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Guidance for implementation of integrated ecosystem assessments: a US perspective

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Ecosystem-based management (EBM) has emerged as a basic approach for managing human activities in marine ecosystems, with the aim of recovering and conserving marine ecosystems and the services they deliver. Integrated ecosystem assessments (IEAs) further the transition of EBM from principle to practice by providing an efficient, transparent means of summarizing the status of ecosystem components, screening and prioritizing potential risks, and evaluating alternative management strategies against a backdrop of environmental variability. In this paper, we draw upon lessons learned from the US National Oceanic and Atmospheric Administration's IEA programme to outline steps required for IEA implementation. We provide an overview of the conceptual framework for IEAs, the practical constraints that shape the structure of individual IEAs, and the uses and outcomes of IEAs in support of EBM.

Keywords: ecosystem-based management, ecosystem indicator, ecosystem risk, IEA, integrated ecosystem assessment, management strategy evaluation.

Introduction

The need for a more holistic and integrated approach to the management of ocean resources is now widely appreciated in the scientific and management communities (U. S. Commission on Ocean Policy, 2004; MEA, 2005; Murawski and Matlock, 2006; Agardy *et al.*, 2011). Ecosystem-based management (EBM) recognizes that humans are integral components of ecosystems that interact with all other components in diverse, complex ways. Despite the appreciation for integrated EBM, there remain few examples of successful implementation (Cowling *et al.*, 2008). This is in part, because we need tools to make the scientific principles of EBM useful to resource managers (Arkema *et al.*, 2006). A preeminent need for implementing EBM is a framework to assess the status of ecosystems relative to specific management goals and objectives and to evaluate the probable outcomes and trade-offs of alternative management strategies. Integrated ecosystem assessments (IEAs) are intended to provide just such a framework (Levin *et al.*, 2009). IEAs provide a structured approach to ecosystem assessment and evaluation that serves as an integrative counterpart to single-species and single-sector assessments now applied in resource management.

A number of IEA frameworks are currently being considered across the globe. For example, the ICES Working Group on the ecosystem effects of fisheries activities, reviewed IEA approaches used in the Northeastern Atlantic, North Sea, Canada, and the United States (ICES, 2010). These approaches differ in the degree to which pressures are linked to ecosystem states, the degree of integration across human and natural dimensions, and the regional consistency that the frameworks promote. However, they all share a motivation to describe the status of the ecosystem relative to some desired state. Here, we focus on NOAA's IEA framework, while acknowledging that IEAs are an emerging tool, which is being approached differently by different countries and agencies.

The basic structural elements of NOAA's IEA framework have been described elsewhere (Levin *et al.*, 2008, 2009). Since NOAA first published its IEA framework, the NOAA IEA programme has grown, and the IEA approach is now being implemented throughout the United States (www.noaa.gov/iea). In this document, we build on the initial IEA formulation of Levin *et al.* (2008) and draw upon lessons learned from NOAA's IEA programme to outline practical steps required for IEA implementation. We provide an overview of the conceptual framework for IEAs, the practical constraints that shape the structure of individual IEAs, and the uses and outcomes of IEAs in support of EBM.

A stepwise process for developing an IEA

In this paper, we follow Levin *et al.* (2009) and define an IEA as a formal synthesis and quantitative analysis of existing information on relevant natural and socio-economic factors in relation to specified ecosystem management objectives. IEAs are a stepwise process consisting of goal and target setting, defining indicators, analysis of status, trends and risk, an overall assessment of ecosystem status, an evaluation of alternative management strategies, and monitoring and evaluation (Figure 1). This process is iterative, allowing for improved understanding and management of the coupled human-natural system over time. We use this framework to organize our discussion below.

Step 1: defining EBM goals

IEAs are driven by clearly defined management objectives; consequently, the IEA approach purposefully begins by identifying priority management objectives to be addressed. This requires that scientists, managers, and stakeholders work together to define the broad vision and objectives of EBM, the spatial scale or scales of interest, and the ecosystem components and ecosystem threats that will be included in the effort. Below we detail each one of these elements.

