INTEGRATED ECOSYSTEM ASSESSMENT: GUIDANCE FOR IMPLEMENTATION

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EXECUTIVE SUMMARY

Increasing demands and pressures placed on our oceans, coasts, and Great Lakes combined with natural variation in the environment is resulting in considerable stress on these systems and the services they provide, many times in ways we do not yet fully comprehend or consider.

In recent years, NOAA has been working to address management in a more comprehensive and holistic manner by advancing, integrating, and expanding its science to enable an ecosystem-based approach to management (EBM). The objective of EBM is to make management of our natural resources more effective. It takes a step beyond traditional management that considers single issues, species, or functions independently, and instead takes into account the richness and complexity of the interactions between them. Additionally, EBM considers the inherent links between human wellbeing and the condition of the ecosystem. Importantly, rather than replacing existing management structures, and the science that informs that management, EBM builds on these and develops them further. Finally, EBM cannot be realized without a solid science core – one that provides an understanding of the ecological systems, including individual components within a system, as well as the social elements.

One of NOAA's most comprehensive programs to achieve EBM is the Integrated Ecosystem Assessment (IEA) program which will enable NOAA to manage resources to achieve ecological, economic, and societal objectives and provides a sound scientific basis for EBM. NOAA defines IEAs as: "a synthesis and quantitative analysis of information on relevant physical, chemical, ecological and human processes in relation to specified ecosystem management objectives". By design, NOAA's IEA approach is a "decision-support system" that uses diverse data and models to forecast future conditions; evaluates alternative management scenarios; and assesses economic and ecological tradeoffs to guide decisions, implement, and evaluate management actions relative to pre-determined objectives. The system further enables revision of the IEA (adaptive management), and identification of data and information gaps. The approach requires close and continual work with relevant stakeholders and managers throughout the process to identify priority management issues in order to provide them with robust decision-support information.

The IEA structure provides a national framework that offers IEA practitioners a consistent, yet flexible, architecture to meet regional needs. It is a multi-step iterative process that begins with scoping to identify priority management objectives and targets; moves to identification and selection of indicators and reference levels to help measure the status of ecosystem elements relevant to the management objective(s); continues to an analysis of risk to evaluate the threats to the indicators posed by human activities or natural processes and to help establish the status of the ecosystem in question; and culminates in the evaluation of management strategies to assess their potential to influence the status of natural and human system indicators and to inform our decisions towards achieving our ecosystem objectives. However the process is not complete following assessment and selection of management actions. The IEA process includes monitoring and evaluation of chosen indicators and management strategies to determine whether the selected strategy has been successful in achieving the defined objective and target.

The development of IEAs in the United States is following a staged implementation strategy, with five of eight proposed regions currently working on building IEAs, each at different levels of implementation. Each of the regions' implementation of IEAs will address all of the defined steps of the IEA process. However, the approach will be tailored to management objectives relevant to each region, will be influenced by available, regionally-specific data sources and models.

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INTRODUCTION

The need for a more holistic and integrated approach to management of ocean resources is now widely appreciated (e.g., U. S. Commission on Ocean Policy 2004, MEA 2005, Murawski and Matlock 2006, OPFT 2010, UNEP 2011, Agardy et al. 2011). In recent years, NOAA has been developing scientifically-based ecosystem management strategies by advancing, integrating, and expanding our science to enable an ecosystem-based approach to management (EBM). The objective of EBM is to make management of natural resources more effective. It takes a step beyond traditional management that considers single issues, species, or functions independently, and instead takes into account the richness and complexity of the interactions between them. Additionally, EBM considers the inherent links between human activity and wellbeing and the condition of the ecosystem and its parts. Importantly, rather than replacing existing management structures, and the science that informs that management, EBM builds on these and develops them further. Finally EBM cannot be realized without a solid science core – one that provides an understanding of the ecological systems, including individual components within a system, as well as the social elements.

Implementing EBM requires a framework to assess the status of Great Lakes, coastal, and ocean ecosystems[1] in relation to specific management goals and objectives and to evaluate the potential outcomes of alternative management strategies. Integrated Ecosystem Assessments (IEAs) are intended to provide just such a framework. IEAs provide a structured approach to ecosystem evaluation that serves as an integrative counterpart to single-species and single-sector assessments now applied in resource management.

Globally, a number of definitions or frameworks for IEAs currently exist. For example, the ICES working group on the ecosystem effects of fisheries activities, reviewed IEA approaches used in the North-eastern Atlantic, North Sea, Canada and the U.S (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

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[1] In this document we consider Integrated Ecosystem Assessments for Great Lakes, coastal and ocean ecosystems. However, in this report, for brevity, we use often the term “marine” to be inclusive rather than using the phrase “Great Lakes, coastal and ocean” repeatedly.

the ecosystem relative to some desired state. Here, we focus on NOAA's IEA framework, while acknowledging that IEAs are an emerging tool that is being approached differently by different countries and agencies.

The fundamental structural elements of NOAA's IEA framework have been previously described (Levin et al 2008, 2009). The specific assessment and management challenges emerging in different regions require an approach that can be tailored to the particular circumstances and needs in each while remaining consistent with the underlying IEA philosophy. Parallel issues emerge in current approaches in single-species and single-sector assessment where the analytical approach is often informed by the nature of the available data and the specific types of management strategies adopted under different circumstances and regional objectives. Thus, a key strength of NOAA's IEA approach is its ability to apply a standard framework that can be tailored to regional management objectives and constraints.

This document describes the overall dimensions of NOAA's IEA process and the steps required for implementation. It provides 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.

CONCEPTS AND TERMINOLOGY FOR INTEGRATED ECOSYSTEM ASSESSMENTS

WHAT IS ECOSYSTEM-BASED MANAGEMENT?

