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Bringing stakeholders, scientists, and managers together through an integrated ecosystem assessment process

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ABSTRACT

For decades, the scientific community has conducted essential background research and developed appropriate modeling tools in support of an ecosystem-based approach to natural resource management. Resource managers and the public, however, lack a clear roadmap for working with scientists to move beyond the traditional single-species approach. With current management processes so strongly focused on working in a species-by-species framework, there are entrenched cultural and institutional challenges to shifting those processes toward ecosystem-based management. We propose using the integrated ecosystem assessment process to both develop new management ideas for a particular ecosystem, and to help shift public policy processes and perceptions to embrace ecosystem approaches to management.

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1. Introduction

Healthy marine and coastal ecosystems are unquestionably the foundation of sustainable development in the coastal zone as well as the conservation of ocean biodiversity. Functioning ecosystems support the provisioning of food, energy, and drugs. They also have cultural value, providing opportunities for tourism, recreation and reflection. Additionally, marine and coastal ecosystems play important roles in nutrient cycling, climate regulation and storm protection. Despite the dependency of human life and livelihoods on functioning ecosystems, a broad scientific consensus has emerged that ocean ecosystems, as well as the goods and services they support, are severely impaired. There is also agreement among scientists, resource managers and policy makers that an integrated, ecosystem-based approach to the management of marine resources holds the greatest promise for restoring marine ecosystems and ensuring the long term delivery of the goods and services that humans require or desire (e.g., [1]).

Implementation of integrated, ecosystem-based approaches to resource management has been urged for decades (e.g., [2–5]); however, it was not until recently that ecosystem-based management (EBM) became firmly established as a guiding principle for resource management in the oceans [6–8]. EBM is now central in efforts to recover depleted marine species and their sustaining ecosystems. EBM is place-based and considers interconnections within and among ecosystems, including interactions within and among social and natural components [9–11]. It differs from single-sector or single-species management in that it defines management strategies for entire systems, not simply for individual components of the ecosystem.

The literature is replete with papers extolling the philosophy and describing the science necessary for EBM. This body of work is largely responsible for moving EBM from a vague concept to a certainty. However, now that resource managers and policy makers are embracing the idea of marine EBM, managers, policy makers and scientists must confront a number of institutional challenges of implementing the tenets of EBM. Importantly, EBM is only partially about bio-physical sciences. Economic, social, and cultural factors affecting communities must also be considered; thus, successful EBM must embrace public participation. Leslie and McLeod [12] identified several challenges to implementing EBM, including: a need to develop a common vision and objectives; a lack of appropriate ocean governance frameworks to implement EBM; and a need to determine when EBM objectives have been achieved. In short, implementing EBM will require that we successfully integrate ecosystem science into the management arena, and share knowledge and priorities between scientists, managers, and citizen-stakeholders. To date, such integration has been lacking.

In response to calls for EBM from several high-level reports (e.g., [6–8,13]) and to facilitate the implementation of EBM for ocean resources in the United States, the National Oceanic and Atmospheric Administration (NOAA) is developing Integrated Ecosystem Assessments (IEA) to bridge the science-policy gap

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[1,14]. Briefly, an IEA is a formal synthesis and quantitative analysis of information on relevant natural and socio-economic factors in relation to specified ecosystem management goals. It involves and informs citizens, industry representatives, scientists, resource managers, and policy makers through formal processes to contribute to attaining the goals of EBM. An IEA is defined by the following steps: scoping, indicator development, risk assessment and management strategy evaluation [1]. IEAs use approaches that determine the probability that ecological or socioeconomic properties of systems will move beyond or return to acceptable limits. They provide a means of summarizing ecosystem status, screening and prioritizing potential risks, and evaluating alternative management strategies against a backdrop of environmental variability. Of the four IEA steps, three are particularly intended to foster the science-policy-stakeholder dialogue: scoping, indicator development, and management strategy evaluation.

