Marine Ecosystem-based Management in Practice: Scientific and Governance Challenges

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Ecosystem-based management (EBM) in the ocean is a relatively new approach, and existing applications are evolving from more traditional management of portions of ecosystems. Because comprehensive examples of EBM in the marine environment do not yet exist, we first summarize EBM principles that emerge from the fisheries and marine social and ecological literature. We then apply those principles to four cases in which large parts of marine ecosystems are being managed, and ask how including additional components of an EBM approach might improve the prospects for those ecosystems. The case studies provide examples of how additional elements of EBM approaches, if applied, could improve ecosystem function. In particular, two promising next steps for applying EBM are to identify management objectives for the ecosystem, including natural and human goals, and to ensure that the governance structure matches with the scale over which ecosystem elements are measured and managed.

Keywords: fisheries, marine food webs, marine ecosystem-based management, marine ecosystems, ocean zoning

Marine ecosystems are complex adaptive systems linked across multiple scales by flow of water and species movements (Levin and Lubchenco 2008). Despite their adaptive character and often redundant linkages, marine ecosystems are vulnerable to rapid changes in diversity and function (Palumbi et al. 2008). Observable, widespread declines in the status of species, habitats, and ecosystem function in the marine environment have led to calls for ecosystem-based management (EBM) as a solution for what ails the oceans (POC 2003, USCOP 2004). The argument that EBM could maintain ecosystem structure—thus allowing the ecosystem to maintain redundancies and resilience to environmental change—is appealing, yet not well tested. Why is there growing consensus that EBM is a promising approach for managing oceans? In short, marine ecosystems are in trouble, indicating that many previous attempts to manage individual threats in the absence of a system-wide approach have not worked.

Dramatic declines in some marine species caused by overfishing provide striking examples of failed management practices and ineffective governance in the face of imperfect scientific knowledge (Lotze et al. 2006, Hilborn 2007). These high-profile failures in single-species fisheries management led, in the mid-1990s, to efforts by the US Congress to mandate improvements in governance and a broader, more ecological approach. For example, Congress required that

Fishery Management Plans identify habitat essential for the productivity of a species or stock (i.e., “essential fish habitat”). Essential fish habitat and other habitat-based approaches have the potential to offer protection for more than just a focal species, but their ancillary benefits to nontarget species are not well understood.

In the late 1990s, academic scientists, natural resource agencies, and nongovernmental organizations began to promote the use of networks of marine protected areas (MPAs) as a management tool to help address the problem of uncoordinated, piecemeal approaches to protecting marine species and habitats (US White House 2000, Lubchenco et al. 2003). The objectives of MPA networks include the enhancement of fisheries yields and protection of marine species and communities. Within their boundaries, effective MPA networks incorporate linkages among habitats that meet the

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Guiding principles for putting marine EBM into practice: Case examples

Implementing an EBM approach in the ocean requires us to think broadly. Broadening the scope of any EBM plan for the oceans will require considering food-web interactions, drivers of ecosystem function, and how human activities interact with species and ecosystem services. On the basis of existing guidance from national and international fisheries management organizations (NMFS 1999, FAO 2003), a combination of ecological and socioeconomic theory, and lessons from existing test cases in marine environments, we summarize six basic principles that characterize EBM approaches in the oceans (box 1; POC 2003, USCOP 2004). Our objective here is to illustrate how some of these general principles are being used in partially developed EBM approaches in four specific marine and coastal areas around the world. The examples we offer illustrate how ecological principles have been combined with considerations of human use patterns to design improved management approaches that constitute the beginnings of a comprehensive EBM strategy for marine species and habitats. In each setting, we specify additional EBM principles that might be included to achieve broader ecosystem objectives.

