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Food for Thought

Toward social-ecological indicator integration in managing oceans and coasts

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Abstract

A holistic understanding of social-ecological systems is essential to foster resilient, adaptive, and sustainable marine ecosystems and human communities. Yet, the integration of social and ecological dimensions is still developing within natural resource management, as are the indicators necessary to monitor them. In this study, we assess the integration of social and ecological indicators in marine management through a case study exploring the use of and degree of linkage between social and ecological indicators in US federal environmental and ocean resource agencies. Using a survey, we collected indicator sets or reports developed by these US federal agencies and found that 7 out of 11 total reports contained both social and ecological indicators. Within those reports, there were 333 social indicators. Only 35% (116) of the social indicators could be directly linked to commonly monitored ecological indicators. Social-ecological connections were focused on many themes, including tourism and recreation, fishing and marine resource use, resilience of coastal communities, well-being, cultural/spiritual value, economic impact, environmental and resource management education, and participation in resource management. These results suggest that some integration of social and ecological indicators within the ocean and environmental-focused federal agencies in the US is occurring, but it is not widespread. Exploring and applying methods that facilitate the integration of social and ecological indicators is the next frontier in achieving management of the environment as a combined social-ecological system.

Keywords: ocean; social-ecological systems; sustainability; human dimensions; ocean observing systems; indicators; natural resource management; marine ecosystems

Introduction

Fostering resilient and sustainable marine ecosystems and associated human communities relies on understanding the complexities of our rapidly changing natural and social systems. This necessitates an integrated social-ecological systems approach where the social (human) and ecological (biophysical) subsystems are considered parts of a coupled, interdependent, and co-evolutionary system that is characterized by feedback loops and interdependencies (Ostrom 2009). Various frameworks and ways of conceptualizing social and ecological systems have been developed (Binder et al. 2013), including the Driver, Pressure, State, Impact, Response framework (Gari et al. 2015), the Ecosystem Services framework (Turner and Daily 2007), the Social-Ecological Systems framework (Ostrom 2009), and the social-ecological-environmental-system framework (Bograd et al. 2019).

Many of these frameworks use ecosystem indicators to provide measurable data on the health, functioning, and sustainability of social-ecological systems. Indicators are measures that provide reliable information on the state or condition of a dimension being studied (Ramenzoni and Yoskowitz 2017). For example, social or socioeconomic indicators are proxy variables that capture representative social, cultural, and economic elements of a particular domain without requiring a full assessment of all the components of that subsystem (e.g. Jepson and Colburn 2013). Ecological indicators, on the other hand, include measures of physical, chemical, and biological components of the system (Berrouet et al. 2018, Clay et al. 2020). Including both social and ecological components in indicators can help to distill complexity while still allowing for a broader understanding and more holistic management of the system (Sterling et al. 2017). More specifically, it would facilitate linking the specific level of a social impact to the specific level of the ecological change and vice versa.

When based on long-term, repeated, and integrated observations, indicators can help to evaluate the resilience or adaptive capacity of a system as a whole and over time. Because indicators can help managers monitor system conditions, as well as to identify drivers of change in a cost efficient manner, they constitute key tools for ecosystem-based and adaptive management (Breslow et al. 2017).

Recognition of the importance of social and ecological integration in marine management has been growing since at least the 1990s (e.g. EPAP 1999, Ostrom 2009, Yoskowitz and Russell 2014, Selomane et al. 2015, Bennett 2019) and more recently within the context of ocean observing systems (Malone et al. 2014). Additionally, progress in implementing and operationalizing social-ecological integration is being made in a variety of regions and applications (e.g. Biedenweg et al. 2016, DePiper et al. 2017, Melbourne-Thomas 2017, Clay et al. 2020, Spooner et al. 2021, Perng et al. 2024). While particular groups are making notable strides, operationalizing these connections is complex, and in many cases, social factors are not fully incorporated into measures of ecosystem service production (Reyers et al. 2013).