Here we define an ecosystem as "a geographically specified system of organisms (including humans), the environment, and the processes that control its dynamics." (Murawski and Matlock 2006)

Ecosystem-based management (also referred to as ecosystem approaches to management, EAM) is an integrated approach to management that considers the entire ecosystem, including humans. It requires managing human activities as a whole instead of separately managing individual ecosystem components or uses; considers all elements that are integral to ecosystem functions; and accounts for economic, social, and environmental costs and benefits (McLeod et al. 2005). The goal of EBM is to maintain an ecosystem in a productive and resilient condition so that it can sustainably deliver the services humans want and need. Thus, EBM promotes long-term sustainability by focusing on the long-term ability to produce a broad suite of ecosystem services. Specifically, McLeod et al. state that EBM:

- emphasizes the protection of ecosystem structure, functioning, and key processes;
- is place-based in focusing on a specific ecosystem and the range of activities affecting it
- explicitly accounts for the interconnectedness within systems, recognizing the importance of interactions between many target species or key services and other non-target species;

- recognizes that society relies upon and benefits from the ecosystem through ecosystem services;
- acknowledges interconnectedness among systems, such as between air, land and sea;
- integrates ecological, social, economic, and institutional perspectives, recognizing their strong interdependences.

WHAT IS AN IEA?

Here we 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. It brings together citizens, industry representatives, scientists, and policy makers through established processes to evaluate a range of policy and/or management actions that are relevant to a diversity of environmental objectives. Importantly, IEAs are a science product that can inform ecosystem-based management actions across a number of sectors (e.g., land use, coastal zone management, shipping, energy development, fisheries). They provide a consistent structure and approach to inform and support decision-making processes and can be tailored to a variety of manager and stakeholder needs.

IEAs are tools, products, and processes. An IEA is a *tool* that uses various forms of analysis and ecosystem modeling to integrate a range of social, economic, and natural science data and information. An IEA is a *product* for managers and stakeholders who rely on scientific support for policy and decision making, as well as for scientists who want to enhance their understanding of ecosystem dynamics. Finally, an IEA is a *process* that begins with involvement of stakeholders to identify critical management and policy questions, moves to a quantitative assessment of ecosystem status, and includes an evaluation of management options. Through the tenets of adaptive management, the process returns full circle and triggers an update of the assessment, and initiates the IEA process again.

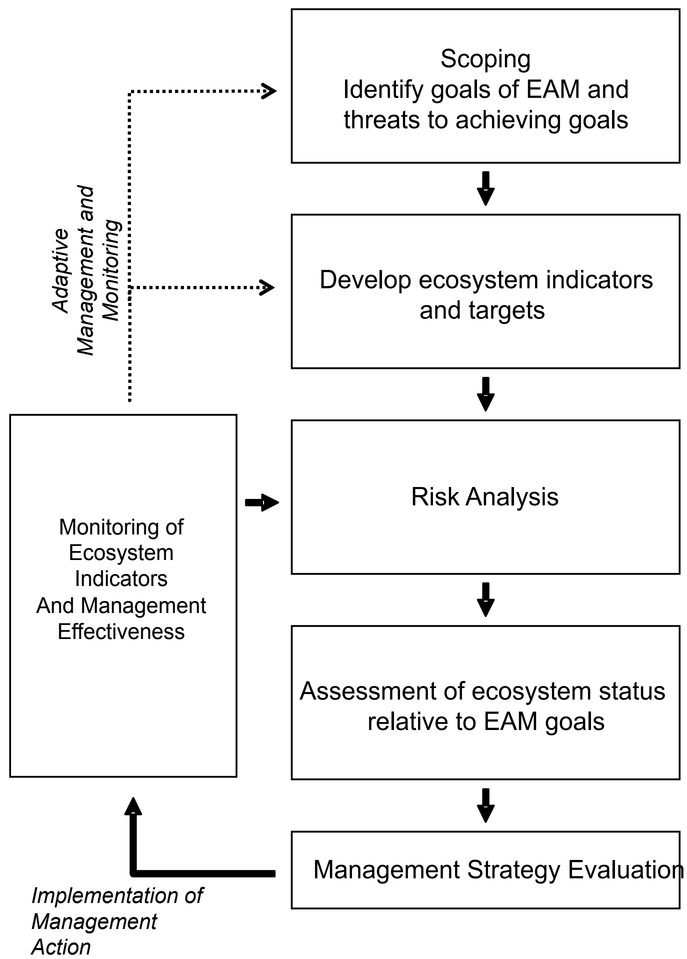

Figure 1. The Step-wise Process of Integrated Ecosystem Assessment (Levin et al. 2008). An IEA begins with a scoping process to identify key management objectives and constraints, identifies appropriate indicators and management thresholds, determines the risk that indicators will fall below management targets, and combines risk assessments of individual indicators into a determination of overall ecosystem status. The potential of different management strategies to alter ecosystem status is evaluated, and then management actions are implemented and their effectiveness monitored. The cycle is repeated in an adaptive manner.

An IEA results in the following products:

- Identification of key management or policy questions and specification of ecosystem goals and objectives
- Assessments of status and trends of the ecosystem
- Assessments of the environmental, social, and economic causes and consequences of these trends
- Forecasts of likely status of key ecosystem components under a range of policy and/or management actions
- Identification of crucial gaps in the knowledge of the ecosystem that will guide future research and data acquisition efforts.

Levin et al. (2009) describe a stepwise process for conducting IEAs consisting of scoping, defining indicators, setting reference levels, risk analysis, assessment of ecosystem status, management strategy evaluation, and monitoring and evaluation (Figure 1). This process is iterative, allowing for improved understanding and management of the coupled human-natural system over time. This framework is used to organize our discussion below.

WHY IEAS?

Resilient and productive ecosystems are the foundation of sustainable development and the conservation of biodiversity. Functioning marine ecosystems support the provisioning of food, energy, and natural products (e.g., pharmaceuticals). They also have cultural value and provide opportunities for tourism, recreation and reflection. Additionally, marine ecosystems play important roles in nutrient cycling, climate regulation and storm protection. In sum, marine ecosystems support human livelihoods, and many economic sectors depend on a functioning ecosystem. However, coastal and ocean ecosystems and the goods and services they support are impaired (Pew Oceans Commission 2003, U. S. Commission on Ocean Policy 2004, U.S. EPA 2012). Scientists, resource managers and policy makers are looking at integrated, ecosystem-based approaches for the management of marine resources while pursuing restoration of marine ecosystems and ensuring the long term delivery of ecosystem services.

