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PRACTICE AND POLICY

Accounting for human–nature linkages in area-based conservation monitoring through social–ecological indicator bundles

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Abstract
As the coverage of area-based conservation increases across the globe, it is critical to improve understanding of the social and ecological outcomes of such measures and the pathways to their outcomes. A social–ecological systems approach to monitoring and evaluation is increasingly advocated; yet, applications remain scarce. We sought to facilitate operationalization of this approach through prioritization of indicators when resources are scarce and to improve capture of social–ecological interactions. We convened a working group of practitioners and academics to explore linked social and ecological interactions through a case study of marine protected areas (MPAs). We used causal models (implemented through causal loop diagrams) in participatory and future-oriented approaches to identify interactions among key nodes of the system that can be a focus of monitoring. These nodes and their interactions provided insight into linked indicators of key system components, for example, biomass, compliance, perceived legitimacy, catches, and perceived fairness. We called these *indicator bundles*. Indicator bundles can be applied to analyze causal modeling diagrams, identify essential elements to monitor, and inform analytical and reporting protocols. The bundles can also help identify key leverage points for adaptive management to improve outcomes of existing interventions. This approach can inform monitoring and evaluation and, ultimately, the design and adaptive management of conservation areas that maximize social and ecological benefits and minimize negative trade-offs.

KEYWORDS
area-based conservation measures, indicator bundles, marine, marine protected areas, monitoring and evaluation, OECMs, social–ecological linkages, social–ecological systems

INTRODUCTION

Convention on Biological Diversity Global Biodiversity Framework area-based conservation tools—protected areas, other effective area-based conservation measures (OECMs), and conserved areas—are being embraced by countries, nongovernment actors, and communities to protect biodiversity and manage human uses (Grorud-Colvert et al., 2021; Gurney et al., 2023). For example, well-sited, protected, and managed marine protected areas (MPAs)—which have been studied more extensively than OECMs—support recovery of depleted species, protect species at risk, and increase biomass of fished species (Dawson et al., 2024; Grorud-Colvert et al., 2021). Many area-based conservation tools also aim to achieve social or cultural goals and objectives (Ban et al., 2023; Jupiter et al., 2014) yet have social impacts ranging from positive to negative (Ban et al., 2019; Gill et al., 2019; Gurney et al., 2021).

Increasing the total area protected to 30% while ensuring that these areas are "equitably governed" and "effectively conserved and managed" (Global Biodiversity Framework Target 3 [CBD, 2022]) will require establishing, managing, and ensuring adequate protection of additional areas. People dependent on these areas may be disproportionately affected. Designing and managing such areas to benefit all components of nature, including people, require understanding how they produce social and ecological outcomes and identifying trade-offs. We used MPAs and MPA networks (hereafter MPAs) as an example of area-based conservation for which the importance of social–ecological linkages is well recognized; yet, monitoring of social and ecological outcomes of MPAs largely occurs in isolation. We devised an approach to identify sets of explicitly linked social–ecological indicators (hereafter indicator bundles) that can inform multiple outcomes related to area-based conservation.

MONITORING AND EVALUATING AREA-BASED CONSERVATION AS SOCIAL–ECOLOGICAL SYSTEMS

Area-based conservation tools are recognized as social–ecological systems (SESs) (Leenhardt et al., 2015; Pollnac et al., 2010; Rees et al., 2018), but few monitoring and evaluation programs are designed to account for their interconnected processes (Meehan et al., 2023; Nature United, 2023a, 2023b). Monitoring and evaluating are essential for determining intended and unintended intervention outcomes, assessing intended policy outcomes, and supporting adaptive management. However, managers tend to conduct ecological and social monitoring separately. For instance, the Great Barrier Reef Marine Park (Australia) began a long-term ecological monitoring program in 1983 (e.g., Kuhnert et al., 2015), but it was not until 2011 that the Social and Economic Long-Term Monitoring Program was developed (Marshall et al., 2016). Data from these monitoring programs are collected and analyzed separately, so opportunities to determine how the social and ecological outcomes are interconnected are missed. Similarly, for MPAs

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in Oregon (USA), ecological and socioeconomic monitoring were developed in tandem but not linked (ODFW, 2022). After undergoing a review, managers of the California (USA) MPA network recognized large data gaps in human-focused studies and the need to link social and ecological indicators (California Department of Fish & Wildlife, 2022). Precedents for integrated social–ecological monitoring exist (e.g., Birds Head Seascape [Mascia et al., 2017]). The Wildlife Conservation Society's Marine and Coastal Monitoring (MACMON) framework (Gurney et al., 2019) for coral reef conservation and management is based on Ostrom's (2009) SES framework; indicators are identified through participatory conceptual modeling of theories of change linking management actions, social–ecological linkages, and outcomes. Thus, a systems perspective can improve understanding of cross-scale interactions, dependencies, and feedbacks between the social and ecological systems.

The social benefits of MPAs are less evident than the ecological benefits (Ban et al., 2019; Grorud-Colvert et al., 2021), and investigations of the mechanisms underpinning social benefits are rare. O'Garra et al. (2023) identified only 3 studies that quantified such mechanisms with respect to protected areas (Ferraro & Hanauer, 2014), marine reserves (Reimer & Haynie, 2018), and conservation incentives (Wiik et al., 2020). That most evaluation programs do not examine social and ecological impacts together and the mechanisms underpinning those impacts limits advancing understanding of social–ecological linkages and application of the SES approach (Mascia et al., 2017; O'Garra et al., 2023).