Although the need for IEAs is strongly supported by scientists, exactly how these assessments could be implemented in public policy is unclear. In this paper, we explore how the IEA process facilitates critical discussions between scientists and managers and between scientists and the public to develop a common vision of management goals and objectives, so that EBM can move past its current position of being strongly supported in the science arena, but not yet widely applied in the public policy arena.

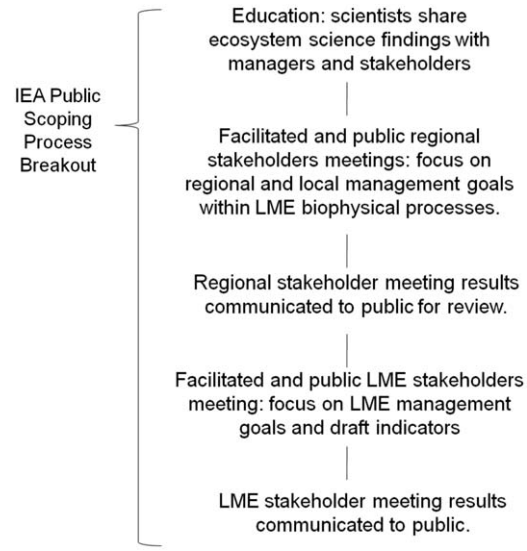

Fig. 1. The public scoping step of the IEA process broken into five phases: education, regional stakeholder meetings, communication of meeting results, ecosystem-wide stakeholder meeting, and a second communication of meeting results phase.

2. Public scoping within the IEA process

As we suggest above, ecosystem science must be integrated into natural resource management processes if EBM is to move forward as a public policy. Ecosystem science must provide more than just carefully vetted and studied information if it is to capture the interest of citizen-stakeholders and to spur action on the part of managers [15]. Ecosystem science must be shared in publicly accessible formats so that managers and the public understand the consequences of not working toward EBM. If marine ecosystem science cannot be made relevant to the experiences and motivations of non-scientists, then it will remain in its current state, an interesting field with minimal policy application. Public scoping for an IEA is intended to open the scientist–manager–stakeholder dialogue with an initial exchange of views and information. Subsequent steps in the IEA process will illuminate the potential consequences of following different future resource management policies.

Methods for public scoping processes vary depending on the issues and potential actions under scrutiny. Levin et al. [1,14] identify an IEA's public scoping step as a looped process, where public scoping recurs as a part of EBM, offering participants in the management process regular opportunities to consider new information and to review EBM's goals. Issues considered under public scoping for an IEA will be complex in scale and scope, and framed by dynamic natural, socio-economic and political processes. To be effective, the IEA scoping step should refrain from immediate assumptions about any outcomes of EBM and emphasize making ecosystem science accessible and policy issues relevant to all participants. These challenges may be addressed in public scoping by starting with an education and discussion process on ecosystem science and on geographic scales for EBM. Scoping then moves into open public discussions on smaller-scale and nested ecosystems, and finally evolves to open public discussions on goals and priorities for large-scale ecosystems and policy-making. As shown in Fig. 1, we break the IEA public scoping step into five phases: education, regional stakeholder meetings, communication of meeting results, an ecosystem-wide stakeholder meeting, and a second communication of meeting results phase.

For ecosystem science to be relevant to managers and stakeholders, it must first be brought out of the realm of professional scientific literature and made available to the public in more accessible formats and forums. Government agencies can improve public interest in and support for EBM if they start the IEA scoping step with an education process, committing to broad dissemination of ecosystem science in accessible formats. For marine ecosystems in the US, agencies can use existing public processes to present their ecosystem science findings. Federal fishery management councils, sanctuary management councils, and state and tribal commissions for marine resource management and conservation are all potential venues for scientists to share what and how much they know about the marine ecosystems of interest to participants in those processes. Beyond these venues, government agencies should use more general education and outreach tools, such as websites and news releases, to make the broader general public aware of ecosystem science.