Articulating the objectives to be addressed by the IEA process

The range of potential issues that could be addressed by an IEA is enormous, and any IEA effort must begin with transparent articulation of the vision and objectives of the assessment. Sainsbury and Sumaila (2003) provide a useful framework for thinking about ecosystem objectives. They define an ecosystem vision as a statement of the way "things should be". For example, in 2005, Washington Governor Christine Gregoire's ecosystem vision for Puget Sound, USA, was that it will "forever be a thriving natural system, with clean marine and freshwaters, healthy and abundant native species, natural shorelines and places for public enjoyment and a vibrant economy that prospers in productive harmony with a healthy sound."(Puget Sound Partnership, 2006). Although such vision statements are necessary, they are too vague to be practically useful. Thus, ecosystem visions need to be decomposed into conceptual and operational objectives (O'Boyle and Jamieson, 2006). A conceptual objective is a high-level statement of what is to be attained. As examples: (i) manage resources sustainable for human nutritional, economical, and social goals or (ii) protect rare or fragile ecosystems, habitats, and species. An operational objective is an objective that has a direct and practical interpretation. Formulating effective operational objectives requires thinking carefully about the specific outcomes of EBM and how success or failure will be measured and detected.

The US National Ocean Policy provides many conceptual objectives that will require the development of operational objectives at

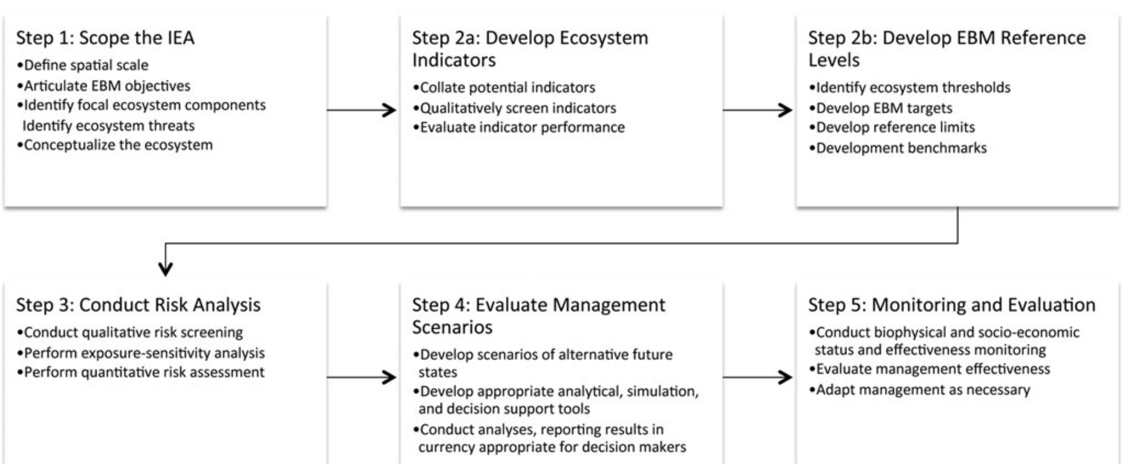

Figure 1. A stepwise process for completing an IEA. An IEA begins with a scoping process, identifies appropriate indicators and reference levels, assesses risk, and evaluates the potential of different management strategies to alter ecosystem status. Monitoring and evaluation occur throughout the process, and the IEA cycle is repeated in an adaptive manner.

national and regional scales. Fortunately, NOAA and other federal and state agencies have a long history of working with Congress and management bodies to translate the conceptual objectives of legislation into operational objectives. For example, in coastal-zone management, NOAA and the EPA provide broad guidance to the states, which then implement the objectives of the Coastal Zone Management Act and Clean Water Act through state-specific programmes.

Defining the spatial scale of an IEA

The spatial scale of an IEA is largely determined by the management questions being addressed, and thus IEAs can vary in scale and extent. As a result, a key step in IEA scoping is to determine the scale of a particular IEA as it relates to defined management objectives. Ecosystem boundaries are human constructs based on biophysical and political distributions; consequently, defining the scale of an IEA is an important exercise that ideally considers biophysical, human dimension, and management considerations. As a consequence, there is no "correct" scale at which to conduct an IEA, but each implementation of the IEA framework will have a specified scale and extent appropriate to the management objectives driving the assessment.

IEAs will almost certainly have to contend with ecosystem processes and human activities that extend beyond the boundaries of an IEA. Oceanographic processes, terrestrial-based inputs, and climate change are just a few examples of this problem. This issue can be addressed by identifying drivers and pressures that occur within the IEA vs. those that emanate from outside the IEA, but must be considered. This delineation has the benefit of defining pressures over which local management agencies have jurisdiction and the externalities that affect the system, but are outside of local control.