Explicit examination of the interactions between social and ecological aspects of MPAs (i.e., social–ecological linkages) can greatly inform MPA monitoring and evaluation design and ultimately management decisions. Social factors affect human well-being and human behavior, encompassing social, health, economic, cultural, and governance domains. Ecological factors affect ocean functioning, encompassing physical, chemical, and geological processes, species and habitats, and biodiversity. We sought to show that a more integrated focus is urgently needed, devised a framework for such a focus, and applied a practical tool (causal diagrams) to advance integrated monitoring. Forward-looking approaches can improve understanding of potential trade-offs and negative impacts before they occur and allow for implementation of strategies that minimize harm (Baker et al., 2023). An SES approach can reveal influential interactions and feedbacks between social and ecological elements of the system and how interventions addressing one element (e.g., ecological) affect other elements (e.g., social). Thereby, SESs can be used to identify positive interactions that managers can use to inform management interventions. To begin the process of operationalizing an SES approach to MPA monitoring and evaluation, we, a group of academics and practitioners working on MPAs, held a 3-day workshop in 2023 to discuss and trial an approach to identify social–ecological linkages in MPA monitoring and evaluation. We also contextualized our approach relative to other social–ecological monitoring approaches.

NEED FOR SOCIAL–ECOLOGICAL LINKAGES IN AREA-BASED CONSERVATION MONITORING AND EVALUATION

Exploring social–ecological linkages in area-based conservation monitoring and evaluation may help more accurately attribute changes in the SES to management policies and actions in support of adaptive management by considering causal relationships (i.e., why change might be happening). Examining SES linkages by explicitly representing them through conceptual causal models (e.g., causal loop diagrams) provides a way of operationalizing a mechanistic approach to evaluation (e.g., Woodhouse et al., 2016), which can illuminate different perspectives of how and why management is generating social and ecological outcomes, allow for consideration of a full range of mechanisms, and highlight what is missing. Causal diagrams are a way to communicate and compare competing theories of how the world works (Pearl & Mackenzie, 2018). Consequently, causal models enhance understanding of the likely processes that explain observed ecological and social responses to conservation. They can also be used to engage those implementing area-based conservation and the communities affected by conservation outcomes; to compare how these parties think interventions have affected or will affect local or regional ecological and social dimensions; and to help identify indicators to monitor. We considered 3 reasons why a focus on social–ecological linkages is important and needed in conservation monitoring and evaluation of MPAs, as an example.

MPA outcomes through social–ecological linkages

The linked ecological and social dimensions of MPAs continually influence each other and affect people's behavior (Figure 1). For example, a transparent and fair MPA planning process may result in support by actors and good compliance with MPA rules (Di Franco et al., 2016). This, in turn, may allow depleted species to recover. Actors can see this recovery (e.g., more and larger valued species during recreational activities or improved fishing with allowable gears), and it may improve their well-being (e.g., improved nutrition and transmission of knowledge about species that were previously rare). People's perceptions of recovery may further increase their support for the MPA, affecting social norms that compliance is expected and thereby further expediting positive ecological responses (Bennett et al., 2019). As a consequence, it is important to understand how actors perceive the MPA, to monitor the relationships between social and ecological dimensions, and to understand the outcomes in each dimension. In some worldviews, everything is connected, people are part of nature, and there is no distinction between nature and people or social and ecological components (Atleo, 2004; Upreti, 2023).

Although feedbacks may sometimes be self-reinforcing, as in the previous example, in other instances, there may be trade-offs

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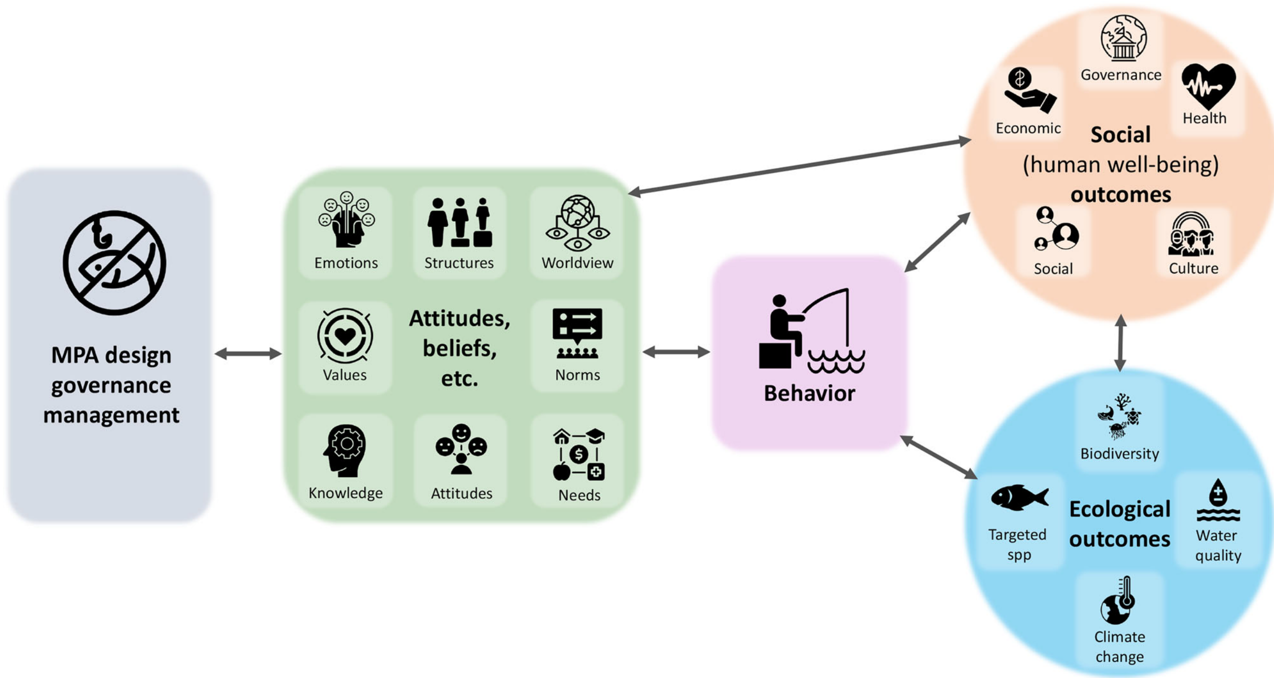