While the degree of integration in social-ecological systems research has been addressed in some studies (Guerrero et al. 2018), a detailed understanding of when and where social and ecological indicators are jointly integrated into environmental decision-making is still needed. Furthermore, while there has been progress in assessing social indicator efforts in US coastal and ocean ecosystems (Ramenzoni and Yoskowitz 2017), this work could be expanded upon to reflect current contexts and uses within marine ecosystems (e.g. Seara et al. 2022). Our goal in this study was to assess if and how social and ecological components of coastal and ocean systems are represented in management-relevant indicators. We use the term "social-ecological integration" to refer broadly to the joint consideration of social and ecological dimensions in indicators for marine management. This integration can occur within individual indicators (e.g. indicators that combine both social and ecological elements) or across a suite of indicators (e.g. social and ecological indicators used together for a common management context). For example, an indicator of "local values and beliefs about marine resources" includes the social part of the indicator first ("local values and beliefs") and the ecological part second ("marine resources") (Pomeroy et al. 2004). In other cases, the social and ecological components are represented across multiple indicators that are conceptually or operationally linked. For example, within offshore wind energy development, a social indicator, "fishing activity near a wind farm," may be related to an ecological indicator, "fish abundance around a wind farm" (Smythe et al. 2018).

Specifically, we expand upon a case study (Satterthwaite and Clay et al. 2023) examining when and where ocean-based social-ecological integration occurs within indicators used by US federal agencies. This case study was conducted by the Ocean Societal Indicators Task Team of the U.S. Interagency Ocean Observation Committee (IOOC) to improve understanding of and address the need for integrating social and ecological indicators within the context of ocean observing systems. The IOOC is a federal committee that helps to organize US federal ocean-related science across federal agencies (A more detailed description can be found here). The Task Team's specific goals were to produce a baseline synthesis of existing ocean-related societal indicators used in US federal agencies and identify types of ocean-related societal indicators and data that could be connected to ecological data from ocean observing systems. We defined indicators as a variable (or set of variables) that measures a specific phenomenon, system, or process (Canter and Atkinson 2011) and "that conveys information about more than itself and serves as an indication of a feature of interest" (Reyers et al. 2013). Below, we highlight key findings and future priorities related to social-ecological indicator integration in marine ecosystems that could assist in advancing the development of an integrated ocean observing system for society.

Methods

Initially, the task team hosted a virtual roundtable as part of the 2021 California Cooperative Oceanic Fisheries Investigations (CalCOFI) Conference, *Social-ecological indicators to support marine management in a changing climate*, to gather initial input from the marine social and ecological research community on the project (CalCOFI Conference 2021). Participants agreed that social indicators play a vital role in providing a more comprehensive understanding of ecosystem services, particularly cultural ecosystem services, which are often harder to quantify, and that collecting social data becomes especially critical in cases where assessing ecosystem services is mandated. Additionally, the intended uses and potential applications of specific societal indicators (e.g. indicators for understanding climate change impacts or conducting vulnerability assessments) was deemed important for a synthesis effort. Then, to gather data on societal indicator sets relevant to ocean, coastal, and Great Lakes governance, we surveyed social scientists from US federal agencies with ocean-related missions, including: the National Oceanic and Atmospheric Administration (NOAA), Bureau of Ocean Energy Management (BOEM), National Science Foundation, National Aeronautics and Space Administration (NASA), Environmental Protection Agency (EPA), and U.S. Geological Survey.

The survey aimed to identify existing socioeconomic indicators or sets of indicators that could inform or link to ocean, coastal, and Great Lakes observing products and data. However, we received no responses related to the Great Lakes. The survey included questions to capture: the name, scope, and geographic focus of the societal indicators; the organizations or parties involved in indicator development; and the accessibility of reports, publications, or online resources associated with the indicators (Appendix 1). The survey (an online Google Form) was distributed via email and shared across federal and social science networks to maximize participation. Participants were also encouraged to share the survey within their networks to further expand outreach and encourage additional responses, following a snowball sampling approach (Bernard 2017). The survey yielded 22 responses. After removing duplicates and submissions that were missing links to or relevant information about the indicators, 11 unique publications remained (Satterthwaite and Clay et al. 2023).