A key goal of IEAs is to move towards clear, well-defined ecosystem objectives built upon a science-based management strategy that fuses ecosystem components into a single, dynamic, fabric in which both human and natural factors are intertwined. Periodic assessment of biological, chemical, physical and socio-economic attributes of ecosystems, relative to specific objectives, allows for coordinated evaluations of national marine ecosystems to promote their sustainability under a variety of human uses and environmental stresses. Moreover, IEAs involve and inform a wide variety of stakeholders and agencies that rely on science support. IEAs integrate knowledge and data collected by NOAA and other regional entities including other federal agencies, states, non-governmental organizations, and academic institutions. IEAs also identify critical knowledge and data gaps, which, if filled, will reduce uncertainty and improve our ability to fully employ ecosystem approaches to management and achieve ecosystem objectives.

A STEP-WISE PROCESS FOR DEVELOPING AN IEA

STEP 1: SCOPING THE IEA

As described, IEAs are driven by clearly defined management objectives; consequently, the IEA approach purposefully begins with the scoping step to clearly identify priority management objectives to be addressed and frames the execution of the process to be responsive to each defined objective. Scoping the IEA requires that scientists, managers and stakeholders work together to define the broad vision and objectives of the IEA, the spatial scale of the IEA relative to those objectives, and the ecosystem components and ecosystem threats that will be included in the effort. Below we detail each one of these elements.

BASICS OF IEA SCOPING

NOAA's IEA framework begins with a scoping process to identify specific ecosystem objectives and threats. Scoping is intended to open the scientist–manager–stakeholder dialogue with an exchange of views and information. Optimally, scoping is conducted 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 goals (deReynier et al. 2010). The conversations that occur through such a process help participants to collectively develop a vision of the current and desired future states of their ecosystem. Issues considered under scoping for an IEA will be complex in scale and extent, and framed by dynamic natural, socio-economic and political processes.

Scoping may be conducted through a series of workshops, public meetings or through a formal survey process. Scoping can be specific and targeted, such as in eliciting preferred indicators for ecosystem health. Scoping can also be more general, such as in assessing non-consumptive values for ecosystem component animals and plants. Scoping must be an ongoing process, modified for each IEA over time to best reflect the information that scientists need from managers and stakeholders, and the available scientific information desired by managers and stakeholders.

EXAMPLE SCOPE, VISION AND FOCAL ECOSYSTEM COMPONENTS FROM THE NORTHEASTERN U.S. IEA.

SCOPE: The organisms found within each ecological subregion of the continental shelf, the physical system within each and related forcing mechanisms, the connections among subregions, and human user-groups.

VISION: To develop an integrated spatial management plan for the Northeast Shelf ecosystem to ensure the sustainable delivery of ecosystem services in this region.

FOCAL ECOSYSTEM COMPONENTS: Ecosystem elements that require management interventions to ensure their continued viability. These include species affected by fishing and other anthropogenic impacts, protected species, and human communities dependent on this ecosystem for food, recreation, and other uses

ARTICULATING THE OBJECTIVES OF AN IEA

The range of potential issues that could be addressed by an IEA is enormous, and any IEA effort must begin by transparently articulating 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 Chrstine Gregiore’s ecosystem vision for Puget Sound 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). While 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: 1) manage resources sustainable for human nutritional, economic and social goals; 2) protect rare or fragile ecosystems, habitats and species; 3) protect and maintain the relationships and dependencies between 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 National Ocean Policy provides numerous conceptual objectives that will require the development of operational objectives at national, state and regional scales. Fortunately, NOAA and other federal and state agencies have a long history of working with Congress and management bodies to translate 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 programs. Similarly, fishery management councils have operationalized the concept of sustainability through a series of management reference points that emerge from basic population dynamics theory.

One of the more significant political challenges to managing the IEA process will be working with jurisdictions with radically different policy priorities and ecosystem principles. Developing realistic ecosystem-scale management objectives for those ecosystems that span the marine waters under the responsibility or jurisdiction of more than one state or tribe requires a rigorous scoping process that involves representatives from the affected jurisdictions. The scoping process should at least be designed to elicit an IEA’s preferred focal components, preferred indicators, and management strategies. Scoping designers might manage this as a one-stage or multi-stage process.

DEFINING THE SPATIAL SCALE OF AN IEA

The spatial scale of an IEA is strongly influenced by the management questions being addressed, and thus IEAs can vary in scale and extent. As a result, a key step in any IEA scoping is to determine the scale of a particular IEA. Ecosystem boundaries are human constructs; consequently, defining the scale of an IEA is an important exercise that ideally considers biophysical, human dimension, and management considerations. There is no "correct" scale at which to conduct an IEA, and each IEA will have a specified scale and extent appropriate to the management objectives driving the assessment. IEAs are currently being conducted or planned at a range of spatial scales from single estuaries (e.g., Puget Sound) or regions (Kona) to large areas such as the Bering Sea, California Current, Gulf of Mexico, and Northeastern U.S continental shelf. In these larger regions, researchers often define subunits based on objective criteria that serve as the starting point for selection of spatial management units. For instance, ecoregions (Spalding et al. 2007) are a biogeographic classification scheme that may be useful in some instances for sub-dividing larger regions. In defining spatial scale, the system is taken to comprise the organisms found within these subregions, the physical system within each and related forcing mechanisms including relevant basin scale processes, the connections among subregions, and human user-groups. In some cases, IEAs can be conducted at multiple spatial scales within a single Large Marine Ecosystem[2]. For instance, in the California Current Large Marine Ecosystem, California, Oregon and Washington are conducting smaller-scale IEAs that are nested within the larger LME region. Obviously, when the scale of an IEA is large, heterogeneity in biophysical and socio-economic components of the ecosystem must be accounted for in any analysis.

IDENTIFYING FOCAL ECOSYSTEM COMPONENTS OF AN IEA

Focal 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. Similarly, the focal components of the Kona ecosystem were identified as: coral reefs, fisheries that include an aquarium, a recreational, and a commercial fishery, open ocean and coastal aquaculture programs, 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

Threats can be human activities or natural phenomena that directly or indirectly affect focal ecosystem components[3]. Identification and prioritization of threats to achieving EBM

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[2] NOAA uses the Large Marine Ecosystems to define NOAA's Regional Ecosystems. It is these Regional Ecosystems that provide the structure for where it is implementing IEA sub-programs.

[3] A complication of EBM is that a threat to one ecosystem component may have positive benefits for other components, and this more holistic consideration of the system is considered further in subsequent sections of this report.

objectives is important so that the IEA team can concentrate efforts where they are needed most. The modeling 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. Empirical analyses are also useful for informing discussion on threats. For instance, compiling and evaluating maps of human use and effects of climate and environmental forcing can be particularly helpful for revealing threats (Rodriguez et al. 2011).

