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# Ecosystem Services as a Common Language for Coastal Ecosystem-Based Management

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**Abstract:** *Ecosystem-based management is logistically and politically challenging because ecosystems are inherently complex and management decisions affect a multitude of groups. Coastal ecosystems, which lie at the interface between marine and terrestrial ecosystems and provide an array of ecosystem services to different groups, aptly illustrate these challenges. Successful ecosystem-based management of coastal ecosystems requires incorporating scientific information and the knowledge and views of interested parties into the decision-making process. Estimating the provision of ecosystem services under alternative management schemes offers a systematic way to incorporate biogeophysical and socioeconomic information and the views of individuals and groups in the policy and management process. Employing ecosystem services as a common language to improve the process of ecosystem-based management presents both benefits and difficulties. Benefits include a transparent method for assessing trade-offs associated with management alternatives, a common set of facts and common currency on which to base negotiations, and improved communication among groups with competing interests or differing worldviews. Yet challenges to this approach remain, including predicting how human interventions will affect ecosystems, how such changes will affect the provision of ecosystem services, and how changes in service provision will affect the welfare of different groups in society. In a case study from*

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*Puget Sound, Washington, we illustrate the potential of applying ecosystem services as a common language for ecosystem-based management.*

**Keywords:** coastal ecosystems, coastal management, communication, ecosystem-based management, ecosystem services

Los Servicios del Ecosistema como un Lenguaje Común para el Manejo de Costas Basado en Ecosistemas

**Resumen:** *El manejo basado en ecosistemas es un reto logístico y político porque los ecosistemas son inherentemente complejos y las decisiones de manejo afectan a una multitud de grupos. Los ecosistemas costeros, que se encuentran en la interfase entre ecosistemas marinos y terrestres y proporcionan una variedad de servicios a diferentes grupos, ilustran estos retos acertadamente. Para tener éxito, el manejo basado en ecosistemas de ecosistemas costeros requiere la incorporación de información científica y el conocimiento y opiniones de grupos de interés en el proceso de toma de decisiones. La estimación del suministro de servicios del ecosistema bajo esquemas alternativos de manejo ofrece una forma sistemática para incorporar información biogeofísica y socioeconómica y las opiniones de individuos y grupos en el proceso político y de manejo. El uso de servicios del ecosistema como un lenguaje común para mejorar el proceso de manejo basado en ecosistemas presenta tanto beneficios como dificultades. Los beneficios incluyen un método transparente para evaluar los pros y contras asociados con alternativas de manejo, un conjunto de hechos y moneda corrientes como base para las negociaciones y la mejora de la comunicación entre grupos con intereses opuestos o cosmovisiones diferentes. Sin embargo, existen retos para este método, incluyendo la predicción del efecto de intervenciones humanas sobre los ecosistemas, cómo afectarán esos cambios al suministro de servicios del ecosistema, y cómo afectarán los cambios en el suministro de servicios al bienestar de diferentes grupos de la sociedad. En un estudio de caso en Puget Sound, Washington, ilustramos el potencial de la aplicación de servicios del ecosistema como un lenguaje común para el manejo basado en ecosistemas.*

**Palabras Clave:** comunicación, ecosistemas costeros, manejo basado en ecosistemas, manejo de la costa, servicios del ecosistema

## Introduction

Managing ecosystems for both environmental sustainability and socioeconomic benefits depends on the effective integration of scientific information with an understanding of how ecosystems affect the welfare of different individuals and groups in society. Ideally, technical information from natural and social scientists, experiential knowledge of people familiar with the ecosystem, and information on the benefits that different individuals and groups receive from goods and services provided by the ecosystem would flow to policy makers and managers to help guide policy formulation and implementation. Policy and management would continually adapt to reflect new information or new circumstances. Of course, real political and management systems are far from ideal.

The need to improve science-based and participatory decision-making processes for effective management of coastal ecosystems has been recognized for decades (e.g., Sorensen 1997). Examples of approaches put forward to improve management include integrated coastal zone management (ICZM) (Clark 1992), community-based coastal management (CBCM) (Pomeroy & Carlos 1997; McClanahan et al. 2005), and ecosystem-based management (EBM) (e.g., Christensen et al. 1996; Slocombe 1998; McLeod et al. 2005). Here we focus on EBM, a place-based management approach that emphasizes protection of ecosystem structure, function, and processes with explicit attention to the interconnectedness among systems and integration of ecological, social, economic, and institutional factors. Despite the recognized need for integrated management, successful examples are relatively rare. Ecosystem-based management can fail for a variety of reasons including political stalemates among groups who derive different benefits from ecosystems (e.g., coastal development, commercial fishing, and conservation interests), a lack of institutions for effective governance (e.g., Ostrom 1990; Hennessey 1994; Crowder et al. 2006), or inadequate science.

We concentrate on the challenge of effectively incorporating technical and experiential information with information about benefits to different groups into EBM to facilitate transparent evaluation of trade-offs among alternative management actions or policies. A focus on ecosystem services (the goods and services provided by ecosystems that generate benefits to people) can provide a "common language" that can facilitate comparisons of management alternatives. Assessing ecosystem services may involve qualitative and quantitative analyses, from a conceptual depiction of how human activities depend on and affect ecosystems to a quantification of the monetary value of particular services. The goal of these assessments is to link management actions directly to changes in ecosystem conditions and to gain an understanding of how those changes may affect the benefits that various individuals and groups derive from ecosystems.