Using the 11 publications of indicator sets compiled from the survey, we identified, analyzed, and developed a database of 366 individual social and ecological indicators (database). The indicator sets were assessed to determine whether they included social indicators, ecological indicators, or both. The individual indicators were first categorized as social or ecological based on whether their predominant metric reflected a social or ecological dimension. We next identified whether an indicator had an explicit, direct connection to ecological or social aspects or data, either in its title or its description. The ecological indicators were categorized into the Essential Ocean Variable themes: Physics, Biochemistry, and Biology/Ecosystems (re. Muller-Karger et al. 2018). The social indicators were categorized into the following themes: tourism and recreation, fishing and marine resource use, resilience of coastal communities, well-being, cultural/spiritual value, economic impact, environmental and resource management education, and participation in resource management, based largely on the categories found in Ramenzoni and Yoskowitz (2017).

When a connection was identified but not linked to a specific category, we classified the indicator as unspecified/all. For example, the indicator "local marine resource use patterns" did not specify which specific types of local marine resources are being used, so would be classified as "unspecified." If the indicator set did not specify integration between the biophysical and societal indicators, but connections could be drawn, we categorized it as having a potential connection, suggesting that these indicators could be linked within a social-ecological framework. Final data were analyzed and visualized using the R software (R Core Team 2023) and associated packages [*here* (Müller 2020); *readr* (Wickham et al. 2024); *dplyr* (Wickham et al. 2023); *ggplot2* (Wickham 2016); ggalluvial (Brunson and Read 2023); *tidyverse* (Wickham et al. 2019); and *RColorBrewer* (Neuwirth 2022)].

Results

The 11 indicator set publications encompassed a range of efforts across multiple scales—from local and site-specific assessments (e.g. Analysis of the Block Island Wind Farm Impacts on Recreation and Tourism), to regional frameworks (e.g. NOAA Integrated Ecosystem Assessments for the California Current and Washington Coast), to national-level indicator systems (e.g. NOAA Fisheries Community Social Vulnerability Indicators and the National Coral Reef Monitoring Program Socioeconomic Indicators). Most of these publications represent important sources of contextual information that inform the development, implementation, and evaluation of management decisions and plans, but may not represent core regulatory management plans. For example, the NOAA Integrated Ecosystem Assessments develop Ecosystem Status Reports that help decision-makers consider key social and ecological dimensions when crafting or evaluating management strategies (Monaco et al. 2021), but are not themselves management documents. However, most Social Impact Assessments of federal fishery management plans now use the Community Social Vulnerability Indicators [see Clay and Colburn (2020) for context].

We found that seven out of 11 indicator set publications (∼63%) included both social and ecological indicators, suggesting a moderate degree of social-ecological integration within indicator sets. The topics covered in publications with both social and ecological indicators were broadly related to marine spatial planning (e.g. Marine Protected Areas—Pomeroy et al. 2004), Ecosystem-Based Management (e.g. Integrated Ecosystem Assessments—Poe et al. 2015 and Breslow et al. 2017), offshore energy (Smythe et al. 2018), coral reefs (U.S. National Ocean Service 2019), and the social vulnerability, resilience, and well-being of coastal communities (Cutter 2024, including specifically marine-dependent communities (e.g. Jepson and Colburn 2013, Clay et al. 2020, Seara et al. 2022). Not surprisingly, many of the reports came from NOAA, the US agency most closely tied to ocean management. The remaining four indicator sets consisted solely of social indicators, highlighting a focus on human dimensions in management, but without explicit ecological components included within the indicator set. This may reflect the fact that some indicator sets were designed to meet specific mandates or regulatory needs focused on social considerations or human impacts.