Identification of threats during the scoping stage in 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 the scoping process. This step builds upon previous work in which the objectives, focal ecosystem components, and threats are identified.

Building conceptual, analytical, or simulation models can be a useful initial exercise in conceptualizing the ecosystem. In some regions conceptual models that visually portray relationships among ecosystem components have been useful tools to build a common understanding of how the ecosystem operates. A common approach for conceptualizing a system is the Driver-Pressure-State-Impact-Response (DPSIR) framework. The DPSIR approach has been broadly applied in environmental assessments of both terrestrial and aquatic ecosystems[4]. In this framework, *Drivers* are factors that result in the pressures that cause changes (positive or negative) in the system. *Pressures* include factors such as coastal pollution, habitat loss and degradation, and fishing effort that can be mapped to specific drivers. *State* variables are indicators of the condition of the ecosystem (including physical, chemical, and biotic factors). *Impacts* comprise measures of the effect of change in these state variables on the delivery of ecosystem services such as changes in biodiversity, coastal

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[4] Although many IEA practitioners find the DPSIR framework useful, it has a number of limitations. First, it tends to focus attention on impairments into the system. Successful EBM requires that we understand all processes affecting ecosystem state, not just pressures. When we more fully understand the processes the govern the dynamics of ecosystem state, we are in a better position to determine how management strategies can change the dynamics to meet EBM objectives. Secondly, the DPSIR framework is ill-equipped to handle complex management scenarios where ecosystem components occur in multiple locations in the framework. For instance, water quality may be considered both a state (since it could be a focus of EBM actions) and a pressure (for example, if it affects other states such as biodiversity or fisheries). Finally, the DPSIR framework does not easily accommodate human dimensions since human activities are typically represented as pressures. Thus, while DPSIR can be a useful conceptual framework, its utility will vary with the particular IEA application, and there may be different approaches that can be used to conceptually model the system (e.g., Salafsky et al. 2002).

protection, recreational opportunities, fishery yield, etc. *Responses* are the actions (regulatory and otherwise) that are taken in response to predicted impacts.

In addition to conceptual models, depending on the specific management goals addressed by an IEA, simple aggregate production models, mass-balance energy flow models, multispecies models with explicit species interaction terms, and end-to-end ecosystem models can be useful. Two modeling frameworks, Ecopath with Ecosim (EwE) and Atlantis[5] have seen wide use in NOAA IEAs. EwE is a trophodynamic model in which functional groups are represented as biomass pools regulated by gains (consumption, production, and immigration) and losses (predation, fisheries, and emigration). The software has two modules: Ecopath, a static, mass-balanced model of the "reference" state of a food web, and Ecosim, a dynamic model in which biomass densities and vital rates change through time in response to perturbations. Atlantis is a simulation modeling approach that includes oceanographic, chemical, ecological, and anthropogenic processes in a three-dimensional, spatially explicit domain. The simulation approach allows projections through time, and forecasting of system response to specific management actions, physical drivers, or climate change is intended primarily as a strategic tool to test and rank management options. As different models and modeling approaches are developed, we expect that IEAs will take advantage of the full range of available tools for conceptualizing the system.

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 ecosystem states and processes that underlie healthy ecosystems and are tied to the identified ecosystem objectives. Indicators are quantitative measures that serve as proxies for characterizing key attributes of biogeochemical and human systems (Heinz Center 2008). Effective indicators serve as measures of the many of the ecosystem services that concern policy makers and stakeholders (Link 2005), and are one of the primary contact points between policy and science.

Hundreds of indicators have been proposed for use in EBM (Kershner et al. 2011). These range from physical indices to abundance of single species (Goericke et al. 2007), to community-level metrics such as the size structure of the community biomass ratios and indices of diversity. There is clearly no shortage of potential indicators of ecosystem status, but the real work is to select from among long lists of potential indicators (Rice and Rochet 2005).

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5 http://www.nwfsc.noaa.gov/publications/documents/atlantis_ecosystem_model.pdf

http://nefsc.noaa.gov/publications/tm/tm218/

Rice and Rochet (2005), Methratta and Link (2006) and Shin and Shannon (2010) outline valuable frameworks for building a portfolio of informative indicators for EBM and thus IEAs. These authors 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 properties they are intended to measure.[6] Levin and colleagues (2011) adapted these frameworks by soliciting and organizing expert judgment from the scientific community regarding potential ecosystem indicators for their study region. 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 (Kershner et al. 2011, James et al. 2012). 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, EAP 2009, Shin et al. 2012).

INDICATORS IN ALASKA ECOSYSTEM ASSESSMENTS

In Alaska, annual Stock Assessment and Fishery Evaluation reports include an ecosystem assessment for each of the three identified sub-regions of the Alaska Exclusive Economic Zone: The Eastern Bering Sea, the Aleutian Islands, and the Gulf of Alaska. Each region has specific indicators to reflect regional ecosystem priorities. For example, Eastern Bering Sea indicators track changes in production whereas Aleutian Islands indicators are integrative and track changes in habitat diversity in response to natural and human-induced alterations to the system. A one-page report card summarizes key changes to the ecosystem and the assessment synthesizes potential causes and implications of changes in ecosystem indicators. The assessment is updated annually and reviewed by the North Pacific Fishery Management Council Scientific and Statistical Committee (Zador and Gaichas 2010)

Efforts in the Gulf of Mexico, Northeastern U.S. and California Current are using ATLANTIS to evaluate diagnostic qualities of indicators (Fulton et al. 2005, Samhouri et al. 2009, Levin and Schwing 2011). Taking the model condition as 'reality', the data collection process is simulated by adding measurement error to generate a set of pseudo-data (e.g. data generated from a model) from which indicators may be calculated. Subjecting the model to new regulations or environmental perturbations, the performance of each indicator in

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[6] There may be more than one audience for information generated by indicators. In this case, the needs of the different audiences may not be the same, and hence a given indicator may provide useful information for one audience but less so for another. Developing a single set of indicators under these circumstances can therefore involve tradeoffs in terms of identifying indicators that have value to multiple audiences even though they are not the "best" for any particular one.

assessing perturbation can be assessed based on its statistical correlation with known model rates and conditions. Multivariate ordination helps evaluate the degree of orthogonality among indicators and rank their explanatory power (Methratta and Link 2006). A balanced set of indicators that represents both ecological and socio-economic impacts allows us to quantify trade-offs in a way useful to an IEA.