Differences in focus, knowledge, and terminology among different groups make reaching consensus in EBM difficult (Berkes & Folke 1998). Groups with different interests in ecosystems often talk past each other, hear what they want to hear rather than what is being said (Weeks & Packard 1997), or discount what is being said as lacking credibility or relevance (Cash et al. 2003). These problems of human communication are exacerbated by the complex ecological interactions and cumulative impacts of diverse human activities across a large suite of ecosystem services. Ecosystem services can serve as a framework within which to facilitate a transparent evaluation of trade-offs through use of a common set of measures. This can foster dialogue among groups with different interests and beliefs and increase the likelihood that they can design and implement management plans that are mutually acceptable.

We examined the challenges of EBM in coastal ecosystems. The complexities of the biophysical system (including marine and terrestrial systems and flows between them) and of human systems (i.e., multiple political jurisdictions and interest groups) at the coastal interface highlight the difficulties of effective ecosystem-based policy and management (Weinstein et al. 2007). Coastal systems include such diverse ecological communities as mangrove forests, coastal marshes, seagrass beds, sand dunes, bivalve reefs, mud flats, and inshore coral reefs. These ecosystems process the flow of nutrients, sediments, and water; support a variety of organisms; and provide a wide range of ecosystem services, such as protection from wave damage and flooding; production of fish and shellfish; enhancement of water quality, recreation, and aesthetic, spiritual, and cultural values (MEA 2005). Over 40% of the world's population lives within 80 km of a coast (this figure is expected to rise to >50% by 2025) (MEA 2005), which suggests that coastal ecosystems will be both more valuable and more vulnerable to disruption in the future.

## Ecosystem Services as a Framework for EBM

### Use of Ecosystem Service Concept in EBM

The interconnected nature of ecosystems means management actions simultaneously affect a range of ecosystem services and ultimately affect multiple groups in society. Virtually all policy and management decisions that affect ecosystems involve trade-offs among ecosystem services and among benefits received by different groups. The great diversity of interested parties involved in most coastal management issues (e.g., commercial fishers, tourism industry, conservation groups, coastal residents, indigenous peoples, upstream landowners) means there will likely be disagreements about the best way to manage ecosystems. Ultimately, however, decision makers must weigh the trade-offs and reach a decision. Framing the EBM decision-making process in terms of ecosystem services can account for the ecological and socioeconomic complexity inherent in working at the ecosystem scale and incorporate the views of a diversity of interested parties. Consideration of ecosystem services can facilitate the EBM process by providing a common set of facts and a common currency for quantifying trade-offs that can help in the often difficult negotiations among groups with competing interests.

This diversity of views among groups is not an insurmountable impediment to successful EBM, but it makes it more difficult to develop a process that all participants view as "salient, legitimate and credible" (Cash et al. 2003). The views of different groups should be considered in the development of an EBM plan. Participatory processes provide a forum for diverse individuals and groups to express and discuss their preferences and possibly to devise workable solutions that minimize disagreement (Chuenpagdee et al. 2004).

Although a participatory process may be necessary for successful EBM, credible scientific information is also required. Analysis of ecosystem services can make it easier for heterogeneous groups to engage effectively in the political process because results of the analysis will make transparent the links between policy and management choices and resulting changes in ecosystem-service provision. Such results also provide a common set of facts on which to base political negotiations.

A number of key challenges warrant special attention in the incorporation of ecosystem services in EBM. Scientific uncertainty may limit the ability to make clear predictions about links between management alternatives, the provision of ecosystem services, and the likely impacts on the welfare of different groups. In contentious negotiations, special interests may promote or suppress certain types of information or overemphasize the uncertainties underlying the information (e.g., by unduly questioning model validation), which can exclude science-based information and input from the participatory process and undermine the legitimacy of policy and management decisions. Although quantification of ecosystem services can go only so far to address such problems, presenting information in a readily accessible form that is understandable to all parties can increase transparency and limit the ability of any one interest group to manipulate the use of information.

In addition, incorporating ecological and socioeconomic data into management decision making may be challenging because scientists fail to translate their results into a form that is useful and easily understood by managers and policy makers with different levels of scientific expertise (Sharp & Lach 2003). Furthermore, the pace of knowledge development in science (typically slow) and the timeline on which policy makers and managers need information (typically fast) may not match.

Finally, it is important to stress that EBM is most effective if there are existing institutions (e.g., laws, regulations, and social norms) that facilitate integrated management. Overlapping governance structures and interacting social and ecological processes among terrestrial, marine, and coastal ecosystems can inhibit clear allocation of responsibility. The different and sometimes conflicting objectives of agencies with mandates to manage different sectors (e.g., tourism, transportation, fisheries, water quality, agriculture, forestry, industry) also present challenges for coordinated ecosystem-scale decision making. For example, although potential solutions exist to conflicts between the needs of water users and endangered fishes in the Sacramento–San Joaquin Delta (California; e.g., an isolated water delivery system moving fresh water around rather than through the delta), state and federal water managers face challenges from possible increases in contaminant concentrations, impacts on recreational fisheries, and increased salinities for in-delta water users (Lund et al. 2007). Without a common set of objectives, the incentive for diverse agencies or governmental groups to work together is small. A clear mandate to sustain the delivery of ecosystem services and a framework for quantifying trade-offs among them can provide a foundation for coordinated management.