As stakeholders and managers become more aware of and educated about ecosystem science, they will wish to have opportunities to reflect their interests back to scientists, one of the traditional functions of public scoping on environmental actions. To take best advantage of information and ideas from these groups, IEA scoping meeting planners need to recognize that stakeholders are more likely to think about and focus on their local geographic environment, rather than on larger-scale ecosystems [16,17]. National-level government agencies, however, have interests in ecosystem-based management at the full range of scales—from local habitat restoration projects to collaboration in international environmental initiatives. Consequently, a hierarchical approach that considers regional ecosystem issues as nested within large marine ecosystems (LMEs) may be most useful [18]. Australia has used this concept in developing management plans for its marine ecosystem, dividing its LMEs into smaller sites nested within each LME [19, 20].

Stakeholders in marine ecosystem science and policy cut across society, from formal government organizations charged with managing the resources, to industry groups looking to profit from those resources, to subsistence fishers or gatherers that feed their families with the resources, to property owners whose properties may abut the resources, to non-governmental

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organizations and others who wish to conserve the resources. A process in which diverse representatives participate in regional meetings should be sought and encouraged so that the scoping process elicits a wide range of opinions and perspectives, and to better ensure the ultimate implementation of management recommendations from the process [21].

Following initial public education, open stakeholder meetings will take place in areas accessible to the ecosystem's stakeholders. These initial meetings focus on the interests and concerns of more localized stakeholders to their nearest marine areas. Regional stakeholder meetings should be open to the public and formally facilitated, with the goal of drafting a set of both localized and LME-wide ecosystem management goals and the perceived threats to achieving those goals. Beginning the stakeholder meetings with this more localized approach allows each stakeholder to share and gather information useful to their particular geographic area of interest or jurisdiction, whether that area is the whole LME, or part of a nested marine ecosystem. Similarly, managers who are responsible for local-scale resource management, or scientists with smaller-scale study areas can benefit from this opportunity to take an in-depth look at how stakeholders view their region's place within the larger ecosystem.

Swift information-turnaround to the public following scoping meetings will be important both to share regional information broadly throughout the LME's interested public, and so that regional stakeholders have confirmation that their contributions are useful and valued [22]. Once the public has had an opportunity to absorb what will likely be a wide variety of stakeholder opinions and ideas at the regional and ecosystem levels, the public process opens again for an LME-level stakeholder meeting. As with the regional stakeholder meetings, the LME stakeholder meeting should be open to the public and professionally facilitated. Taking into account the information developed from the regional stakeholder meetings, LME stakeholder meetings will draft LME-wide ecosystem management goals and the perceived threats to achieving those goals [1,14]. To transition the IEA process to its next step, indicator development, the LME stakeholder meeting will also draft a list of potential indicators of ecosystem health, prioritizing those natural resources and systems of greatest interest to the public.

IEA coordinators close out the public scoping step of the IEA by swiftly providing results of the LME stakeholders meeting to the public. IEA coordinators will need to develop a communication plan that provides: continual dialogue during the lifetime of the IEA; an action plan to translate science and research information into policy advice; and a firmly established communications network to quickly disseminate both the results and advice to all interested parties [23]. Setting the stage for open communication at the start of the IEA is essential to bridging the science-policy gap in EBM, and will serve all of the participants well as the IEA moves into its next step, development of ecosystem indicators.

3. Developing ecosystem indicators

Following the public scoping process, the next step in the IEA is developing ecosystem indicators. Like scoping, the process to develop ecosystem indicators offers an opportunity to improve communication between scientists, managers, and citizen-stakeholders. Ecosystem indicators are central to IEAs because they serve as proxies for the ecosystem services about which policy makers and stakeholders are concerned [24]. As such, indicators are one of the primary contact points between policy and science. Imprecise, inaccurate or uninspiring indicators will doom IEAs to the dustbin of EBM. Thus, a critical step in the IEA process must be to generate indicators that are both compelling to the public and decision makers, but that also capture the key ecosystem states and processes that underlie healthy ecosystems. We submit that a process that integrates rigorous scientific analyses with public review is most likely to produce meaningful indicators.