Identifying focal ecosystem components of an IEA

Components of an ecosystem include everything: the physics, geology, chemistry, biology, and human dimensions. Focal ecosystem components are the major elements of an ecosystem that can be used to organize relevant information in a limited number of discrete, but not necessarily independent categories. In the California Current IEA, a workshop with NOAA managers was used to develop a set of focal components that included: ecological structure and function, fisheries, protected species, habitat, and human communities (Levin and Schwing, 2011). Similarly, the focal components of the Kona ecosystem were identified as: coral reefs, ornamental, recreational, and commercial fisheries, open ocean and coastal aquaculture programmes, tourism, shared-use areas involving industry and natural resources (e.g. manta ray habitat and commercial diving), critical cetacean habitat, and natural energy facilities. The Northeast Continental Shelf IEA defined focal ecosystem components as ones that require management interventions to ensure their continued viability, such as species directly or indirectly affected by fishing activities and other anthropogenic impacts, protected species, and human communities dependent on the ecosystem for food, recreation, and other uses.

Identifying key threats to ecosystem components

Identification and prioritization of threats to achieving EBM objectives are important so that the IEA team can concentrate efforts where they are needed most. The analytical efforts described below can be useful in identifying key threats. Additionally, formal or informal discussions with partners and stakeholders can be useful for focusing efforts.

The identification of threats during the initial stage of the IEA process allows regional experts an opportunity to highlight ecosystem components that are highly exposed to human and natural pressures. In essence, the identification of threats is the base from which a formal risk analysis is launched (risk analysis is discussed below).

Putting it all together: conceptualize the ecosystem and the IEA

Developing a common understanding of the context of the IEA, including the biophysical, socio-economic, and management systems that affect the ability to achieve the vision of the IEA is the ultimate step in scoping an IEA. This step builds upon previous work in which the objectives, focal ecosystem components, and threats are identified.

Conceptual ecosystem models have proven useful for understanding ecosystems and can be helpful for synthesizing diverse scientific information. Conceptual models have a successful history in resource management (Bowen and Riley, 2003), especially when scientists, resource managers, and stakeholders jointly develop models in workshop settings (Svarstad *et al.*, 2008). Collaborative model development assists in building consensus and helps move beyond disagreements to a focus on how the ecosystem is structured and functions.

Step 2: defining ecosystem indicators and reference levels

Description of different approaches to select and evaluate ecosystem indicators

A critical step in the IEA process is to select indicators that capture the key aspects of the focal ecosystem components identified in step 1. Indicators are quantitative measures that serve as proxies for characterizing key attributes of biogeochemical and human systems (Heinz Center for Science and the Environment, 2008). Effective indicators serve as the measures of the many ecosystem services that concern policy-makers and stakeholders (Link, 2005) and are one of the primary contact points between policy and science.

Hundreds if not thousands of indicators have been proposed for use in EBM (e.g. Kershner *et al.*, 2011; James *et al.*, 2012). Rice and Rochet (2005), Methratta and Link (2006), and Shin and Shannon (2010) outline valuable frameworks for sorting through voluminous lists and building a portfolio of informative indicators for EBM. These authors argue that indicators should be directly observable and 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 properties they are intended to measure. Levin *et al.* (2011) adapted these frameworks by soliciting and organizing expert judgement from the scientific community. Then, building on Rice and Rochet (2005), a team of scientists representing different agencies and areas of expertise worked through proposed indicators and determined how well they met criteria related to public awareness, cost effectiveness, theoretical foundation, measurability, and availability of historical data (Levin *et al.*, 2011). This type of screening process is a necessary first step, but it cannot rigorously evaluate key indicator traits such as sensitivity, responsiveness, or specificity. Similar screening processes have been adopted in other regions (Link *et al.*, 2002; Ecosystem Assessment Program, 2009; Shin *et al.*, 2012).