### Links between Ecosystem Functions and Ecosystem Services

Natural and social sciences must be integrated in order to understand the links among ecosystem functions and ecosystem services and to measure the benefits of ecosystem services. Incorporating ecosystem services in EBM requires understanding how services derive from ecosystems within the place that is being managed. Measuring ecosystem services requires accurate quantification of the ecosystem functions resulting from interactions between organisms and their environment (MEA 2005; NRC 2005) and a conversion of those functions into ecosystem services. The relationship between a given function and particular structural components of the ecosystem may be nonlinear and depend on spatial configuration and context, which makes it difficult to understand the importance of that function and its links to services (Barbier et al. 2008; Koch et al. 2009). For example, the magnitude of wave attenuation provided by coastal habitats depends on water column depth, habitat structure, wave direction, coastal physiography, and seasonality (Fonseca & Cahalan 1992; Mazda et al. 2006; Koch et al. 2009). Seagrass may attenuate waves during the growing season when biomass is maximal, but contribute very little to wave attenuation and resultant coastal protection during winter months when seagrass beds are sparser (Chen et al. 2007). Scientists rarely quantify thresholds below which an ecosystem function is no longer provided, although such thresholds are considered critical to management of coastal resources (Auster 2001).

Although natural and anthropogenic disturbances in coastal systems affect the magnitude and quality of ecosystem functions, effective management must distinguish between small or infrequent disturbances that cause temporary shifts in ecosystem functions—from which systems rebound quickly—and disturbances that cause more fundamental and long-lasting changes. Large-scale catastrophic events or cumulative effects of human activities may cause a regime shift in an ecosystem and a concomitant change in ecosystem functioning (e.g., the shift from a seagrass-dominated to a phytoplankton-dominated system due to eutrophication; Valiela et al. 1997; Yamamuro et al. 2006). Nevertheless, predicting changes in ecosystem functioning due to disturbances within and across ecosystems is difficult and thus confounds effective communication with managers and the interested public, which in turn impedes successful management (Doak et al. 2008).

Describing and quantifying ecosystem functions of interdependent coastal systems requires scientific data and analyses from multiple disciplines and interdisciplinary problem solving. Effective interdisciplinary collaboration can be impeded by differences in people's terminology, methods, training, and beliefs (Lele & Norgaard 2005). For example, intact terrestrial riparian zones may enhance biodiversity in coastal marine zones by reducing sediment and nutrient delivery to coastal waters, yet watershed biogeochemists and coastal marine biologists rarely collaborate. One notable exception is the interdisciplinary effort being made to understand the growing dead zone in the Gulf of Mexico—a large hypoxic zone linked to nutrient runoff from land use upstream (Rabalais et al. 2002). Major environmental disturbances that disrupt the flow of ecosystem services, such as coastal fisheries production in the Gulf of Mexico hypoxic zone, often serve as a catalyst for interdisciplinary collaboration.

When scientists working in different disciplines and on different parts of an ecosystem do not collaborate, decision makers may think they are being given conflicting information. For example, scientists working on restoration of salt ponds to tidal marshes in South San Francisco Bay may offer information on how quickly ponds fill with sediment once tidal action is restored (Williams & Orr 2002), but ignore other aspects of changing tidal dynamics. Although their results may show that tidal marsh restoration increases habitat for endangered birds and mice, the creation of a new sediment sink in the South Bay and adjustment of estuarine hydrology that results from opening the ponds may cause erosion of tidal flats elsewhere in South Bay and a concomitant loss of shorebird habitat (Warnock & Takekawa 1995). To truly deliver information that is "salient, legitimate and credible" (Cash et al. 2003), scientists must strive to inform the wider policy and management audience. For the concept of ecosystem services to be useful to this audience, a multi- or interdisciplinary approach should be used to assess the consequences of management actions for the full suite of services within a system.

Although ecosystem services depend on ecosystem functions, the two are not synonymous. An ecosystem service is something that benefits people. Without human demand for a given ecosystem function, there is no ecosystem service. Moving from ecosystem functions to services typically requires translation of units of measure. Mangroves, seagrass beds, and coastal marshes provide habitat for juvenile fishes (ecosystem function), which ultimately may contribute to commercial and recreational fish landings (ecosystem service), and wave attenuation (ecosystem function), which may protect coastal property from storm surge (ecosystem service). Alerting decision makers that habitat has been lost without connecting that loss to the decline of valuable fish harvests or coastal protection does not effectively communicate the importance or severity of that loss relative to the suite of issues managers are asked to address. As this example shows, one ecosystem function may support multiple ecosystem services (Table 1). Similarly, multiple ecosystem functions from one or more habitats may contribute to a single ecosystem service. An explicit translation from functions to services underscores the diverse benefits humans derive from ecosystems. This recognition can illuminate potential unintended consequences of human actions that negatively affect ecosystem functions and services.

## Understanding Ecosystem Service Benefits

A major challenge of EBM is that management decisions can affect multiple ecosystem services and result in trade-offs among services and benefits to different groups. For example, how should one compare an increase in the value of shrimp aquaculture that benefits the owners of shrimp ponds with storm protection and increased fish harvests from mangrove protection that benefit coastal residents and fishers (Barbier et al. 2008)? Measuring services in biophysical terms (e.g., wave height reduction and metric tons of harvest) does not allow for easy comparison. Measuring services in terms of the benefits they generate to people can more easily allow for such comparisons.