Many indicators, such as physical indices (e.g., [25]), abundance of single species [26], or groups of species (e.g., [27]), sizes of individuals [28], the size structure of the community [29], biomass ratios [30], indices of diversity [31] and various metrics of ecosystem function derived from models (e.g. [32],) have been proposed for use in EBM. Socio-economic indicators [33] may be used to better characterize the interactions of humans within the studied ecosystem (e.g., [34]), particularly in areas where coastal communities may be economically vulnerable to shifts in levels of harvestable living marine resources (e.g., [35,36]). There is clearly no shortage of potential indicators of ecosystem status, but the real work is to wisely select from among long lists of potential indicators [37,38].

Rice and Rochet [37] outline a useful framework for identifying a suite of informative indicators for ecosystem management. They argue that indicators should be directly observable, based on well-defined theory while also being understandable to the general public, cost effective to measure, supported by historical time series, sensitive and responsive to changes in ecosystem state (and management efforts), and responsive to the properties they are intended to measure.

Generating a list of potential indicators for EBM that meet many of these criteria is a laborious but straightforward process. For instance, in Washington State's Puget Sound, a process is underway that solicits and organizes experienced judgment from the scientific community concerning potential ecosystem indicators for the region. Using a framework comparable to that proposed by Rice and Rochet [37], a team of scientists representing different agencies and areas of expertise are working through proposed indicators and determining how well they meet criteria related to public awareness, cost effectiveness, theoretical foundation, measurability and the availability of historical data [39]. This sort of qualitative screening exercise is an appropriate initial step, but cannot rigorously evaluate the sensitivity, responsiveness, or specificity of indicators.

Formal evaluation of the performance of indicators requires either extensive empirical analyses or simulation modeling. Empirical evaluation of indicator sensitivity, responsiveness or specificity requires extensive data as well as knowledge about the statistical properties of the indicators and processes structuring the ecosystem. Computer simulation provides an alternative approach for evaluating indicator performance in cases where extensive data are lacking. Fulton et al. [30], for example, used the Atlantis ecosystem model to determine the degree to which potential indicators reflected changes in ecosystem properties. In this approach, an operating model is used to simulate the dynamics of the system over time. A sampling model is used to simulate a monitoring program and produces a time series of pseudo-data with realistic sampling and process error. These pseudo-data are then processed using standard techniques to generate time series of indicators. Indicators are then evaluated by their ability to detect or predict changes in "true" values of key ecosystem attributes (which are known from the simulation model). Using this approach, Fulton et al. [30] showed that a portfolio of indicators that include species with high turnover, groups targeted by fisheries, habitat defining taxa, and species with long generation times near the top of the food web provided a good overall view of the system.

Indicators not only need to accurately reflect the state of the ecosystem, they should also inspire engagement, when action is called for. Scientists may call for careful tracking of lackluster organisms such as ratfish, nematodes, or copepods. While these

species may be ecologically critical, such indicators are unlikely to motivate major policy initiatives or drastic changes in public behavior. On the other hand, iconic taxa like marine mammals, sea turtles, salmon, or large fishes may not provide us with all the information we need to successfully conduct EBM [40]. That is, they may be inadequate proxies for all the critical ecosystem attributes with which we are concerned. To bridge this gap between the values and needs of the public at large and those of ecosystem scientists, we need an approach to ecosystem status indicators that melds conservation biology and conservation psychology [41].