Efforts in the Gulf of Mexico, Northeastern US, and California Current are using ecosystem models to evaluate the diagnostic qualities of indicators (Fulton *et al.*, 2005; Samhouri *et al.*, 2009; Levin and Schwing, 2011). These models are used to simulate varying levels and different types of perturbations to the ecosystem. The performance of each indicator in tracking perturbations or ecosystem structure and function can be assessed using a variety of statistical techniques (e.g. time-series analysis, cross-correlations, etc.).

As with all phases of the IEA, indicators need to be regularly updated and revisited as more information becomes available, as environmental conditions change, and as new threats emerge. Finally, because indicators are a key point of connectivity between science and policy, it is important to generate portfolios of indicators that are not only scientifically rigorous but are also understandable and salient to stakeholders (Levin *et al.*, 2010).

Science to inform the establishment of ecosystem management reference levels

Establishing a set of indicator values that reflect progress towards specific management objectives is critical for successful EBM. Such reference levels provide context for evaluating performance and progress towards EBM goals. Reference levels can be diverse and include both ecosystem state variables of interest (e.g. habitat area, measures of diversity, etc.) as well as metrics of ecosystem pressures (e.g. shoreline development, nutrient, or contaminant input). These levels can be drawn from the underlying properties of the natural and human systems or they can be designated as part of the process of setting management goals. Establishing a reference level is informed by science, but ultimately reference levels are set to achieve a desired policy outcome.

For an IEA, reference levels serve a variety of purposes. The most obvious is the role they play in the establishment of targets for restoring and protecting the ecosystem (Sainsbury *et al.*, 2000; Bottrill *et al.*, 2008). A reference target is the level of an ecosystem indicator that represents the desired state of the ecosystem. A reference limit, on the other hand, is the attribute level that marks an ecosystem state to be avoided (Samhouri *et al.*, 2011). In fisheries management, for instance, "optimum yield" is a reference target and "overfished" is a reference limit. Because some ecosystem indicators respond slowly to management action or natural drivers, there is a need for benchmarks or intermediate indicator values that demonstrate progress towards those levels.

Ecosystem-based reference levels are needed to refine the limits of acceptable resource use, plan for future climate- and human-induced changes to ecosystem services, and inform conservation and recovery plans for sensitive species and habitats. Scientific analysis can contribute to the setting of reference levels in several ways. For example, perturbations to ecosystem models have been used to explore non-linearities between pressures and ecosystem state (e.g. Samhouri *et al.*, 2010). To complement these modelling approaches, statistical models may prove useful for investigating the relationship between ecosystem state variables and natural and anthropogenic pressures. No matter what approaches are used, the goal of this step is to identify thresholds and inflection points that may provide a basis for the identification of reference levels. Importantly, as we noted at the beginning of this section, the identification of reference levels is a societal choice and the role of IEAs is to inform that choice.

Step 3: risk analysis—impacts of natural perturbations and human activities on ecosystem status

Description of different approaches for conducting risk analysis

Once ecosystem indicators and reference levels are selected, the next IEA step evaluates the risk to the indicators posed by human activities and natural processes. The goal of these risk analyses is to qualitatively or quantitatively determine the likelihood that an ecosystem indicator will reach or remain in an undesirable state (i.e. breach a reference limit). Ecosystem modelling and analysis are important in determining incremental improvements in ecosystem indicators in response to changes in human-induced pressures. Risk analysis must explicitly consider the inevitable uncertainties involved in understanding and quantifying ecosystem dynamics and their positive and negative impacts on social systems.

Risk analysis must include pressures that occur on land (e.g. coastal development, agriculture, changing river flows, etc.), in the air (e.g. weather, climate), and in the ocean itself (e.g. shipping, naval exercises, fishing, energy extraction, and physical and chemical conditions; Halpern *et al.*, 2009). Thus, an ecosystem risk analysis ideally requires an understanding of the distribution and intensity of land-, air-, and sea-based pressures, as well as their impacts on ecosystem components. Additionally, because the cumulative effect of multiple stressors may not simply equal the sum of the individual stressors' effects, risk analysis should consider cumulative impacts (Crain *et al.*, 2008; Ban *et al.*, 2010; Kaplan *et al.*, 2012).

There are a number of approaches to risk assessment; however, most forms of risk assessment can be used within the ecological risk assessment framework described by Hobday *et al.* (2011). Briefly, this is a hierarchical approach that moves from qualitative but comprehensive analyses (level 1) to a less comprehensive, semi-quantitative analysis (level 2) and to a focused, fully quantitative analysis (level 3).