The rigorous evaluation of indicator performance requires empirical analyses or simulation modeling. Moreover, the selection of appropriate reference points and response trigger conditions can only be made using a quantitative framework. 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. For instance, Trenkel and Rochet (2003) examined the performance of a series of population and community-level indicators in the Celtic Sea fish assemblage. They used data from a groundfish survey to test hypotheses related to pre-selected reference points. The performance of indicators was evaluated using estimates of precision (e.g. coefficient of variation) and statistical power. Computer simulation modeling provides another tool for evaluating indicators. For example, Samhouri et al. (2009) used the EwE food web models to determine the degree to which potential indicators reflected changes in ecosystem attributes. In this approach, EwE is used to simulate the dynamics of the system over time, thus producing a time series of pseudo-data. These pseudo-data are 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). As with all modeling efforts, it is important to understand model uncertainties and sensitivities. Confidence in these modeling efforts is increased by ensuring that the models are built on accepted physiological and ecological principles, and the ability of the models to recreate past observed variability in potential indicators (Stock et al. 2011). Nonetheless, dealing with these issues is a major challenge for using models to identify indicators (and other aspects of IEAs) (Link et al. 2012).

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 an 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, etc.). 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 toward those levels.

Baseline values of indicators are another type of reference level. These are indicator levels derived from time periods or locations that are chosen to reflect a "baseline condition" of the ecosystem. It is thus possible to express the status of an ecosystem indicator relative to that which might exist in a system free from human pressures (Link et al. 2002, Samhouri et al. 2011).[7]

Ecosystem-based reference levels are needed to refine acceptable resource use limits, 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 Ecopath with Ecosim and Atlantis have been used to explore nonlinearities between pressures and ecosystem state (e.g. Samhouri et al. 2010). To complement these modeling 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 identification of reference levels. Importantly, as we noted at the beginning of this section, 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 probability that an ecosystem

[7] However, one of the central tenets of EBM under the National Ocean Policy is that we consider humans to be a part of, not separable from, our ocean ecosystems. Thus, while baseline reference levels can provide important context for IEAs, they would serve as reference levels similar to baseline "unfished" states for single stocks, not as reasonable end goals for management processes.

indicator will reach or remain in an undesirable state (i.e., breach a reference limit). Ecosystem modeling and analysis are important in determining incremental improvements or declines 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, 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.

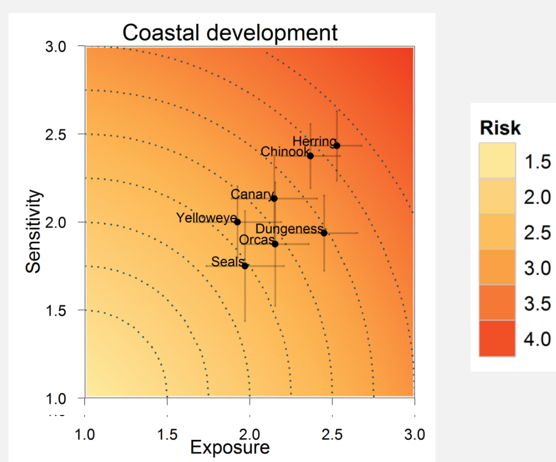
There are a number of approaches to risk assessment; however, most forms of risk assessment can be used within the ecological risk assessment framework described by Hobday and colleagues (Hobday et al. 2011). Briefly, this is a hierarchical approach that moves from qualitative but comprehensive analyses (Level 1) to a less comprehensive, semi-quantitative analysis (Level 2), 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 scoping process, 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. A common level 2-type analysis is the US Environmental Protection Agency (EPA) framework (EPA 1998). This framework has proven useful for conducting semi-quantitative risk analysis in IEAs (Levin and Wells 2011, Samhouri and Levin 2011), see

RISK ASSESSMENT IN PUGET SOUND

Samhouri and Levin (2012) implemented the analysis phase of the EPA process to examine risk to a variety of ecosystem indicators in Puget Sound. They defined risk to an indicator as the Euclidean distance of the species from the origin in a space defined by exposure and sensitivity to particular human activities. Exposure was estimated as a function of spatial, and temporal overlap of activities, also incorporating management factors that could aggravate or mitigate the exposure, and sensitivity was estimated as a function of the degree to which life history attributes or behavior affected an indicator’s ability to resist or recover from exposure to a human activities.



Puget Sound Risk Assessment Box). This framework consists of 3 main steps: problem formulation, analysis, and risk characterization (EPA 1998). In the EPA model, problem formulation assembles and summarizes information, operationally defines assessment end points, and develops a plan for analysis. In large part, this step in the EPA framework overlaps with the previous steps in the IEA framework. The analysis step of the EPA framework evaluates stressor data (e.g. what types of stressors, their spatial distribution and their intensity). It then characterizes the ecological effects of the exposure of ecosystem components to these stressors. The final step of the EPA process uses the exposure and effects information to estimate risks and analyze underlying uncertainty.

If the 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 (PVA). A number of modeling approaches lend themselves to level 3 analyses, but all are dependent on the amount and quality of the available data. What model one uses in a level 3 analysis depends on the nature of the data and other available information. However, as with any modeling exercise understanding such issues as sampling error, density dependence, nonstable age structure, and environmental uncertainity will be critical for quantitatively estimating risk. Presenting the uncertainity in estimated risks is crucial, especially when data are poor or model parameters are uncertain.

STEP 4: EVALUATION OF MANAGEMENT STRATEGIES FOR PROTECTION OR RESTORATION OF ECOSYSTEM STATUS

APPROACHES FOR EVALUATING MANAGEMENT STRATEGIES

The IEA process described thus far has identified a process for identifying high-level goals of EBM, a means to evaluate progress towards those goals, and an approach to assess the risk and consequences of failure to reach those goals. The next step in the IEA process uses simulation, analytical or conceptual modeling 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.