Across all indicator sets, we identified 366 individual social and ecological indicators, of which 333 (91%) were social indicators. Social indicators play a crucial role in management by providing insights into human dimensions that influence or are impacted by ecosystem changes. When directly connected to ecological dimensions of the system, they help to capture the coupled dynamics of the system, inform both social and ecological outcomes, and support more holistic and effective management. Of the social indicators, 116 (35%) were or could be linked to ecological indicators/indices, suggesting some degree of social-ecological integration within indicators (Appendix 2; Satterthwaite and Clay et al. 2023). For example, social-ecological indicators included, "days times miles of shoreline closed due to sewage, bio-toxins, or pollutants"; "cultural importance of reefs"; "exposure and vulnerability to severe storms"; and "Number and type of vendors [selling] locally caught and raised seafood." The social indicators that could be directly linked to ecological indicators were mainly related to fishing and marine resource use; social well-being, cultural or spiritual value; and resilience of coastal communities, including, resilience to climate change (Fig. 1). These results align with previous findings on the key themes of social indicator efforts in US coastal and ocean related agencies (Ramenzoni and Yoskowitz 2017).

Most social indicators were connected to ecological indicators that aligned with the biological Essential Ocean Variables (EOVs; Muller-Karger et al. 2018). The biological EOVs that were linked to social indicators included fish, invertebrates, macroalgae, marine mammals, seabirds, microbes, phytoplankton, hard coral, and sea turtles (Miloslavich et al. 2018). Some social indicators were also connected to physical EOVs, such as ocean temperature, sea ice, and sea level rise (Appendix 2).

Discussion and conclusion

There has been a growing recognition of the need for social-ecological indicator integration in marine management and efforts are underway, as confirmed by the findings of this study. Integration is occurring within indicator sets used in marine management in the USA, yet integration within individual indicators is much more limited. This may be due to a combination of multiple, interrelated factors. These include: (i) challenges related to data, knowledge gaps, and complexity; (ii) fragmented governance and policy, disciplinary, and institutional silos; and (iii) limited capacity and resources (Leenhardt et al. 2015, Addison et al. 2018, McKinley et al. 2020, Curren et al. 2022). For example, there is a persistent lack of long-term, fit-for-purpose social data and, even where such social data exist, integration is challenging due to scale mismatches between social and ecological data (Leenhardt et al. 2015, Curren et al. 2022). Additionally, complex interactions between social and ecological components make it challenging to develop an actionable understanding of, and integrated conceptual models of, specific systems (Leenhardt et al. 2015, Addison et al. 2018, McKinley et al. 2020, Curren et al. 2022).