FIGURE 1 Simplified depiction of marine protected area (MPA) design, governance, and management as interventions that affect attitudes, beliefs, and so forth, which then influence human behaviors, in turn affecting social and ecological MPA outcomes (green box, drivers of behavior [partially based on Eyster et al., 2022]; social outcomes circle, categories of human well-being [Kaplan-Hallam & Bennett, 2018]; ecological outcomes circle, ecological outcomes of MPAs [Grorud-Colvert et al., 2021]). A description of social and ecological outcomes of MPAs is in Appendix S2.

(Gill et al., 2019; Klein et al., 2013). For example, ensuring the recovery or resilience of sensitive species may require excluding some or all extractive activities. In the short term, if there is sufficient compliance with regulations, people may be negatively affected (e.g., reduced livelihood opportunities, increased conflict in areas outside an MPA that remain open) while ecological recovery advances (Hopf et al., 2016). In the long term, increased or persistent populations can spill over the MPA boundaries and benefit local fisheries and possibly offset lost catches (Jacquemont et al., 2022). A perception of anticipated trade-offs between ecological and social outcomes can lead to MPAs with weak levels of protection out of the fear of possible negative social outcomes (e.g., in the Mediterranean [Claudet et al., 2020]). In other cases, there may be a mismatch between how actors are perceiving changes and empirical observation of changes. For example, actors may perceive declines in targeted species, whereas biological surveys show an increase (Christie, 2004) or vice versa (Christie et al., 1994). Comprehensive monitoring that links these social and ecological outcomes could identify such mismatches and suggest alternative management interventions or improved communication (Nature United, 2023b). Central to this challenge is setting reasonable expectations for the rate and magnitude of ecological and fishery responses to the establishment of MPAs (Barcelo et al., 2021; Kaplan et al., 2019; Nickols et al., 2019; White et al., 2011).

MPAs that influence people's behavior

Human behavior is the key mechanism that connects ecological and social components of MPAs and that mediates biodiversity conservation outcomes in MPAs (Grorud-Colvert et al., 2021). Examples of human behavior that influence biodiversity outcomes include individual actions, such as compliance (or noncompliance) with regulations, especially for extractive activities, such as fishing (Iacarella et al., 2021); recreational visits (e.g., ecotourism) because of an MPA's protected status (Free et al., 2023); and volunteering to participate in MPA outreach, restoration, and monitoring programs (Meyer et al., 2022). Collective actions also matter. For example, groups of people may organize themselves to support or oppose the MPA or coordinate cleanup and stewardship efforts. Protected areas also indirectly alter people's behavior outside of their boundaries, for example, by increasing conflicts between users if people are displaced from MPAs (Powell et al., 2024) or attracted to the boundary of MPAs (Kellner et al., 2007).

Human behavior can be influenced by factors that are unrelated to ecological outcomes of MPAs. For example, the perceived legitimacy and fairness of an MPA establishment process can have strong influence on people's support or opposition, in turn affecting their willingness to comply (Ordoñez-Gauger et al., 2018; Powell et al., 2024; Turner et al., 2016). Other influences on behavior (e.g., on compliance) may

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be unrelated to the MPA, instead originating from external factors (e.g., poverty resulting in the need to fish for food in an MPA). Some examples of such drivers in the context of MPAs that draw on psychology, sociology, and economics (Eyster et al., 2022) are in Figure 1 (green box). As an underexplored area of research in MPAs, better understanding factors that influence human behavior may lead to additional opportunities for interventions (Kollmuss & Agyeman, 2002).

Focus on social–ecological linkages to determine different scales of social and ecological MPA outcomes

Although MPAs can have clear boundaries, their functioning extends at multiple spatial and temporal scales (Sève et al., 2023). The simplest case is a small remote MPA that is managed by and affects one or a small set of neighboring human communities, making it relatively straightforward to link ecological and social changes. In networks of MPAs, especially in populated coastal regions, social–ecological interactions might be more diverse (people and habitats) and spatially extensive than for a single small MPA, and the network may involve multiple communities, institutions, and sectors (e.g., small-scale and industrial fisheries, transportation, and energy). Processes at broader scales also influence MPA outcomes (e.g., climate change, fisheries management, behavior change due to a pandemic) (Fletcher et al., 2015). Temporal scales are also important in MPAs and can link to spatial scales. Ecological recovery happens through time and depends on the life-history characteristics of species, historical and remaining fishing pressures, compliance, and so forth (Abesamis et al., 2014; Kaplan et al., 2019). Social impacts of MPAs, in contrast, start to manifest during the planning process, long before any boundaries may exist or ecological responses start (e.g., through conflict, collective action for or against the MPA, mental health impacts of anticipating implications of MPAs [Ban et al., 2019]). Sometimes only negative effects are felt by extractive resource users for quite some time before ecological recovery starts to accrue, and ecological recovery will only benefit those with spatial access to recovered or spillover areas. This can have severe disaggregated effects on the community and in some cases lead to displacement of people. Understanding the spatial and temporal scales of outcomes can influence decisions about the scale of management interventions and uncover reasons for performance issues (e.g., when ecological responses do not happen as expected) (Fletcher et al., 2015).