Following the publication of the Millennium Ecosystem Assessment (MEA 2005), systematic scenario analysis is increasingly being used as an approach to evaluate management options. Scenario analysis generates 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). Scenarios typically include assessments of the ecosystem state variables and driving forces, descriptions of critical uncertainties, and approaches for resolving them (Swart et al. 2004). One unique attribute of scenarios is that they acknowledge the interdependencies of system components. The advantages of qualitative scenarios include more flexibility to incorporate multiple stakeholder perspectives and greater capacity for creative thinking. Quantitative scenarios can provide geographical and numerical specificity to the concepts provided by qualitative scenarios (Alcamo et al. 2005).

Formal Management Strategy Evaluation (MSE) is a modeling approach that can be used to analyze posited scenarios. MSE is widely used in management of protected species (e.g., marine mammals) and fisheries, and is beginning to see use in EBM (Sainsbury et al. 2000, Fulton et al. 2007) such as in our IEA effort. 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 formal MSE is not optimality. Rather, MSE is used to screen out poorly performing management strategies and to identify 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 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 uses simulation models to compare alternative strategies in a virtual world. The MSE approach is built upon an operating model that depicts ‘true’ ecosystem dynamics. The aim of this operating model is to capture key physical, chemical, ecological, and socio-economic processes that generate system dynamics. Data are sampled from the operating model to simulate research surveys, which results in simulated measurements of key ecosystem indicators such as biomass of species, diversity, mean trophic level, and so forth. These simulated surveys incorporate typical biases and error inherent in a monitoring program (e.g., replicating incomplete spatial coverage that may arise in fishery-independent data, or biased site selection associated with fishery-dependent data). These pseudo-data are then passed to a management model which, ideally, would be the very model used in real-world management (e.g., in risk analysis or stock assessment). This management model estimates the predicted status of individual species or indicators and the ecosystem as a whole. This information may be compared against the reference state in the operating model. In principle, management models should include reference points linked to simulated management actions. Human responses to simulated decisions may then be represented in the operating model, incorporating uncertainty in compliance and potentially influencing the simulated ecosystem state. Repeating these steps creates a simulation of the full management cycle.

MSE incorporates a number of important features (Sainsbury et al. 2000) that make it an ideal supporting process for IEAs. 1) Simulations are performed in the operating model on the managed system as a whole. For management towards ecological objectives we require explicit representation of the ecological system; similarly, for economic objectives we require

MSE IN ACTION IN THE BERING SEA

As part of the Bering Sea Integrated Research Project, a variety of modeling projects were funded to synthesize broad scale information (see http://bsierp.nprb.org/modeling/index.html for more information). In particular, an MSE is being used to evaluate multispecies stock-assessment models and Ecosim through comparing hindcasts of the models with currently used single species models, as well as model validation, performance, and sensitivity using outputs from an end-to-end ecosystem model. Meanwhile, the Gulf of Alaska Integrated Ecosystem Research Program is currently collecting trophic and physical data but the MSE portion of the project remains unfunded. The Alaska IEA will synthesize these data for the ecosystem assessment and this can be used to conduct MSEs for that region.

explicit ecological-economic linkages. 2) Performance metrics are evaluated quantitatively in a simulation framework utilizing the indicators developed earlier in the IEA process. Scenario analysis tends to generate multiple alternative descriptions of potential outcomes, including processes of change, thresholds and uncertainties (Alcamo 2008). 3) A variety of models or sub-models 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). Models may range in complexity from extensions of single species stock-assessments parameterized with functional responses of one or more additional species to more complex ecosystem food web models that link multiple species and their environment through dynamic coupling (e.g., the vertically integrated ROMS/NPZ/FEAST model, ROMS/Atlantis, or Ecospace which can accept some hydrodynamic inputs). 4) It is the whole management decision system being evaluated in MSE; this may include a full suite of input/output harvest control rules, pre-set management responses or other decision support mechanisms, as well as the monitoring and assessment program that supports the decision process. 5) 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 tradeoffs. 6) The MSE process often identifies data and knowledge gaps, which in turn can be used to inform future research to reduce compound errors that impact certainty around management outcomes. Because each management question will be unique, so will the development of each of the MSEs. Each MSE must be developed having the most appropriate degree of detail and realism to match the management questions at hand. The operating model must also be capable of working with the ecosystem indicators developed through the IEA scoping process, of replicating the monitoring and data collection process, and providing the management model with appropriate inputs at sufficient resolution. Moreover, models may be optimized for relevant control rule scenarios.

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). In the case of IEA indicators, monitoring must directly address the operational objectives developed as part of the scoping process. While apparently simple, monitoring becomes difficult because it costs money. Thus, successful monitoring depends on developing efficient sampling programs that allow a cost-effective determination of the state of the ecosystem and the effectiveness of management actions.

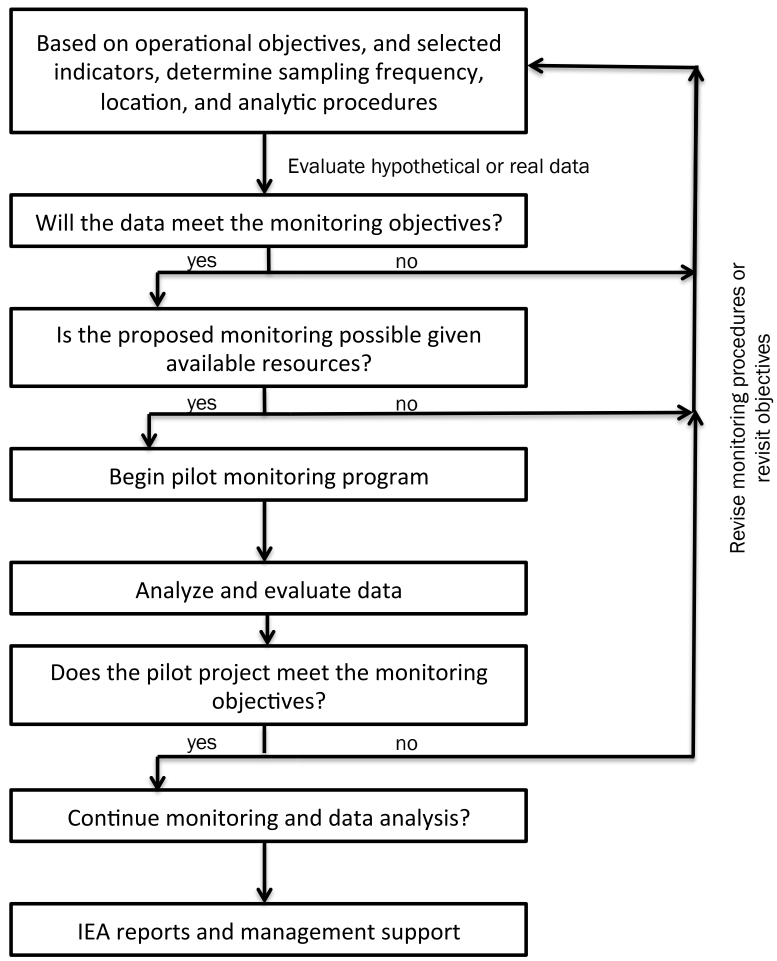


Figure 2. A systematic approach for developing effective monitoring programs for IEAs. Details are provided in the text. Adopted from MacDonald et al. (1991).