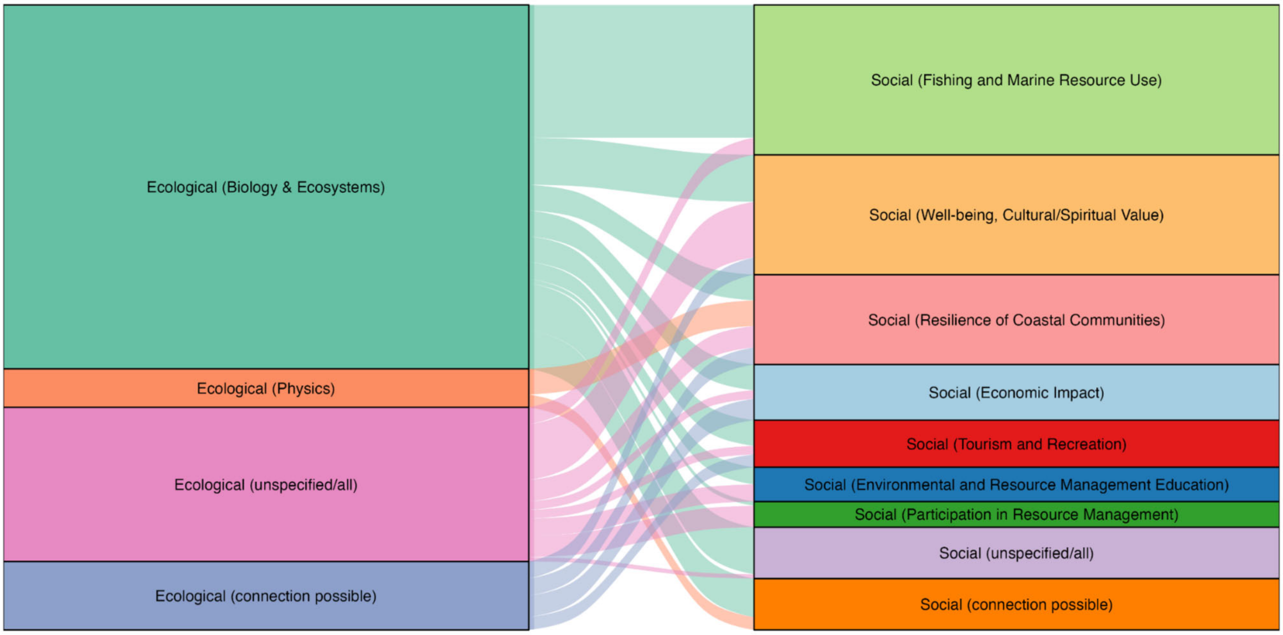

Figure 1. A Sankey diagram illustrating direct connections between ecological and social indicator categories. For a complete list of social and ecological indicators see Appendix 2.

Finally, siloed efforts create gaps between social and natural domains, as well as between social-ecological research and its application in marine management. These fragmented efforts lead to challenges in aligning objectives, methods, and data across domains. They also limit the creation of integrated frameworks that can support decision-making across the interconnected dimensions of social-ecological systems. As a result, institutional mandates often remain narrowly focused on specific ecological, economic, or social outcomes, rather than supporting integrated management strategies (Leenhardt et al. 2015, Addison et al. 2018, Curren et al. 2022). For example, a case study in Canada found that managers favored ecological over social concerns (Curren et al. 2022). Finally, limited institutional support for social scientists and a lack of training in integrated approaches among researchers and practitioners further hinders effective social-ecological integration (McKinley et al. 2020).

Although integration is challenging, directly linking social and ecological components within indicators is important because it captures the interdependence between human well-being and ecosystem health. This, in turn, enables managers to identify trade-offs, co-benefits, and feedbacks that might be missed if indicators were considered separately. Within marine-related federal agencies, ecological data are often collected through long-term ocean observing systems and monitoring programs (CalCOFI ; Satterthwaite et al. 2021, Gallo et al. 2022), while the social, economic, and very limited cultural data have been collected primarily through standard federal government surveys (e.g. U.S. Census, U.S. Bureau of Labor Statistics) or to support regulatory requirements and ecosystem-based management (re. Ramenzoni and Yoskowitz 2017). These long-term efforts to collect social and ecological data are challenging to sustain. Such efforts could be further incentivized by including both social and ecological performance metrics in existing management and regulatory frameworks. Additionally, the social and ecological aspects of management are generally not integrated with each other (Guerrero et al. 2018, Weller et al. 2019), possibly because the social-ecological connections can be challenging to operationalize (Ramenzoni and Yoskowitz 2017).

Thus, despite existing efforts, social data collection and indicator development lag behind that for ecological indicators of the marine environment (Harshaw et al. 2007, Leenhardt et al. 2015). Even in cases where indicators are being developed, they largely remain siloed in "social" and "ecological" repositories or reports, which could result in missed opportunities to integrate and apply them effectively in managing social-ecological systems. Efforts are still emerging, though the work is not equally focused across all disciplines, regions, and management bodies. However, given that our investigation highlighted the convergence of many social and ecological indicator variables around themes that are at the center of challenges facing marine managers (e.g. managing activities concerning natural resource use and human and economic health), the issue of integration is critical.