From a practical perspective, social–ecological monitoring could enable the inclusion of diverse monitoring motivations and methods within a broad and inclusive framework (i.e., help balance local specificity and regional standardization, create opportunity for considering different values and views). Essentially, if people can agree on a few key relationships across SESs that should be tracked (e.g., compliance with species regulations), this allows for some flexibility and variability across indicators selected by subregions or communities and provides consistency throughout the region. Balancing regional consistency with site-specific flexibility (e.g., in picking specific metrics) across MPAs is a challenge that the social–ecological monitoring process might be more able to accommodate than other more rigid monitoring approaches.

SOCIAL–ECOLOGICAL LINKAGE LENS TO DEVELOP INDICATOR BUNDLES THROUGH CAUSAL MODELS

Efforts to develop or update monitoring priorities for MPAs emphasize the need for an approach that captures key social–ecological linkages. We explored a promising approach (participatory conceptual mapping), focusing on one method (causal loop diagrams), as an example of a future-oriented approach that can help with thinking through potential monitoring frameworks for MPAs. We focused on this approach because related theories and methods (e.g., conceptual maps, theories of change) have been used widely when designing conservation interventions (e.g., Margoluis et al., 2009), although without an emphasis on social–ecological linkages (but see the theories of change in Gurney et al. [2019] and Mascia et al. [2017]). In our workshop, we focused on the context of the Great Bear Sea MPA network in British Columbia, Canada, to ground our discussion (Beaty et al., 2024, www.mpanetwork.ca). That proposed network is developing its monitoring plan. Many of the coauthor team are involved in it, which provided us with an opportunity to trial an approach that could prove useful in informing that process. The network's goals are similar to many other MPA networks, making them broadly relevant to other MPA networks, single MPAs, and other social–ecological contexts. We do not provide details about this one MPA network because our approach and resulting examples are broadly applicable.

Creating conceptual maps

At our in-person workshop, we carried out several iterative steps to create conceptual maps that depicted how the proposed MPA network may influence social and ecological outcomes. Concept mapping emerged in the 1980s as a "structured process, focused on a topic or construct of interest, involving input from multiple participants, that produces an interpretable pictorial view of their ideas and concepts and how these are interrelated" (Trochim, 1989). Although our workshop exercise was exploratory and was used to identify ways of understanding social–ecological linkages, we loosely followed the general process of participatory conceptual mapping (Trochim & McLinden, 2017) and systems mapping (Mahajan et al., 2019) and suggest that this approach is broadly applicable. In the workshop, 3 broad steps were taken (Figure 2): first, preparation and problem definition; second, generation of diagrams of social–ecological linkages; and third, analysis, refinement, and application of social–ecological indicator bundles.

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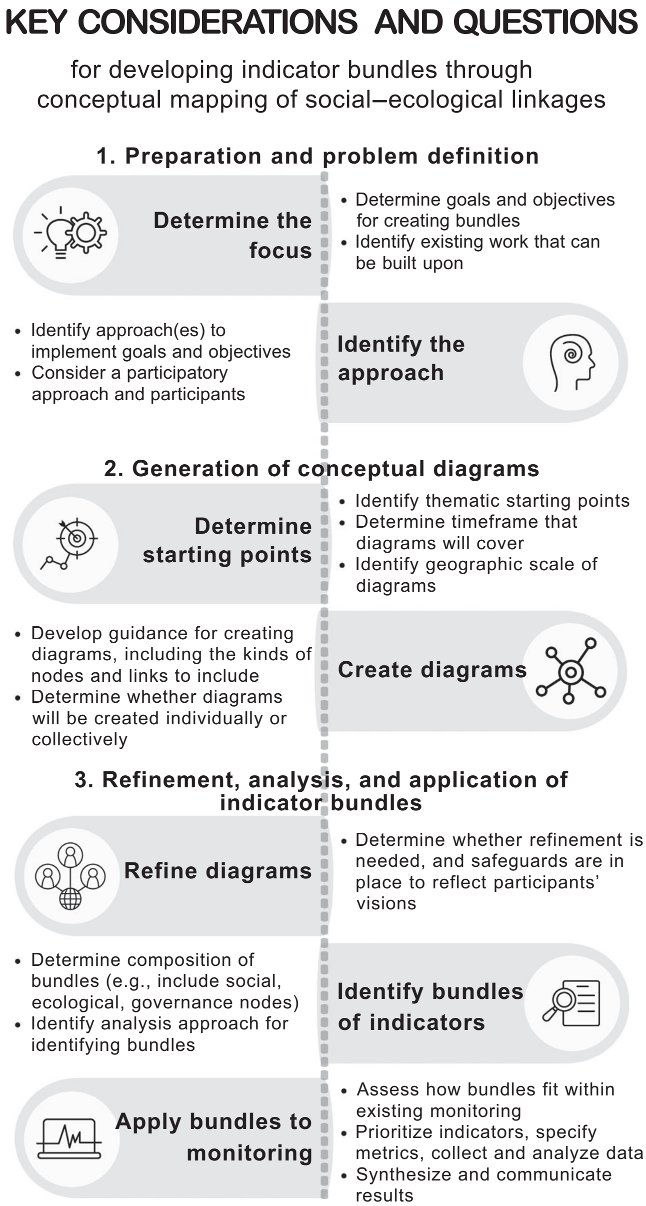

FIGURE 2 Key considerations and questions to ask when developing indicator bundles. Details in Appendix S1.