In general there are two types of monitoring that are particularly important to IEAs. Trend monitoring is a systematic series of observations over time for the purpose of 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 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 program also confronts the issue of how *well* one wants to know the answer. Successfully addressing these elements defines the indicators (the what and how), and the sampling design (where, when, and how well).

The steps to developing a successful monitoring program are highlighted in Figure 2. Briefly, the previous IEA steps will provide specific operational objectives and indicators. Developing the monitoring enterprise requires the development of the sampling design. Once the sampling design is determined, real or pseudo-data can be analyzed to determine the degree to which the data generated from a sampling program will meet the monitoring objectives. Next, one should consider the feasibility of the program and ensure that appropriate resources are available to implement the monitoring program. Ideally, the next step is to conduct a pilot study to further ensure that monitoring objectives can be met. Finally, a full-scale monitoring program is implemented leading to the generation of data to complete the IEA loop.

Importantly, monitoring includes not only measurements of the biophysical environment, but also includes social and economic systems. McLeod and Leslie (2009) suggest that socio-economic monitoring will enhance the ability of managers to:

a. estimate how coastal management is contributing to community development
b. value marine resources from ecosystem services and cultural and economic significance
c. measure people's support for various management actions including conservation
d. facilitate stakeholder involvement by gaining greater understanding of perceptions
e. tailor management to local conditions by developing education programs based on community understanding of resource conditions and threats.

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). Generally, the evaluation of ecosystem status is performed without direct consideration of the management actions designed to affect the ecosystem component under consideration. Thus, a status evaluation is focused on giving an interpretation of where an ecosystem component is at a particular time. Thus, assessment of the state of ecosystem indicators relies fundamentally on status evaluations.

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. The goal of adaptive management is to learn and then adapt ongoing management. Adaptive management thus can be viewed as a way of "learning by implementing."

Iterative, adaptive management is based on the philosophy of implementing management in steps or stages while monitoring and evaluating the system to determine the effect of the change in management. One can imagine a scenario where the IEA analysis has several models showing a big gain in ecosystem sustainability and service production by doubling freshwater runoff to an estuary that had been subject to prior diversion (e.g. dam or re-routing); however, another model shows the increased freshwater will eutrophy the estuary resulting an ecologically undesirable state. In this scenario, the management decision might be to first undertake a 20% increase in freshwater runoff for the first couple of years while continuing to monitor and evaluate the ecosystem indicators. If this first increment did not cause an increase in eutrophication, but improved essential fish habitat the management plan might then continue to ramp up freshwater runoff. However, if eutrophication increases, adaptive management might suggest reducing freshwater runoff to its prior level, and going back to the drawing board to develop more options for management.

COMPLETING AN IEA

IEA PRODUCTS

The ultimate aim of an IEA is to improve decision making in resource management by implementing the IEA framework described above, and by generating products that are relevant to stakeholders, resource managers and policy makers. IEA products thus take on a number of different forms in order to effectively reach a

PRODUCTS FROM NOAA IEAS

For Policy Makers

- One page policy briefs
- Short-form videos (for example, http://video.google.com/a/?pli=1#/Play/contentId=77dbb1cdc2fb006f)
- Presentations
- Websites

For Resource Managers

- Summary documents of IEA results,
- Overview documents of IEA modeling tools
- Webinars, Workshops, & Presentations
- Websites
- Short-form videos

For Stakeholders and General Public

- Short-form videos
- Websites
- Public exhibits
- Public talks

For Scientists

- Peer-review journal articles
- NOAA Technical Memoranda
- White papers

diversity of audiences.

The credibility of an IEA is based on sound science that is broadly communicated. Thus, an IEA technical report and scientific papers in peer-reviewed journals will always be key outputs of IEAs. Technical reports and journal articles reach some scientific and management audiences, but effective communication of IEAs requires products beyond conventional scientific reports. Web-based products are an attractive option as they can provide different levels of information for different audiences and can be easily updated as new information becomes available.

The development of products targeting non-technical audiences (e.g., stakeholders, policymakers, etc.) will increase understanding and support of the IEA process, strengthen IEAs by facilitating partnerships, and will help identify additional applications for IEAs. These products may take the form of websites, brochures, webinars, videos, power point presentations and media stories. Table 2 highlights how these products intersect with various steps of the IEA loop.

PEER REVIEW

Rigorous science is at the core of any IEA. Thus, peer review is an essential component for all technical IEA products. Ecological and socio-economic analyses, ecosystem models and multi-disciplinary products IEAs require distinct and separate review structures and venues than currently exist. As IEA programs mature and their products see increasing use, such IEA review programs must emerge. In the meantime, there are many mechanisms for peer review already used by NOAA that can be adopted and adapted as needed. Some of these review mechanisms are internal to NOAA, some are composed of external reviewers and some are a mixture of internal and external reviewers (Table 1). Not all existing potential peer-review groups are suitable for review of IEAs at present, and many groups will have a single-sector perspective that may prove problematic for multi-

Tabel 1. Potential groups with expertise that could be considered for review relevant portions of IEA work:

Topic Area	Potential Review Group	Further Information
ESA and MMPA Species	Independent Science Review	http://www.nwcouncil.org/fw/science.htm
	Technical Recovery Teams	http://www.nwfsc.noaa.gov/trt/
	Recovery Implementation Science Teams	http://www.nwfsc.noaa.gov/trt/rist.cfm
	Pacific Science Review Group Atlantic Scientific Review Group Alaska Scientific Review Groups	http://www.nmfs.noaa.gov/pr/sars/group.htm
International Science Review	Scientific Committee of International Whaling Commission	http://www.iwcoffice.org/commission/iwcmain.htm#committee
	Commission for Conservation of Antarctic Marine Living Resources	http://www.ccamlr.org/pu/e/sc/intro.htm
	International Scientific Committee for Tuna and Tuna-like Species	http://isc.ac.affrc.go.jp/

sector products. Nonetheless as IEA science matures input from these groups may be relevant. Some examples are:

Center for Independent Experts (CIE) – – NMFS funds a program to promote independent peer review of NMFS science. CIE members may review stock assessments or science products, participate in assessment workshops, panels and science product groups, or serve as chairs of advisory panels and working groups. http://www.ciereviews.org/process.php. For Example, the NEFSC held a CIE review of their ecosystem modeling approaches in March of 2011 (http://www.nefsc.noaa.gov/ecosys/modeling_review.html).[8].