Explicit consideration of trade-offs among ecosystem services and among the interests of various groups can be facilitated by estimating the monetary value of ecosystem services. With monetary estimates of the value of ecosystem services, benefits and losses to various groups can be assessed and quantified with a common metric. Economists quantify the benefits of an ecosystem service to an individual in terms of what that person is willing to give up to obtain an increase in the level of service provision (i.e., "willingness to pay"). For some ecosystem services, such as commercial fish harvests, market prices provide useful information about the monetary value of

**Table 1. A list of coastal-zone ecosystem functions and the multiple services a function or suite of functions can provide.**

| | *Ecosystem service* | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Ecosystem function* | *aquaculture production* | *carbon sequestration* | *climate regulation* | *erosion control* | *fisheries production* | *pharmaceuticals* | *pollution buffering* | *protection against storm surges, wind damage* | *recreation* | *shoreline stabilization* | *tourism* | *water quality* |
| Biodiversity | | | | | X | X | | | X | | X | |
| Carbon cycling | | X | X | | | | | | | | | |
| Evapotranspiration | | X | X | | | | | | | | | |
| Habitat | X | | | | X | X | | | X | | X | |
| Light attenuation | | | X | | X | | | | | | | |
| Nursery areas | | | | | X | | | | | | X | |
| Nutrient cycling, flushing, uptake | X | | | | X | | X | | | | | X |
| Population dynamics | | | | | X | X | | | X | | X | |
| Sediment trapping | X | | | X | | | X | X | | X | | X |
| Wave attenuation | | | | X | | | | X | | X | | |
| Wind attenuation | | | | X | | | | X | | X | | |

benefits. The price is a measure of willingness to pay in the context of market supply. Market prices summarize information about consumer preferences and the relative value of goods and services. Most ecosystem services, however, are not sold in markets (e.g., existence value of species and intact natural ecosystems) (MEA 2005; NRC 2005). Gathering information about the relative value of these ecosystem services requires other approaches. Economists have developed nonmarket valuation techniques and applied them to a range of ecosystem services, including fisheries production, tsunami and storm-surge protection, and environmental amenities such as proximity to coastlines (Brander et al. 2006; Barbier 2007).

Nevertheless, the economic approach to measuring benefits has limitations. First, data on the benefits of ecosystem services to specific groups (versus society as a whole) may be lacking. Second, many ecosystem services cannot be easily reduced to monetary values (e.g., spiritual and cultural values). Disputes among different groups may require extensive dialogue and explicit discussion of trade-offs that will likely be multifaceted rather than measured in a common currency (e.g., disputes between commercial interests, who readily deal with monetary values, and indigenous groups, who do not).

Nonmonetary indicators of ecosystem benefits can be useful in some situations and may be less expensive and take less time to apply. Such approaches may be better suited to address spiritual, cultural, or aesthetic values that are quite difficult to capture in monetary terms. Extensive in-person interviews, quantitative surveys, and other analyses by social scientists can generate evidence about deeply held beliefs of individuals and groups and the benefits they derive from ecosystems. Analysis of voting patterns on public referenda can also shed light on what is important to various constituencies.

None of these methods, however, are perfect. When individuals are uninformed about important ecosystem functions or other scientific information (or fail to understand the relationship between the functions and services they care about), evidence gathered through interviews, surveys, or economic valuation may fail to reflect underlying beliefs and values. Qualitative or anecdotal information from interviews may be viewed as lacking scientific merit (Hall-Arber & Pederson 1999), and responses may not be truthful if there is lack of trust (e.g., fishers afraid to identify key fishing grounds for fear those areas will be designated as reserves where fishing is prohibited) (Conway et al. 2002). In addition, collecting information about benefits can be time-consuming and costly.

A particular danger in trying to incorporate information about the monetary value of ecosystem services into EBM is that important details about how management or policy alternatives affect ecosystems and how these changes affect the provision of services and benefits to human welfare can be lost. For example, some prominent valuation studies estimate the total value of ecosystem services by summing the estimated monetary value of all potential services on a per-hectare basis and multiplying by the total number of hectares (Costanza et al. 1997). Such methods do not include important information about ecosystem variability and social context that plays a critical role in determining the value of services. In addition, studies that compare the value of services in a fully functioning ecosystem and in a degraded ecosystem, where it is assumed no services are provided, are seldom relevant for management decisions. Although there are examples of radical changes in ecosystems that approximate this all-or-nothing condition (e.g., mangrove deforestation), many disturbances cause changes in functions well short of ecosystem collapse. Understanding how intermediate changes in ecosystem functions affect the provision of ecosystem services and benefits to diverse groups is vitally important to inform policy decisions, particularly in the context of trade-offs among different services and different user groups (Barbier et al. 2008).

### Envisioning an Ecosystem Services-Based EBM Process

A central goal of EBM is the sustainable delivery of ecosystem services. Attaining this goal requires a fundamental shift in policy, governance structures, decision-making processes, and the science that supports them—a shift that is starting to happen in some parts of the world. In Fig. 1, we lay out possible steps in a generic EBM process that focuses on the collection and integration of information about ecosystem services into public decision making. This figure builds on similar ecosystem-services frameworks (e.g., MEA 2005; Turner & Daily 2008; Daily et al. 2009). Each EBM process will be unique, given the diverse issues, opportunities, and actors associated with the specific place to be managed. What we describe subsequently is not a formula, but rather an example and potential launching point for the development of a process tailored to the goals for a particular place and management mandate.