Preparation and problem definition

Determining the focus of the conceptual mapping exercise is essential. In the workshop, we aimed to characterize the mechanisms and pathways through which ecological changes influence social aspects of MPAs, and vice versa, and identify ways in which MPA monitoring programs can be used to assess the linked social–ecological outcomes. Invitees held academic and practitioner roles and had practical experience working with or supporting MPAs and MPA networks. We started by aligning our understanding of key outcomes of MPAs, guided by the synthesis in the MPA guide for ecological outcomes (Grorud-Colvert et al., 2021) and a framework for human well-being for social outcomes (Ban et al., 2019).

To apply the approach for the purpose of informing MPA monitoring, participatory conceptual mapping would require careful selection of participants, paying attention to representation in the mapping process (e.g., of rightsholders, stakeholders, gender, etc.), including recognition of subgroups within groups or holding multiple geographically distributed workshops to ensure sufficient opportunity for diverse representation. Participants in the process influence the outcomes; hence, diverse groups may have different types of knowledge and understanding of key variables to consider and different conceptualizations of causal linkages between variables (Horowitz et al., 2018). Our goal was academic, trialing an approach that could then be used to inform MPA monitoring; hence, participants were selected for their expertise (practitioner or academic experience working on MPAs and understanding of social and ecological components) and were not intended to represent actor groups.

Generation of diagrams of social–ecological linkages

We drew causal loop diagrams on whiteboards as a tool to express our conceptual models of social–ecological linkages in MPAs. These diagrams visualize how different aspects of a system are causally interrelated and how components directly and indirectly influence each other. We used a future-oriented approach, identifying social–ecological linkages that are likely to occur, based on our collective experience in the region and elsewhere. We asked participants to focus on the important components of the system, akin to the essential variables approach (e.g., Pereira et al., 2013; Reyers et al., 2017).

Many different thematic starting points are possible, and suitable entry points for creating diagrams are context specific (e.g., by actor group, number and types of habitats/ecosystems, MPA goals). Our starting points were 4 thematic areas related to changes that might occur when an MPA is established: a change in extractive use (e.g., small-scale fishing), nonextractive use (e.g., tourism), governance and management (e.g., conservation, stewardship), and engagement (outreach and education). Our temporal starting point was MPA establishment because, if managed effectively, that is when ecological recovery can start to occur, although we recognize that social outcomes can begin to emerge even before establishment (Smith et al., 2006). We tasked participants with thinking about the causal relationships among important components of the MPA system that happen within their thematic area when an MPA is established. Participants self-selected into self-facilitated subgroups, composed of 4 or 5 people, based on thematic area and took a few minutes to sketch out their own diagram before creating a joint diagram through discussions. In these diagrams, nodes (the boxes in the diagram) represented the system components (e.g., outcomes, behaviors) and arrows depicted the directional and influential relationships between components and whether these relationships caused an increase or decrease in the nodes they were linked to. We iteratively convened the whole group for feedback on the subgroup diagrams. However, given the limited time and exploratory nature of our exercise, the subgroup diagrams

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turned out quite different from one another. A more structured approach, with predetermined categories of nodes, would help create more consistent diagrams. Appendix S1 contains guiding questions for creating conceptual diagrams.

Analysis, refinement, and application of social–ecological indicator bundles

Analysis and refinement might be necessary. After the workshop, we—a subset of attendees—reflected on the overall approach and re-created some of the diagrams to add and assign the following categories of nodes: ecological outcomes, social outcomes, behavior, attitudes and beliefs, and connections to the other diagrams (Figure 3). The purpose of re-creating the diagrams, which were initially drawn on a whiteboard, was to digitize them and assess whether categorizing nodes could help identify key social–ecological linkages to inform monitoring. Despite a focus on important components of the system, our diagrams still had a large number of nodes and links. We then developed the concept of indicator bundles to frame elements that might be most important to monitor.

A concept explored during our workshop was "benefit-relevant indicators" (Olander et al., 2018), which have been used relative to ecosystem services as a way to map linear chains of indicators that reflect an ecosystem's benefits to society. Building from discussion on this topic, an emergent idea was that the conceptual mapping process can be used to identify "bundles" of indicators (Raudsepp-Hearne et al., 2010). Bundles are a combination of indicators that each provide insight into a major component (i.e., governance, behavior, social, ecological) in the focal region and theme. The bundles concept is less linear than benefit-relevant indicators and can include feedback loops (causal loops) to describe indicators that work together in a causal structure to determine why the MPA is working as expected or not. Creating bundles allowed us to ask which indicators, when monitored in conjunction with one another, improve understanding of the reasons why given social and ecological outcomes are occurring? The causal loop diagrams outlined potential causal mechanisms. However, the sheer volume of indicators that can be applied to each component makes selection a complex and onerous task for many managers (for examples of the kinds of indicators commonly used, see Appendix S2 and references therein). By using the indicator bundles concept, managers can be better able to narrow down the selection process, creating a bundle comprising a single indicator representative of each major component of the system. Indicator bundles must be casually linked and, if relevant, should include external factors that are likely to affect the system (e.g., climate change).