Saunders [41] defines conservation psychology as "the scientific study of the reciprocal relationships between humans and the rest of nature, with a particular focus on how to encourage conservation of the natural world." As a field of study, it grew out of psychologists' efforts in the earliest years of the 21st century to better organize disparate social science research efforts into human relationships with the environment and with environmental sustainability [42–44]. While Grumbine [9] credits conservation scientists from the 1930s and 1940s, particularly Aldo Leopold [45] with the origins of EBM, the scientific movement to apply EBM to ocean resources emerged during the same period as conservation psychology's coalescence. The connection between these two fields of study—marine ecosystem science and conservation psychology—is important here because one of the purposes of an IEA is to help all of the process participants to shift their thinking beyond single-species management and toward management challenges at an ecosystem-wide level. For the public scoping portion of the IEA, we have proposed tapping into the more intimate and personal connection people have with their local environment by beginning scoping for smaller or nested marine ecosystems within the LME. For indicator development, we acknowledge the connection that citizens may have to certain more charismatic species within an ecosystem and suggest that such connections should be recognized by including indicators for those species, such as abundance or habitat quality, within the suite of indicators for an LME. However, we are explicitly not suggesting that the abundance or health any one species, charismatic or otherwise, be used as an indicator for the health of the entire ecosystem [46,47].

As shown in Fig. 2, we break the IEA's indicator development step into three phases: scientific review of indicators developed during the public scoping step, public review and comment, and final selection of indicators. The IEA's indicator development step begins with IEA scientists reviewing the results of the public scoping process. Scientists will evaluate the stakeholder-proposed indicators for: (1) the attributes of ecosystem function to be addressed by the suite of potential indicators, (2) the degree of redundancy in indicator coverage, and (3) what attributes of ecosystem function may not have been addressed by the suite of indicators [48]. Knowing what attributes may not be adequately covered by the enhanced suite of indicators allows scientists to conduct analyses and propose indicators to fill these gaps. If there are several proposed indicators that could be used to provide information on a given management goal for an ecosystem function, priority should be given to those indicators that both meet the Rice and Rochet [37] framework, and which are most resonant with the public.

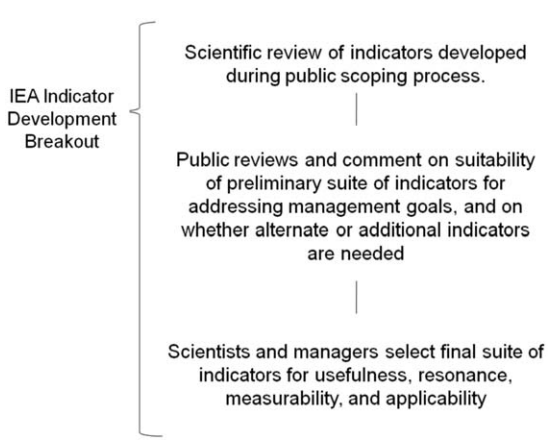

Fig. 2. The indicator development step of the IEA process broken into three phases: science review of indicators from public scoping process, public review and comment period, final selection of indicators.

The suite of ecosystem indicators developed from public scoping and refined through scientific review will be sent out for a period of public review and comment on the suitability of those indicators for addressing management goals and priorities, and on whether there are additional or alternative indicators that might also be used. Comments from the public will then inform the third phase of indicator development, where IEA scientists work with managers to set the final suite of indicators, again keeping in mind indicator usefulness, resonance, measurability, and applicability to management goals.

4. Risk analysis

After indicator development, Levin et al. [1] identify the next step in the IEA process as risk analysis. Risk analysis is a quantitative modeling process intended to identify the status of the ecosystem and its components relative to both its historical status and to the prescribed management targets derived from public discussion during the scoping and indicator development steps of the IEA [1]. To be used in support of management, risk assessment necessarily requires adjacent public discussion processes [49–51]. The IEA process provides opportunities for interactions between scientists, managers, and the public prior to the risk analysis step in the public scoping and indicator development steps. Therefore, within an IEA, risk analysis is a scientific effort, the results of which are to be reported on and discussed in the next IEA step, management strategy evaluation. Since the intent of this paper is to discuss the science–management interface, we will move directly to management strategy evaluation.

