the system to inform area-based management strategies. These examples demonstrate how existing methods can be

used or adapted to bridge gaps of scale to arrive at solutions that are transdisciplinary and actionable.

Case study 3: Integration of diverse perspectives

Socio-ecological system-science integrates the human with the ecological dimension and acknowledges the complexity of human-nature interactions. Yet, achieving true transdisciplinarity requires that natural and social scientists agree on the nature of a problem and how to describe it, and build a common conceptual framework that synthesizes available knowledge. There exist, however, cultural issues across scientific fields that are historically distinct, with separate methods and terminologies. This is a well-known challenge and can certainly be overcome through will, patience, and hard work to be more fluent in each other's science. Moreover, an increasing number of studies advocate for incorporating local knowledge, produced by the non-academic world, or cultural heritage as important considerations to address sustainability challenges (Castagnino et al. 2022).

Capacity development and capacity sharing can play a key role in addressing these challenges. For example, the Integrated Marine Biosphere Research (IMBeR) program has been particularly successful in its integration of natural and social science through workshops/summer schools that bring together different disciplines and multiple 'ways of knowing' can encourage co-production of strategies to address pressing problems in a transdisciplinary perspective. Further, dialogue among ecosystem modelers and diverse stakeholders in one innovative study led to improved understanding, new potential solutions, and greater understanding and buy-in to the process (Fulton et al. 2015). But in many cases, improved awareness of the need for such approaches has not translated into more integrative scientific outcomes. When transdisciplinary studies are properly designed, they can integrate natural and social sciences to achieve relevant and transformative endpoints. A good example of this is Ecosystem-based fisheries management (EBFM). A recent review of case studies in EBFM shows how capacity building through partnerships between science and stakeholders (industry, managers, user groups) can help cross the science-policy interface (Macher et al. 2021). This can take the form of, for example, co-development of new tools to solve a common problem or improved understanding of decision-making processes through participation in it. This can only be achieved through investment in capacity development initiatives facilitating dialogue and understanding between actors as a step toward inter- and trans-disciplinary solutions (Figure 1).

Lessons learned

We have argued that addressing ocean-change impacts on socio-ecological systems are hindered by system complexity, disparate spatial scales of study and action, and cultural differences among disciplines (Figure 1). Capacity Building, however, can resolve some of these challenges, and we identify encouraging examples identifying possible pathways to achieving transformative action. Capacity Building and Sharing require a multifaceted approach that combines building relationships, aligning incentives, (co-)developing new methodologies, and creating a supportive environment for collaboration. By fostering a culture of openness and mutual benefit, organizations and communities can enhance their collective capacity to drive sustainable development. Acknowledgement of this need has been developed through education programs, but progressing further will require building upon successful model studies, such as those presented here.

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Figure legend

Figure 1. Conceptual figure showing how interdisciplinary research and capacity development can be transformative in overcoming challenges and fostering sustainable socio-ecological systems.

References

Beauchesne, D., R.M. Daigle, S. Vissault, D. Gravel, A. Bastien, S. Bélanger, P. Bernatchez, M. Blais, H. Bourdages, C. Chion, and P.S. Galbraith. 2020. Characterizing exposure to and sharing knowledge of drivers of environmental change in the St. Lawrence system in Canada. *Frontiers in Marine Science* 7: 383, https://doi.org/10.3389/fmars.2020.00383.

Castagnino, F., R.A. Estévez, M. Caillaux, X. Velez-Zuazo, and S. Gelcich, S. 2023. Local ecological knowledge (LEK) suggests overfishing and sequential depletion of Peruvian coastal groundfish. *Marine and Coastal Fisheries* 15: p.e10272, https://doi.org/10.1002/mcf2.10272.

Dirnböck, T., Bezák, P., Dullinger, S., Haberl, H., Lotze-Campen, H., Mirtl, M., Peterseil, J., Redpath, S., Singh, S.J., Travis, J. and Wijdeven, S.M. 2013. Critical scales for long-term socio-ecological biodiversity research. Pp.123-138 In: Singh, S., Haberl, H., Chertow, M., Mirtl, M., and Schmid, M. (eds*) Long Term Socio-Ecological Research. Human-Environment Interactions, vol 2*. Springer, Dordrecht. https://doi.org/10.1007/978-94-007-1177-8_6.

Fulton, E.A., Boschetti, F., Sporcic, M., Jones, T., Little, L.R., Dambacher, J.M., Gray, R., Scott, R. and Gorton, R., 2015. A multi-model approach to engaging stakeholder and modellers in complex environmental problems. *Environmental Science & Policy* 48, pp.44-56. https://doi.org/10.1016/j.envsci.2014.12.006

Gladstone-Gallagher, R.V., Hope, J.A., Bulmer, R.H., Clark, D.E., Stephenson, F., Mangan, S., Rullens, V., Siwicka, E., Thomas, S.F., Pilditch, C.A. and Savage, C., 2019. Old tools, new ways of using them: Harnessing expert opinions to plan for surprise in marine socio-ecological systems. *Frontiers in Marine Science* 6: 696, https://doi.org/10.3389/fmars.2019.00696

Jagers, S.C., N. Harring, Å. Löfgren, M. Sjöstedt, F. Alpizar, B. Brülde, D. Langlet, A. Nilsson, B.C. Almroth, S. Dupont, and W. Steffen. 2020. On the preconditions for large-scale collective action. *Ambio*, 49: 1282-1296, https://doi.org/10.1007/s13280-019-01284-w.

Macher, C., N.A. Steins, M. Ballesteros, M. Kraan, K. Frangoudes, D. Bailly, M. Bertignac, F. Colloca, M. Fitzpatrick, D. Garcia, and R. Little, R. 2021. Towards transdisciplinary decision-support processes in fisheries: experiences and recommendations from a multidisciplinary collective of researchers. *Aquatic Living Resources* 34: 13, https://doi.org/10.1051/alr/2021010.

Ponce Oliva, R.D., F. Vasquez-Lavín, V.A. San Martin, J.I. Hernández, C.A. Vargas, P.S. Gonzalez, and S. Gelcich. 2019. Ocean acidification, consumers' preferences, and market adaptation strategies in the mussel aquaculture industry. *Ecological Economics* 158: 42-50, https://doi.org/10.1016/j.ecolecon.2018.12.011.