The framework involves a participatory process including the interested public, scientists, and decision makers. Because we focus here on a hypothetical public process, decision makers derive from two main groups: policy makers at all levels of government (often elected or appointed officials) who decide the policies that guide management, and managers who direct on-the-ground operations (e.g., implementation and enforcement of regulations via governmental agencies). Members of both groups may be involved at different stages of the process.

There are many ways the EBM process may be initiated. Sometimes the emergence of a new issue catalyzes this process. For example, in Massachusetts proposals for offshore development of wind energy led to passage of the Massachusetts Oceans Act and development of the

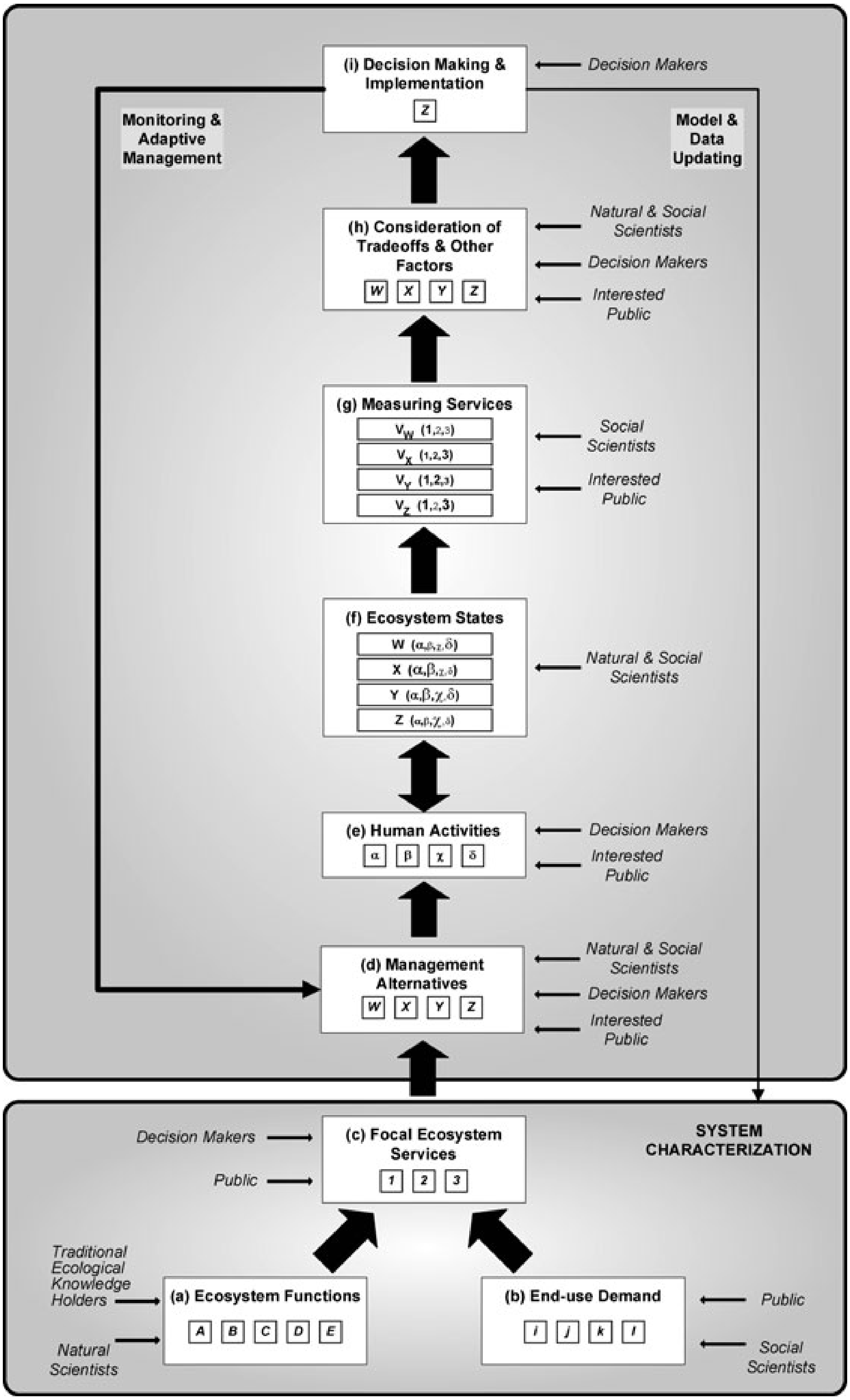


*Figure 1. A framework for integrating ecosystem services into ecosystem-based management. Boxes are steps in the process. Each box contains the key information being collected or quantified and specific information is represented by variables. Wide arrows indicate the flow of information through the process. Small arrows indicate information inputs from participants. In steps f and g, information in interior boxes is expressed in the form of a vector of values for the focal ecosystem services (1–3) under each of the four management alternatives (W–Z). In these vectors, services with high values are indicated by numbers in large, bold type, whereas those with lower values are shown in small type. Once a decision is made, ecosystem state is monitored and the decision can be revised in the future under adaptive management, as shown by the arrow on the left. Less frequently, base information and representative models of the system may be updated, as shown by the arrow on the right.*

first statewide comprehensive ocean management plan in the United States. In other cases, ecosystem considerations may be the starting point. However the process is started, a key step is collecting information from natural and social scientists and the broader public about the system (Fig. 1, steps a–c).