5. Management strategy evaluation

Management strategy evaluation (MSE) provides another opportunity within the IEA for interaction between scientists, managers and citizen-stakeholders by modeling potential ecosystem behavior and changes under a range of potential future management scenarios [52–55]. At the MSE step, IEA participants are together exploring possible future outcomes for current management practices within the ecosystem. MSE also explores potential management responses that may shift those outcomes to better align outcomes with management goals articulated earlier in the IEA process.

For a given ecosystem, particularly one at the LME scale, citizens and government agencies will have a broad range of management goals and desires, some of which may not complement each other. MSE uses ecosystem modeling to assess which management strategies may be most likely to achieve particular management goals and to what degree those goals may be achieved [53]. For example, one management goal may be to recover all exploited populations within an LME to 60% of their estimated unfished biomass levels, while another goal may be to

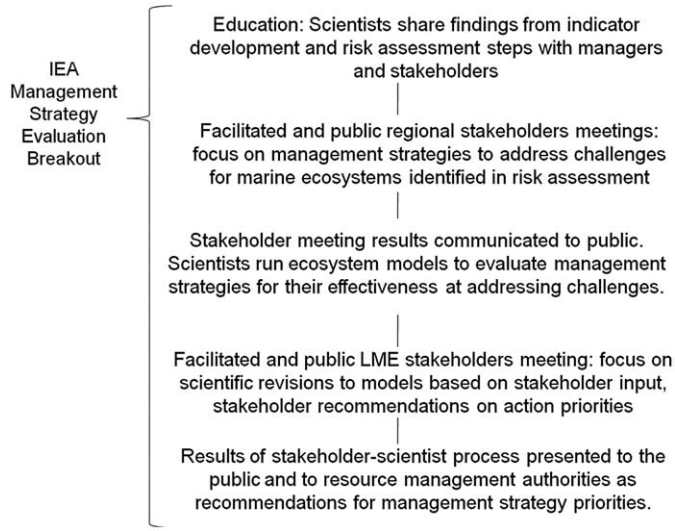

Fig. 3. The MSE step of the IEA process broken into five phases: share scientific findings from prior steps; regional stake holders meetings; ecosystem model evaluation of management strategies; finalize stakeholder recommendations and model refinements; share recommendations with the public and appropriate policy processes.

minimize interannual variability in allowable catch levels of exploited populations. MSE evaluates the likelihood and degree to which these potentially incompatible goals could be met using a variety of different management strategies, ultimately allowing managers to choose the management strategy most in line with the highest priority management goals [56].

MSE model(s) for an IEA evaluate the effects over time of a range of physical and chemical processes and management strategies on components of the biophysical ecosystem as well as elements of the human system. Participants in an IEA, particularly a first-time IEA for a given ecosystem, may wish to consider conducting a detailed MSE for one or two nested marine ecosystems within the LME before attempting LME-wide models. As shown in Fig. 3, we break the IEA MSE step into five phases: education, stakeholder meetings at the regional level, communication of meeting results and scientific evaluation of ecosystem model effectiveness, LME-level public meeting to review MSE modeling results and make final policy recommendations, results of management strategy prioritization communicated to the public.

For the MSE step of the IEA, IEA coordinators re-convene stakeholder groups at the regional level. Similar to the public scoping process, stakeholders here propose potential management tools to achieve the goals identified under public scoping, given the information available from the indicator development and risk assessment steps about ecosystem and ecosystem component status. As with stakeholder meetings from the public scoping step, stakeholder meetings in the MSE step should be open to the public and formally facilitated. Also similar to the public scoping step, the MSE step begins with education, an opportunity for scientists to present their work from the risk assessment step and the types of information that can and cannot be generated from ecosystem models. During the MSE public discussions, ecosystem scientists also have opportunities to pose questions to the stakeholder bodies, so that the scientists may better refine their models to address management priorities.

After modeling proposed scenarios, a final and LME-level public stakeholder meeting will provide stakeholders, scientists and managers the opportunity to refine the management strategies evaluated in the ecosystem models. Stakeholders will finish the meeting by making recommendations to address the challenges revealed in earlier steps of the IEA—both by prioritizing the order in which those challenges should be addressed and by recommending the management strategies to be used to address the challenges.