An example can illustrate the indicator bundles approach. Consider understanding of recovery and maintenance of populations. An ecological indicator might be the biomass of one or more ecologically important species that were previously overfished. Recovery and conservation will be influenced by compliance with the MPA rule that prevents fishing (behavior indicator). Compliance, in turn, is influenced by fishers' perceptions of the MPA (e.g., perceived legitimacy, an attitudes and beliefs indicator) and perceived fairness of MPA decision-making (governance indicator). These 5 indicators—biomass, compliance, perceived legitimacy, catches, and perceived fairness—form a bundle that is causally linked and could help identify why ecological recovery or positive social outcomes are or are not occurring (Figure 4a). If ecological recovery is not happening, a manager would have increased ability to identify potential causal factors by examining the outcomes of other indicators in the bundle. For instance, ecological recovery could be inhibited by a lack of compliance with fishing regulations, which could be attributed to broader perceptions that fish catch outside MPA boundaries is insufficient to support local livelihoods or that processes for MPA implementation were not fair. If fish biomass indicators suggest slow or no recovery, concurrent data show poor compliance with regulations, and perceptions of MPA benefits are negative, then overfishing is a likely culprit and further behavior-change interventions might be needed. In contrast, lack of recovery in conjunction with data showing high compliance might suggest that MPA design, siting, or broader environmental factors, such as ocean conditions, are responsible, which might require different interventions, such as modifying the design of the MPA, reducing other stressors, or engaging in active restoration activities. If, instead of monitoring the bundle or multiple bundles, the sole focus is on monitoring ecological indicators and if recovery is not occurring as expected, a manager would not be able to explain it or identify the most appropriate leverage link in the causal loop model for intervention. The same is true for the social outcome indicator; monitoring biomass recovery in the MPA can help determine why fish catch is increasing or not.

Additional examples of indicator bundles emerged from our workshop (Figure 4b,c). For nonextractive use, when tourism increases to support the local economy, MPAs might bring new economic opportunities to local communities and to users (e.g., harvesters) whose activities might have been displaced with the creation of the MPA through employment (social outcome indicator). Such employment could influence perceptions (attitudes and beliefs indicator) about the MPA, which affects participation in stewardship (behavior indicator), in turn shaping ecological performance (e.g., abundance of species important for tourism, an ecological outcome indicator). For governance, MPAs might bring new funding and increased capacity for the operation of the areas (e.g., financial and staff capacity, legitimacy and trust, governance indicators) and support the creation of advisory committees related to adaptive management (social outcome). Such capacity could enhance enforcement or engagement (social outcomes indicators), which could influence trust and legitimacy (e.g., Indigenous guardians' participation, a governance outcome indicator), compliance (a behavior indicator), and ultimately ecological performance (e.g., fish biomass, an ecological outcome indicator). These examples illustrate how simultaneous monitoring of multiple linked (i.e., bundled) indicators can help managers understand why they do or do not see the ecological or social responses to MPAs.