Natural scientists and traditional ecological knowledge holders (e.g., tribal members, fishers) provide information to characterize the multiple ecosystem functions that underpin ecosystem services (Fig. 1, A–E in step a). Social scientists and members of the public characterize the human benefits from these services that make the services relevant to human well-being (Fig. 1, i, j, k, l in step b). Decision makers and the interested public (i.e., stakeholders and engaged members of the public who actively participate in the process) then determine which ecosystem services are important enough to include in the planning exercise (Fig. 1, boxes 1, 2, 3 in step c).

Management alternatives are developed by decision makers with input from the interested public and scientists (Fig. 1, W, X, Y, Z in step d). Management alternatives influence human activities in various sectors (Fig. 1, boxes $\alpha$, $\beta$, $\chi$, $\delta$ in step e). Both public and private decisions (i.e., those made by decision makers and by members of the public) influence human-activity levels at this step. As indicated by the double-ended arrow between steps e and f, human-activity levels affect ecosystem functioning and services, and the level of provision of various ecosystem services can, in turn, influence human activity levels. Input from natural and social scientists can help predict the state of the ecosystem (both biogeophysical and socioeconomic components) and probable levels of the focal ecosystem services for each management alternative (i.e., the vector of focal services 1–3 in Fig. 1, step f). The benefits of services may be measured in various qualitative and quantitative ways (not limited to monetary valuation) by social scientists, stakeholders, and public participants in order to understand the differential benefits conferred to various groups under each management alternative (Fig. 1, step g).

To streamline the diagram, the benefits of ecosystem services are represented under each management alternative (vectors of services 1–3 in Fig. 1, step g), but in reality, benefits differ across groups, so each management alternative actually generates a matrix whose elements represent the benefits to a particular group from a particular service. Participants in the process then have a common set of measures with which to evaluate the trade-offs in ecosystem services among alternatives (Fig. 1, step h) and to show the distributional impact of alternatives across different groups. Participants may also consider a suite of other factors, such as feasibility, enforceability, equity, funding, and jurisdiction.

As new information enters the process, participants may choose to backtrack within the decision-making loop and revise the management alternatives (e.g., if none of the options appear palatable to stakeholders or decision makers). Ultimately, decision makers are called upon to choose among and implement one of the alternatives (Fig. 1, step i), to start over, or to cancel the process. Because ecosystems and social systems are dynamic, decisions will need to be revisited and revised periodically on the basis of new scientific information and continued input from participants in the iterative process of monitoring and adaptive management. Less frequently, the initial phase of system characterization may need to be revisited to accommodate new information.

## Case Study

The use of ecosystem services as a component in EBM is relatively new in coastal systems. One of the best examples comes from recent efforts to restore and protect Puget Sound, Washington (U.S.A.). This case exemplifies the benefits of the ecosystem-services approach to EBM and highlights some of the challenges.

Consideration of ecosystem services was an implicit part of the development of watershed-level restoration plans for Puget Sound, as part of the Shared Salmon Strategy for recovery of endangered salmon (Shared Strategy 2007). Watershed councils for the area considered alternative strategies to meet target population sizes for salmon. Once council members agreed on population targets, they examined the consequences of meeting the target for land use, freshwater flows, estuarine function, and harvest, and the trade-offs among these different ecosystem functions that support salmon. Doing so helped illuminate ancillary benefits of improving ecosystem functions (e.g., potential for enhanced recreational opportunities as an added benefit of increased in-stream flows) and broadened the debate. The resulting restoration plans garnered significant public support because of the intensive and informative process in which the costs and benefits of the different scenarios were discussed and weighed.

The Shared Salmon Strategy has been incorporated into a larger, ongoing, participatory, ecosystem based management planning process called the Puget Sound Partnership (PSP), which explicitly integrates ecosystem services in the process. The state's new public-private partnership was challenged to "develop recommendations for the Legislature, Congress, and [the Governor] to preserve the environmental health, goods and services needed by the year 2020 to ensure that the Puget Sound's marine and freshwaters will be able to support healthy populations of the native species, as well as water quality and quantity to support both human needs and ecosystem functions" (PSP 2006). To clarify ecosystem goals and prioritize strategies, the PSP analyzed the broad suite of ecosystem services on which humans in Puget Sound depend and how different activities affect the ecosystem. Through a series of interviews, stakeholders helped identify the top 5–10 most important ecosystem services and key trade-offs among them (Iceland et al. 2008). The PSP's leadership council and stakeholder groups then evaluated that information to assign priorities to potential strategies for ecosystem recovery. This process informed the 2008 Action Agenda (PSP 2008) and ultimately influenced federal, state, and local agencies, nongovernmental organizations, and citizens whose activities affect the condition of the Puget Sound ecosystem (e.g., departments of ecology, transportation, nonprofit restoration groups). In the future, the consequences of alternative ecosystem recovery strategies will be quantitatively modeled to further inform decision making for the Puget Sound.