Scientific Statistical Committees (SSC) – Each regional fisheries management council has an associated SSC that is charged with reviewing the science that underpins council management plans, management actions and development of recommended fishing levels. These committees consider a broad range of topics that include stock and habitat assessments, evaluation of management actions, socio-economic analyses and ecosystem-based fisheries management. Councils may want their SSCs to review IEA products before products affect Council management practices and priorities.

Review Panels - Line Offices (NMFS, OAR and NOS) in NOAA routinely convene panels of external or mixed external and internal experts to review science undertaken by the Agency. These include review of science centers and laboratories, research and development programs, and monitoring and assessment programs. A similar process could be used to review IEA science as needed.

PROGRESS TOWARD IMPLEMENTING IEAS IN THE UNITED STATES

The development of IEAs in the United States is following a staged implementation strategy with regions to be fully executed in a defined sequence. Five of eight proposed regions are currently working on developing IEAs, and are at various stages. The California Current System has been selected as the first Large Marine Ecosystem for full IEA development, followed by the Gulf of Mexico and the Northeast Continental Shelf. IEAs for the Alaska region and the Pacific Islands are next in the sequence. It is anticipated that the Southeast Shelf, Caribbean, and Great Lakes will follow as program capacity grows. This strategy reflects budget realities; funding for each region must be sufficient to complete the task in an integrated and timely fashion. With the program funding that has been received to date, each of the five regions has received some funding, with those earlier in the sequence at higher levels. Lower-level funding is being provided to permit developmental work in the later regions to prepare for full IEA development as each region is sequentially fully supported.

[8] Importantly, the NEFSC ecosystem modeling review process was a distinct process focused on the outputs of ecosystem models and IEA-related decision-support products. The success of this process highlights the need to move beyond “shoe-horning” the review of IEA products into existing review process that are often already stretched to capacity.

Table 2. The five part, iterative NOAA IEA process to be implemented in each of the Large Marine Ecosystems and anticipated goals, actions, products and targeted users of each step.

Steps	Goals	Actions	Products	Users
1. Scoping	Educate about current status Identify knowledge gaps Determine key IEA elements: geographic scale & ecosystem drivers, pressures, and threats Define EBM objectives Identify potential ecosystem references levels to address impacts & responses	Workshops, public meetings, telephone / internet surveys	Presentations, videos, webinars, peer-reviewed publications, list of research priorities	Scientists, managers, stakeholders, funding agencies, general public
2. Define Indicators & reference levels	Evaluate indicators, identify thresholds, and reference points	Workshops, public meetings, surveys	Presentations, webinars, website, status reports, peer reviewed publications, policy briefs	Scientists, managers, stakeholders, general public
3. Risk Analysis and Ecosystem Assessment	Assess anthropogenic and natural impacts on ecosystems	Implement 3 – tiered risk assessment	Presentations, webinars, website, status reports, peer reviewed publications, policy briefs	Scientists, managers, stakeholders, general public
4. Management Strategy Evaluations (MSEs)	Compare management strategies for maintenance, protection or restoration of ecosystem status	Conduct scenario analysis using conceptual or quantitative models	Presentations, webinars, website, peer reviewed publications, policy briefs	Managers, scientists, stakeholders
5. Monitoring & Evaluation	Monitor ecosystem response to management actions & evaluate actions for adaptive management	Develop appropriate trends and effectiveness monitoring, evaluate ecosystem status and management effectiveness, implement adaptive management	Presentations, webinars, website, peer reviewed publications, management recommendations	Managers, scientists, stakeholders

Development of the California Current IEA is nearing completion and represents the first full IEA for the program as a whole. Although IEA development is an evolutionary process to be refined and modified over time as information accrues and as conditions change, the completion of the initial California Current IEA will establish an important benchmark. Each of the IEAs to follow will be tailored to the individual objectives, data sources and availability, model choices, and management needs for each region and will therefore be distinctive. All, however, will address the five steps identified above, with 2 through 5 repeated on a regular basis to incorporate changes inherent to the dynamic nature of each ecosystem. While our objectives center on fully developing IEAs in each region, a series of interim products have been developed in several regions. Currently, each of the 5 first tier priority regions have undertaken some level of scoping activity (Step 1) with follow-up scoping sessions to occur in the future. All regions have initiated processes to identify key indicators to set the stage for completion of Step 2. An essential element of this process is to review and evaluate existing indicators, identify available information sources for indicator development, and to undertake a gap analysis to identify missing information and required data. To date, specification of reference levels (Step 3) to serve as targets and limits to guide management actions has been explored most fully in the California Current and Northeast Shelf systems., in accord with funding priorities. However, it is anticipated that experiences in these regions will substantially aid in the development of reference levels for the other systems. Risk analyses have progressed to the fullest extent in the California Current IEA (e.g., Samhouri and Levin 2011) but interim ecosystem assessments have been developed for sub-regions of the Northeast and Alaskan ecosystems. The compilation and exploration of indicator performance in Alaska and the Northeast provide the basis for the development of an Ecosystem Considerations Report of the Stock Assessment and Fishery Evaluation report for the Alaska region, and an Ecosystem Status Report for the Northeast is being provided[9]. The California Current IEA will provide the foundation for an annual ecosystem report for the Pacific Fisheries Management Council, and other regions have similar products in development. Lastly, development and testing of the operating models at the core of Management Strategy Evaluation are now underway in each of the five regions which have received IEA funding.

[9] These activities began prior to the development of the IEA program.

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