The integration and coordination of ocean social and ecological indicators can be further developed and enhanced through inter- and trans-disciplinary social-ecological collaborations (Bodin 2017), research (Guerrero et al. 2018), and capacity building and knowledge sharing (Olsson et al. 2004). For example, agencies could hire social scientists to work alongside natural scientists in interdisciplinary teams focused on ecosystem-based management planning, evaluation, and implementation, as has been done for the NOAA IEA Ecosystem Status Reports (Monaco et al. 2021). Current resources and collaborations could be leveraged and built upon to support this integration. For example, the indicator database developed through this work can serve as a resource to identify and utilize numerous previously developed indicators (see Appendix 2). Additionally, ongoing human dimensions and social-ecological initiatives could support development of new joint social-ecological indicators or portfolios of indicators (e.g. Breslow et al. 2014, ICES 2024). Interdisciplinary training programs, workshops, and shared platforms would enable the exchange of knowledge and methodologies between marine social and ecological scientists and decision-makers (re. Cvitanovic et al. 2015; see also ICES 2019, ICES 2020, ICES 2022).

Ensuring that the social-ecological connections are explicit and considering composite indicators or indices to capture the complexity of ecosystems could also help to enhance this integration (Reyers and Selig 2020). For example, we noted that the generic term "natural resources" was used in some cases, but the use of more specific descriptions, e.g. fisheries, minerals, or biodiversity could help to clarify the social-ecological connections. Building shared conceptual models of the social-ecological system with social and ecological scientists, resource managers, local communities, and other interested parties can also help to build a common framework for understanding, assessing, and specifying the complex interactions (e.g. Southeast Alaska—Wadden Sea–Vugteveen et al. 2015, California Current–Levin et al. 2016, Rosellon-Druker et al. 2019).

Ideally, efforts to develop new indicators should build off of existing indicator sets, such as those focused on specific topics like climate change vulnerability in coastal communities (Himes-Cornell and Kasperski 2015, Colburn et al. 2016, Seara et al. 2022). However, as novel conditions or situations arise, new indicators or indicator sets may be needed that incorporate ecological and social data relevant to the new focus or issue. This development process should prioritize indicators with social-ecological connections (e.g. benefit relevant indicators–Olander et al. 2018) and involve interdisciplinary collaborations and broad engagement. For example, local communities, industries, cultural groups, indigenous peoples, and other interested parties can be involved throughout the development process using a variety of participatory and collaborative methods, starting with defining the indicators, and scales. Engagement methods may include surveys, interviews, workshops, focus groups, public comments, town halls, stakeholder advisory committees, participatory and community-based monitoring, and/or joint scientist-stakeholder research collaborations (e.g. Wiber et al. 2004, Fontalvo-Herazo et al. 2007). This engagement can help to enhance the relevance, ownership, and effectiveness of indicators (Sterling et al. 2017). For example, the NOAA Fisheries community social vulnerability indicators have been ground-truthed and validated through engagement with local fishing communities to ensure that the indicators accurately reflect the actual experiences and realities of those communities (e.g. Sepez et al. 2006, Pollnac et al. 2015, Lavoie et al. 2018).

Finally, further work could assess existing social-ecological integration in other governance systems, such as across different scales (e.g. local, national, and international) and within other resource contexts (e.g. estuaries or forests) to identify the existing indicators and gaps, and to facilitate knowledge sharing (e.g. Harshaw et al. 2007, Bigagli 2015, Sebesvari et al. 2016, Melbourne-Thomas 2017, Tanner et al. 2019, Pacheco-Romero et al. 2022). Finally, sustained, integrated data collection and indicators are important to capture trends and changes in social-ecological systems over time. Moving toward integration and operationalization of these social and ecological indicators for use by environmental managers will require innovation and investment, but will foster the sustainability and resilience of marine ecosystems globally.

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Author contributions

All authors contributed to the conceptualization, methodology, and investigation. EVS, PMC, and RS prepared the original draft. All authors contributed to writing, review, and editing. Formal analysis was conducted by EVS, PMC, RS, MC, and CW. Data curation was performed by EVS, MC, and CW. Visualization was performed by EVS. Project administration was carried out by EVS, PMC, MC, CW, and NR.

Supplementary data

Supplementary data is available at *ICES Journal of Marine Science* online.

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Data availability

The data supporting the findings of this study are provided as a supplementary file titled "Appendix 2: DATASET". This file contains the downloaded CSV version of the original social–ecological indicator database, with additional categories added to facilitate the development of Figure 1.

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