Puget Sound Partnership has faced challenges in implementing an ecosystem services approach. Some groups initially rejected the approach because they equated it with a utilitarian view of nature, whereas others assumed monetary valuation was its only tool. In addition, expecting a state agency to rapidly implement a new approach to resource management was considered by some unrealistic in light of limited expertise and the dearth of examples on which to build. Nevertheless, a series of workshops and in-depth interviews with individual sectors helped PSP participants understand and embrace the approach (Iceland et al. 2008). Furthermore, the results from the initial planning phase highlighted several common interests among diverse stakeholder groups that were previously underappreciated (especially water regulation, recreation, ecotourism, existence values, and ethical views). This example demonstrates that the use of ecosystem services as a common framework to support EBM, even in a process explicitly set up to do so, requires an initial investment in education, communication, and outreach to be successful. As more coastal management efforts embrace this approach and successful precedents are established, the need for such investments may diminish.

### Remaining Challenges

The complexity of biophysical and human systems requires a common set of facts to clearly communicate the potential consequences management alternatives could have on the suite of ecosystem services that various groups in society care about. An important advantage of incorporating ecosystem services into EBM, whether it involves a qualitative consideration of linkages between benefits to humans and the ecosystem or quantitative valuation in a common currency, is that it provides a way to integrate information about effects on different groups into a common framework that can support EBM (Fig. 1). Measuring ecosystem services can make the job of assessing the relative merits of alternative management or policy options more rational and transparent because management actions are explicitly linked to changes in ecosystem state that affect human well-being and unintended consequences are illuminated.

Despite the benefits of an ecosystem service-based framework for EBM, a number of important challenges remain. It can be difficult to predict how human interventions will affect ecosystems, how such changes will affect the provision of ecosystem services, and how changes in service provision will affect the welfare of different groups in society. Furthermore, interdisciplinary research will be needed to improve understanding of these important linkages. Establishing an effective participatory process for EBM is no small task, and incorporating ecosystem services in EBM does not guarantee an adequate voice to all interested parties. Care must be taken in creating effective channels of communication for all interested groups. And although this method can limit manipulation of the public process by single-interest groups, it cannot eliminate the possibility without careful attention to the composition of the participant group and strong public engagement in the process.

A common set of objectives and, in some cases, new governance structures, will be necessary to support an effective participatory process and provide an incentive for governmental groups to work together. As in ecosystem-scale management elsewhere, integration of diverse information and views can be challenging at the land-sea interface because of the lack of an integrated institutional framework and the overlap of multiple political jurisdictions and economic sectors. A clear legislative mandate to sustain the delivery of ecosystem services and an overarching policy framework for quantifying trade-offs among management scenarios could serve as a foundation for coordinated management. Recent calls for more-integrated approaches to coastal management may provide significant scope for use of ecosystem services in addressing environmental problems at the land-sea interface. Although improving the integration and communication among actors in the decision-making process will not be sufficient to assure successful management, it is undoubtedly a necessary step.

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### Literature Cited

Auster, P. J. 2001. Defining thresholds for precautionary habitat management: actions in a fisheries context. North American Journal of Fisheries Management **21:**1–9.

Barbier, E. B. 2007. Valuing ecosystem services as productive inputs. Economic Policy **22:**177–229.

Barbier, E. B., et al. 2008. Coastal ecosystem-based management with nonlinear ecological functions and values. Science **319:**321–323.

Berkes, F., and C. Folke. 1998. Linking social and ecological systems: management practices and social mechanisms for building resilience. Cambridge University Press, Cambridge, United Kingdom.

Brander, L. M., R. J. G. M. Florax, and J. E. Vermaat. 2006. The empirics of wetland valuation: a comprehensive summary and a meta-analysis of the literature. Environmental and Resource Economics **33:**223–250.

Cash, D. W., W. C. Clark, F. Alcock, N. M. Dickson, N. Eckley, D. H. Guston, J. Jäger, and R. B. Mitchell. 2003. Knowledge systems for sustainable development. Proceedings of the National Academies of Sciences USA **100:**8086–8091.

Chen, S. N., L. P. Sanford, E. W. Koch, F. Shi, and E. W. North. 2007. A nearshore model to investigate the effects of seagrass bed geometry on wave attenuation and suspended sediment transport. Estuaries **30:**296–310.

Christensen, N. L., et al. 1996. The report of the Ecological Society of America committee on the scientific basis for ecosystem management. Ecological Applications **6:**665–91.

Chuenpagdee, R., J. Fraga, and J. I. Euan-Avila. 2004. Progressing toward co-management through participatory research. Society and Natural Resources **17:**147–161.

Clark, J. R. 1992. Integrated management of coastal zones. Fisheries technical paper, report 327. Food and Agriculture Organization of the United Nations, Fisheries and Aquaculture Department, Rome.

Conway, F., J. Gilden, and A. Zvonkovic. 2002. Changing communication and roles: innovations in Oregon's fishing families, communities and management. Fisheries **27:**20–27.

Costanza, R., et al. 1997. The value of the world's ecosystem services and natural capital. Nature **387**:253–260.

Crowder, L. B., et al. 2006. Resolving mismatches in U.S. ocean governance. Science **313**:617–618.

Daily, G., et al. 2009. Ecosystem services in decision-making: time to deliver. Frontiers in Ecology and the Environment **7:**21–28.