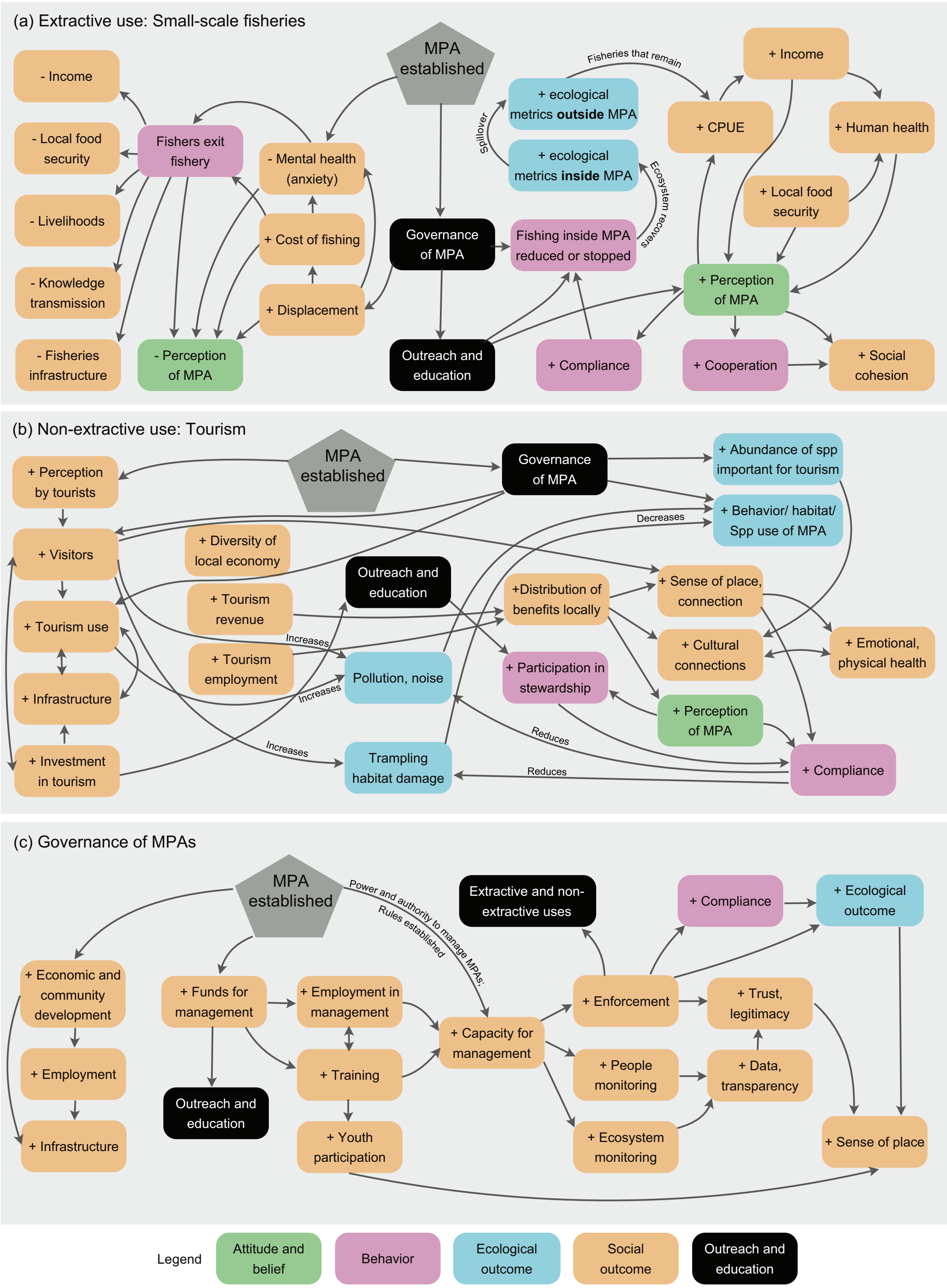

FIGURE 3 Causal loop diagrams generated at a workshop assessing the impacts marine protected area (MPA) establishment has on (a) extractive uses (e.g., small-scale fisheries), (b) nonextractive uses (e.g., tourism), and (c) governance of MPAs. Because the diagram generated by the outreach and education subgroup in the workshop was structured very differently, it is not included here.

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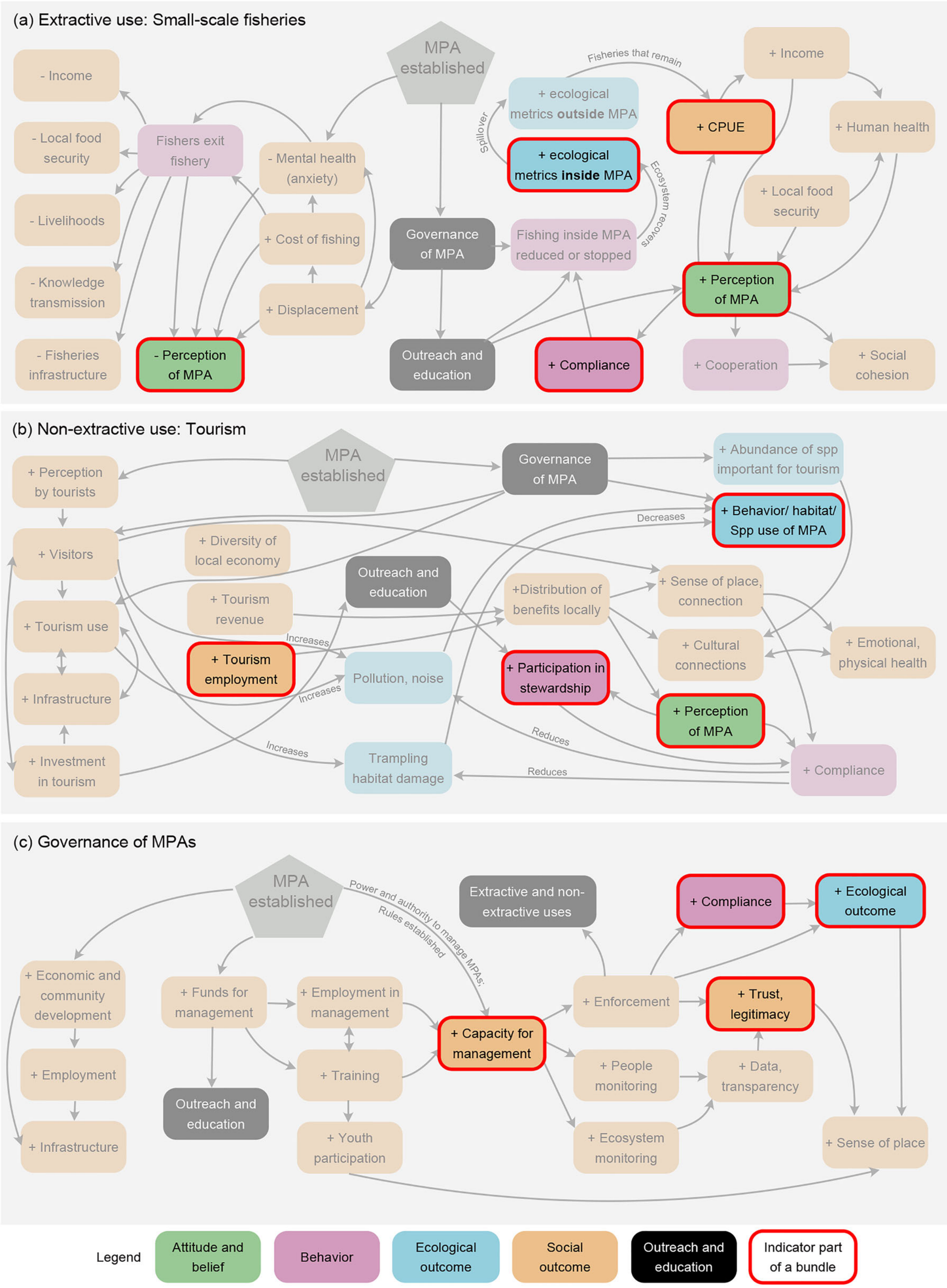

FIGURE 4 Example of indicator bundles (red outline) for each participant subgroup in a workshop where the impacts of marine protected area (MPA) establishment were assessed (Figure 3).