Providing stakeholders with an opportunity to recommend policy priorities based on what they have learned through the IEA process is essential to implement EBM, particularly for ecosystems under the jurisdiction of democracies with a strong history of citizen participation in governance. EBM, as many authors have reminded us, represents a significant shift in how governments, scientists, and citizen-stakeholders think about natural resources and the place of humans within ecosystems. Conducting an IEA can foster a common vision for management priorities for an LME or nested marine ecosystem.

The ecosystem models needed to conduct the MSE step of the IEA are crucial as managers and citizen-stakeholders determine whether EBM objectives have been achieved. Stakeholders educated with the results of MSE must ask themselves several questions when recommending policy priorities. First, what action is most urgently needed right now? Are there policy changes that can and should be made immediately to halt the decline of particular species or ecosystem functions within the ecosystem? Second, what policy actions are possible to take right now? After assessing the result of the MSE, stakeholders may see policy changes that can be made swiftly and easily that may have some desired effect on ecosystem function or components. Those policy changes that are possible in the near-term may not be the most urgently needed actions, but stakeholders may still consider them high-priority in order to promote positive movement toward EBM. Third, what action is urgently needed over the long-term? Are there some long-lived species that could benefit from a policy change that might not be immediately possible within current governance frameworks? If so, what are the paths to accomplish that policy change in time to have a positive effect on the ecosystem for those species? And, fourth, what policy changes are necessary for both the short- and long-term health of the ecosystem that simply cannot be implemented under current governance frameworks, or that might not be expected to show near-term measurable results? Just as an ecosystem is composed of a wide variety of interacting parts, natural resource governance in many nations is a complex and interconnected web of jurisdictions, laws, and knowledge sources. Even if a nation's governance framework is not ideally designed for implementing EBM, a committed and creative group of citizen-stakeholders, scientists, and managers can find ways to make change happen within current frameworks if they first meet the essential challenge of finding a common vision for their ecosystem of interest [57–59]. The common vision developed via the IEA process will help guide governments in making effective and efficient changes to take better advantage of the collective wisdom of IEA process participants.

6. Conclusion

By more fully developing the details of the IEA process, we have placed a strong emphasis on the linked work of managers, scientists, and citizen-stakeholders within the process. Scientific modeling has developed to where it can now support a shift in public management processes for natural resources through the exploration of EBM [60]. High concept public policy processes in the United States and elsewhere have called for EBM, suggesting ambitious changes to the governance structure ocean resources [6–8]. Developing EBM concepts for particular ecosystems now requires managers to initiate an open and public dialogue

between themselves, scientists, and citizen-stakeholders. The IEA dialogue process we have described is intended to provide ongoing feedback between the loosely-defined groups of participants (scientists, managers, and citizen-stakeholders), so that participants in each group have regular opportunities to learn from the others to better build a common vision for the ecosystem.

Nordhaus [61] and Nordhaus et al. [62] identified the political business cycle, showing links between how the economies of representative democracies are managed and the timeframe of the electoral cycle. Perhaps not surprisingly, the work of Nordhaus and others has shown that the short-term desires of politicians to get re-elected often outweigh the long-term planning needs of a stable economy. Similar influences affect natural resource management, so that management decisions for ecosystems or their components may be altered by short-term political processes with little vision for the timescales of ecosystem variability. Ultimately, the ideas and interests of citizen-stakeholders may have the greatest influence over EBM implementation. Stakeholders may be able to push the political process more effectively than other participants in EBM because they will have the freedom of longer attention spans than managers who are affected by the political process. Stakeholders will also have a more flexibility than scientists, who must maintain a degree of independence for their work to be trusted. Ultimately, we suggest that EBM generally, and IEAs in particular, requires a strong commitment to transparent and respectful communication of knowledge. That commitment will allow the resource management process to work toward the desired shift in management focus, where we consider the functions of whole ecosystems and our place within them.

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