A level 1 analysis for each pressure qualitatively scores each human activity or natural perturbation for its impact on the focal ecosystem components of the IEA. Those pressures receiving a high impact score move onto level 2 analyses. As part of the ongoing engagement process described above, scientists and managers need to define what levels of impact score constitute "high" or "low" for this process. Thus, a level 1 analysis separates out those activity-component pairs that warrant further investigation from those that are given the all clear.

A level 2 analysis considers the exposure of an ecosystem component to a pressure and the sensitivity of the component to that pressure. This framework has proven useful for conducting semi-quantitative risk analysis in ecosystem-based fisheries management (Stobutzki *et al.*, 2002; Hobday *et al.*, 2006, 2011; Patrick *et al.*, 2010) and has been useful for IEAs, as well (e.g. Samhouri and Levin, 2012). In this approach, risk to an indicator can be defined as the Euclidean distance of the indicator from the origin in a space defined by exposure and sensitivity to particular human activities. Exposure can be estimated as a function of spatial and temporal overlap of activities, and sensitivity can be estimated by the degree to which life-history attributes or behaviour affects an indicator's ability to resist or recover from exposure to a human activities. If this level 2 analysis determines the impact of an activity on a species or other ecological component is high and there are no planned management interventions to remove it, the reasons are documented and the assessment moves to level 3.

The level 3 analysis takes a quantitative approach such as is used in stock assessments and population viability analyses. A number of modelling approaches lend themselves to level 3 analyses, but all are dependent on the amount and quality of the available data. What model is used in a level 3 analysis depends on the nature of the data and other available information.

Step 4: evaluation of management strategies for protection or restoration of ecosystem status

Approaches for evaluating management strategies

The next step in the IEA process uses simulation and analytical or conceptual modelling to evaluate the potential of different management strategies to influence the status of natural and human system indicators and to achieve our stated ecosystem objectives.

Scenario analysis generates the multiple alternative descriptions of potential outcomes, including processes of change, thresholds, and uncertainties (Alcamo, 2008). Scenarios explore alternative perspectives about underlying system processes and can illuminate key issues, by using a consistent set of assumptions about the system state to broaden perspectives (Raskin, 2005; Refsgaard *et al.*, 2007). They generate alternative, internally consistent, logical descriptions of the future. Scenarios can be qualitative, in which "storylines" are developed, or quantitative, in which the outcomes of numerical models are explored (Refsgaard *et al.*, 2007).

Formal management strategy evaluation (MSE) is a modelling approach that can be used to analyse posited scenarios. MSE is widely used in the management of protected species (e.g. marine mammals) and fisheries and is beginning to see use in the EBM (Sainsbury *et al.*, 2000; Fulton *et al.*, 2007). By evaluating a range of management scenarios using multiple performance indicators (and potentially multiple operating models), formal MSE can be used to test the utility of modifying indicators, management targets, assessments, monitoring plans, management strategies, and decision rules. Importantly, the objective of MSE is not optimality. Rather, MSE is used to screen out poorly performing management strategies, identify trade-offs among objectives, and distinguish approaches robust to various types of uncertainty. Increasingly, MSEs are being used to evaluate interactions between separate management tactics and interactions between management, ecosystem processes, and large-scale drivers like climate change. For example, recent applications have attempted to the minimize risk of uncertainty on target and bycatch species (e.g. Stram and Ianelli, 2009), ESA at-risk species, critical habitats, and human communities under various short- and long-term climate scenarios (Hollowed *et al.*, 2009)

MSE incorporates a number of important features (Sainsbury *et al.*, 2000) that make it an ideal supporting process for IEAs. (i) Simulations are performed in the operating model on the managed system as a whole. For management towards ecological objectives, we require the explicit representation of the ecological system; similarly, for economic objectives, we require explicit ecological-economic linkages. (ii) Performance metrics are evaluated quantitatively in a simulation framework utilizing the indicators developed earlier in the IEA process. (iii) A variety of models or submodels may be used in the evaluation process; thus, scenarios may explore alternative hypotheses on ecosystem functioning or may use a consistent set of assumptions about the system state to illuminate key issues and broaden perspectives (Raskin, 2005; Refsgaard *et al.*, 2007). (iv) The MSE process allows ample opportunity for stakeholder involvement (e.g. workshops) and is greatly strengthened by discussion regarding management strategies to be evaluated, target species to include, incorporation of long-term monitoring data, comparison of model outcomes (including socio-economic impacts), and discussion of management trade-offs. (v) The MSE process often identifies data and knowledge gaps, which in turn can be used to inform future research.