Doak, D. F., et al. 2008. Understanding and predicting ecological dynamics: are major surprises inevitable? Ecology **89**:952–961.

Fonseca, M. S., and J. A. Cahalan. 1992. A preliminary evaluation of wave attenuation by four species of seagrass. Estuarine, Coastal and Shelf Science **35:**565–576.

Hall-Arber, M., and J. Pederson. 1999. Habitat observed from the decks of fishing vessels. Fisheries **24:**6–13.

Hennessey, T. M. 1994. Governance and adaptive management for estuarine ecosystems: the case of Chesapeake Bay. Coastal Management **22:**119–145.

Iceland, C., C. Hanson, and C. Lewis. 2008. Identifying important ecosystem goods and services in Puget Sound. Summary of interviews and research for The Puget Sound Partnership. Puget Sound Partnership, Seattle. Available from http://www.psp.wa.gov/ (accessed January 2009).

Koch, E. W., et al. 2009. Non-linearity in ecosystem services: temporal and spatial variability in coastal protection. Frontiers in Ecology and the Environment **7:**29–37.

Lele, S., and R. B. Norgaard. 2005. Practicing interdisciplinarity. BioScience **55:**967–975.

Lund, J., E. Hanak, W. Fleenor, R. Howitt, J. Mount, and P. Moyle. 2007. Envisioning futures for the Sacramento–San Joaquin Delta. Public Policy Institute of California, San Francisco.

Mazda, Y., M. Michimasa, Y. Ikeda, T. Kurokawa, and T. Asano. 2006. Wave reduction in a mangrove forest dominated by *Sonneratia* sp. Wetlands Ecology and Management **14:**365–378.

McClanahan, T. R., S. Mwaguni, and N. A. Muthiga. 2005. Management of the Kenyan coast. Ocean and Coastal Management **48:**901–931.

McLeod, K. L., J. Lubchenco, S. R. Palumbi, and A. A. Rosenberg. 2005. Scientific consensus statement on marine ecosystem-based management. Communication Partnership for Science and the Sea. Available from www.compassonline.org/pdf_files/EBM_Consensus_Statement_v12.pdf (accessed November 2007).

MEA (Millenium Ecosystem Assessment). 2005. Ecosystems and human well-being: current state and trends. Island Press, Washington, D.C.

NRC (National Research Council). 2005. Valuing ecosystem services. The National Academies Press, Washington, D.C.

Ostrom, E. 1990. Governing the commons: the evolution of institutions for collective action. Cambridge University Press, Cambridge, United Kingdom.

Pomeroy, R., and M. B. Carlos. 1997. Community-based coastal resource management in the Philippines: a review of programs and projects, 1984–1996. Marine Policy **21:**445–464.

PSP (Puget Sound Partnership). 2006. Sound health, sound future: protecting and restoring Puget Sound. Puget Sound Partnership, Olympia, Washington.

PSP (Puget Sound Partnership). 2008. 2008 Action agenda of the Puget Sound Partnership. Final ecosystem plan for the Puget Sound Ecosystem. Puget Sound Partnership, Olympia, Washington. Available from http://www.psp.wa.gov/ (accessed January 2009).

Rabalais, N., R. Turner, and D. Scavia. 2002. Beyond science into policy: Gulf of Mexico hypoxia and the Mississippi River. BioScience **52:**129–142.

Shared Strategy for Puget Sound. 2007. Puget Sound salmon recovery plan. Shared Strategy for Puget Sound, Seattle. Available from http://www.sharedsalmonstrategy.org/plan/index.htm (accessed January 2009).

Sharp, S. B., and D. Lach. 2003. Integrating social values into fisheries management: a Pacific Northwest study. Fisheries **28:**10–15.

Slocombe, D. S. 1998. Defining goals and criteria for ecosystem based management. Environmental Management **22:**483–493.

Sorensen, J. 1997. National and international efforts at integrated coastal management: definitions, achievements, and lessons. Coastal Management **25:**3–41.

Turner, R. K, and G. C. Daily. 2008. The ecosystem services framework and natural capital Conservation. Environmental Resource Economics **39:**25–35.

Valiela, I., J. McClelland, J. Hauxwell, P. J. Behr, D. Hersh, and K. Foreman. 1997. Macroalgal blooms in shallow estuaries: controls and ecophysiological and ecosystem consequences. Limnology and Oceanography **42:**1105–1118.

Warnock, S. E., and J. Y. Takekawa. 1995. Habitat preferences of wintering shorebirds in a temporally changing environment: Western Sandpipers in the San Francisco Bay Estuary. The Auk **112:**920–930.

Weeks, P., and J. M. Packard. 1997. Acceptance of scientific management by natural resource dependent communities. Conservation Biology **11:**236–245.

Weinstein, M. P., et al. 2007. Managing coastal resources in the 21st century. Frontiers in Ecology and the Environment **5:**43–48.

Williams, P. B., and M. K. Orr. 2002. Physical evolution of restored breached levee salt marshes in the San Francisco Bay estuary. Restoration Ecology **10:**527–542.

Yamamuro, M., J. Hiratsuka, Y. Ishitobi, S. Hosokawa, and Y. Nakamura. 2006. Ecosystem shift resulting from loss of eelgrass and other submerged aquatic vegetation in two estuarine lagoons, Lake Nakaumi and Lake Shinji, Japan. Journal of Oceanography **62:**551–558.