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INSIGHTS AND PRACTICAL CONSIDERATIONS FOR MONITORING PROGRAM DEVELOPMENT

Monitoring the social and ecological components of area-based conservation in a concomitant manner is important for understanding the mechanisms behind linked outcomes. Using MPAs as an example of area-based conservation, we showcased the value of collectively developing conceptual models through causal loop diagrams that specifically consider the coupled social–ecological nature of MPAs to inform evaluation programs, and introduced the idea of indicator bundles. We provided some suggestions for key considerations and questions to ask when developing bundles in Appendices S1 (summary in Figure 2).

A key lesson was that the indicator development process matters as much as the output. There is no single correct version of the final diagrams because they are meant to depict people's understanding of the system; who is present is thus crucially important. Requiring participants to specify their own understanding, objectives, and values and to be transparent about their assumptions can build trust in the monitoring framework, build motivation for participatory monitoring, and make trade-offs explicit. Although there is no single correct model, identifying bundles can help increase knowledge on causal mechanisms associated with MPA effectiveness, and the process of developing such diagrams can also help with engaging diverse groups, understanding motivations for conflict, and addressing compliance and noncompliance (Wade & Biedenweg, 2019), which can lead to more informed MPA management.

Several other insights and opportunities emerged. Although we took a forward-looking approach, the same exercise could be used retroactively to create diagrams of outcomes that have occurred. The approach is flexible and can be scaled depending on the time available and the needs of the actor groups. The idea of indicator bundles can then be applied to analyze the diagrams, to identify essential elements to monitor, and to inform analytical and reporting protocols. A key contribution is to enable an SES approach and thereby to overcome the gap between SES theory and conservation practice. We hope that these ideas can be built on by the area-based conservation practitioner and academic communities to improve planning, monitoring, and evaluation and ultimately improve ocean health and human well-being outcomes.

LIMITATIONS AND NEXT STEPS

Although identifying indicator bundles can help practitioners develop or revise monitoring and evaluation programs, it is important to recognize the limitations of the approach. First, the bundles that might emerge from this approach are dependent on the conceptual models created and those who created them. Practitioners implementing or academics studying conservation may have different mental models of how the system works than actors affected by conservation (Biggs et al., 2011; Moon et al., 2019). Furthermore, different actor groups often have different interests. Proponents and academics implementing and monitoring area-based conservation are rarely accountable to the communities affected. Implementers may more likely develop conceptual models of how conservation leads to positive outcomes, whereas those affected by conservation may develop models of how conservation leads to negative outcomes. This dichotomy could also influence what theories of change are subsequently used in the monitoring program (Crosman et al., 2021; Singh et al., 2023). Consequently, who is invited to be part of the process and how their input is applied are crucially important and need to be carefully thought through.

In cases where there are differing perspectives, it may be useful to build multiple models and develop multiple indicator bundles. For example, conflicting perspectives, such as between conservation proponents and affected communities, can be used to determine indicator bundles. Doing so may increase legitimacy of the intervention because including local community perspectives, causal models, and indicators can signal a fair consideration of their concerns. Perhaps multiactor consensus on a model and indicator bundles can be found. If there is a lack of consensus, monitoring could be done from multiple perspectives using indicator bundles relevant to various groups (e.g., by Indigenous guardians and by Western scientists), giving equal weight to each group's mental model of causal relationships.

The concept of indicator bundles is nascent (but see Olander et al. [2018]), and further refinement will be important as the concept gets tested and implemented. For example, different spatial and temporal scales will need to be considered, and the processes at play for specific indicators and at different scales need to be considered for different applications of this concept. The effects of one component in an SES on another can vary greatly across space and time. Behavioral and social outcomes could be immediate and dispersed across multiple areas (e.g., increased conflicts and fishing in non-MPA areas due to displacement). Ecological outcomes could take years and be localized (e.g., fish recovery in MPA) or, alternatively, could be immediate and localized due to a behavior change in reaction to establishment (e.g., intensive fishing within the proposed MPA boundaries in anticipation of establishment). As such, developers of monitoring and evaluation programs must be knowledgeable of the local system and broader SESs while developing models and monitoring programs that are contextually relevant. It is thus important to be explicit about scales when developing indicator bundles (e.g., for each node in the conceptual model, note the relevant spatial and temporal scale). Allowing for some flexibility and variability across indicators selected by subregions or different human communities is important because it enables consistency throughout the region in the general monitoring approach. For example, indicators that are relevant at smaller spatial scales and to local human communities and management can be designed to be meaningful also at the network level.

Further development of the indicator bundles concept is anticipated as it is applied and field-tested. Guidance that may be useful in the future could include practical implementation

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tools, such as a protocol for selecting actor groups to participate, a framework for reconciling and synthesizing divergent perspectives into coherent and actionable indicator bundles, and procedural guidelines that allow practitioners to adapt and prioritize the monitoring approach for specific local and regional contexts over time. We have provided some such guidance in the Supporting Information Appendices.

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SUPPORTING INFORMATION

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