Step 5: monitoring and evaluation

Monitoring and evaluation of chosen indicators and management strategies is an integral part of the IEA process. Monitoring and evaluation is necessary to determine whether management strategies improve ecosystem services and sustainability and quantifies the trade-offs that have occurred since implementation of the management strategy.

Monitoring

At its core, monitoring is straightforward; it is the collection of biotic, abiotic, and human dimension data. In the context of IEAs, monitoring is the systematic collection of data to reliably answer clearly articulated management questions (Katz, 2013). For IEA indicators, monitoring must directly address the operational objectives developed as part of the IEA process. While apparently simple, monitoring is costly and subject to the changing priorities of funding agencies. Thus, successful monitoring depends on developing efficient sampling programmes that allow a cost-effective determination of the state of the ecosystem and the effectiveness of management actions.

In general, there are two types of monitoring that are particularly important to IEAs. Trend monitoring is a systematic series of observations over time to detecting change in the state of an ecosystem component (MacDonald *et al.*, 1991). Typically, the observations are not taken with the aim of evaluating management actions, although such data may prove useful in this context as well. Trend monitoring focuses on the indicators of ecosystem state developed in step 2 of the IEA. Effectiveness monitoring is used to evaluate whether specific management actions had the desired effect. Effectiveness monitoring focuses on changes in threats identified in the scoping phase of the IEA and links threat reduction to changes in the status of key ecosystem components. Thus, effectiveness monitoring requires the observations of threats as well as the ecosystem component(s) targeted by the management action.

Katz (2013) notes that the key elements of monitoring are determining "what, where, (and sometimes) how" to measure the system. He also notes that in the best cases, a monitoring programme also confronts the issue of how well one wants to know the answer. Successfully addressing these elements defines the indicators (what and how) and the sampling design (where, when, and how well). Importantly, monitoring includes not only the measurements of the biophysical environment but also includes social and economic systems (McLeod and Leslie, 2009).

Evaluation

Evaluation of ecosystem status involves using data generated from trend monitoring to assess the condition or status of particular ecosystem components (Stem *et al.*, 2005). In contrast to status evaluation, evaluations for measuring management effectiveness are necessarily linked to discrete management actions and obviously are directly linked to effectiveness monitoring. Stem *et al.* (2005)

describe two types of effectiveness evaluations. Impact evaluations are generally one-time assessments frequently performed at the conclusion of a management project. The goal of impact evaluations is to determine how well a particular project performed. A second form of effectiveness evaluation is adaptive management—an iterative process that integrates the design of management strategies and monitoring to systematically evaluate management actions (Walters, 1986). Successful IEAs will evaluate the effectiveness of management actions and provide information to managers so they can adjust actions, as needed.

Conclusions

After decades of struggle over what EBM means, whether it is possible, and if it is needed, we have arrived at a time when comprehensive EBM is emerging and is supporting efforts to recover and conserve marine ecosystems (e.g. Lubchenco and Sutley, 2010). To further the transition of EBM from principles to practice, we must develop approaches that provide an efficient, transparent means of summarizing the status of ecosystem components, screening and prioritizing potential risks, and evaluating alternative management strategies against a backdrop of environmental variability. IEAs provide a means to do just this. Importantly, while the science of IEAs is progressing, Samhouri *et al.* (in review) note that operationalizing IEAs in management will require additional work and provide insight into how this might be facilitated.

In this paper, we opted out of producing an IEA "cookbook" with simple recipes for accomplishing each IEA step. Ecosystems, including their associated institutions, are too variable for such a prescriptive treatment. Instead, we provide a cookbook without recipes (cf. Haller, 1976), with the goal of providing basic guidance that can be tailored to the specific management needs, scientific capacity, and governance structures in any region. Like all science-management processes, we expect that as IEAs propagate and the scientific and management communities gain experience with them, a collection of best IEA practices will emerge. Currently, however, we look forward to a period of creativity and innovation that will rapidly advance the rigor and utility of this try.

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