The waters of the Southern Ocean surrounding Antarctica

Ecosystem-based fishery management has been practiced in the waters surrounding Antarctica since the early 1980s, but management in the region currently lacks comprehensive ecosystem objectives, indicators, and management strategies to incorporate the full ecosystem consequences of the fisheries into a broader context (box 2). The Southern Ocean waters are highly productive, and fisheries for marine mammals, fish, and invertebrates have been in operation there for about two centuries. Since 1982, management of Antarctic marine resources has been regulated by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), whose membership consists of representatives of Antarctic Treaty nations, and whose mandate is to conserve the Antarctic marine ecosystem. The CCAMLR has pioneered an ecosystem approach to fisheries management. The goal of this approach is to avoid significant adverse impacts both on target species and on nontarget ecosystem components that are dependent on fished species or affected by fisheries in other ways, for example, through trophic interactions or bycatch (Kock 2000, Constable 2001). The primary species groups included in the Antarctic marine ecosystem are krill and other zooplankton, squid, finfish, wide-ranging seabirds such as petrels and albatrosses, penguins, and marine mammals such as seals and toothed and baleen whales (figure 1). All of these species groups either have been directly commercially harvested or have suffered incidental mortality due to fishing activities (Constable 2004). The CCAMLR’s mandate is to coordinate the management of all marine species in the Southern Ocean ecosystem, except for seals south of 60°S and whales, which are covered under different management agreements (CCAMLR 2006).

The krill fishery illustrates the CCAMLR’s approach to ecosystem-based management. Krill (Euphausia superba) is an important forage species for Antarctic predators, and also has become an important commercial species. In response to concern over high harvest rates, the CCAMLR developed and used models to determine sustainable rates of krill removal. These rates were then modified to account for the
1. Define the spatial boundaries of the marine ecosystem to be managed.
The spatial extent of the ecosystem determines which species, other ecosystem attributes, and human activities are the focus of management. So-called large marine ecosystems already have been delineated on the basis of large-scale biological, geomorphological, and hydrological features (see the figure below; Sherman 1995). The US Commission on Ocean Policy further recommends including watersheds that affect nearshore ecosystems within their boundaries (USCOP 2004). Because sociopolitical feedbacks and variation in ecosystem responses to environmental conditions may occur at smaller spatial scales than those over which large-scale ecological processes operate (Hutton and Leader-Williams 2003, Adger et al. 2005), nesting several ecosystem management efforts within larger ecosystems may be advisable.

2. Develop a clear statement of the objectives of ecosystem-based management (EBM).
What biological and social values are desired from an ecosystem? For example, one aim of EBM could be to maximize overall ecosystem yield and benefits to society of total fishery harvests (Hilborn 2007). Alternatively, the objective of EBM could be to reach target levels of ecosystem services such as nutrient cycling or toxics filtering and ecosystem properties such as resilience in ecosystem dynamics, biodiversity, redundancy, and modularity (e.g., Rosenberg and McLeod 2005, Levin and Lubchenco 2008, Palumbi et al. 2008). Working through a deliberative political process to get broad agreement on the objectives helps tremendously in subsequent discussions about how to achieve ecosystem goals.

3. Include humans in characterizations of marine ecosystem attributes and indicators of their response to change.
There is growing consensus among biologists and policymakers that including human uses of and interactions with natural resources in EBM approaches improves the likelihood of achieving desired ecosystem outcomes (POC 2003, USCOP 2004, Hennessey and Sutinen 2005, Hilborn 2007). It is important to be clear in articulating what natural- and human-system attributes of the ecosystem best indicate the status of the desired objectives so that progress can be tracked over time and adjustments in strategies can be made as needed (e.g., Adger et al. 2005, Livingston et al. 2005).

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**Box 1. Six basic principles for using an ecosystem-based management framework to manage marine resources.**

1. Define the spatial boundaries of the marine ecosystem to be managed.
2. Develop a clear statement of the objectives of ecosystem-based management (EBM).
3. Include humans in characterizations of marine ecosystem attributes and indicators of their response to change.

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**Large Marine Ecosystems of the World**

1) East Bering Sea
2) Gulf of Alaskan
3) California Current
4) Gulf of Mexico
5) Gulf of California
6) Southwest US Continental Shelf
7) Northeast US Continental Shelf
8) Northwest US Continental Shelf
9) Newfoundland Labrador Shelf
10) Nordic/Polar Humberian
11) Pacific Northwest American Coastal
12) Caribbean Sea
13) Humboldt Current
14) Patagonian Shelf
15) South Brazil Shelf
16) East Brazil Shelf
17) North Brazil Shelf
18) West Greenland Shelf
19) Barents Sea
20) Norwegian Sea
21) North Sea
22) Baltic Sea
23) Baltic-Baltic Shelf
24) Danish Coastal
25) Mediterranean Sea
26) Canary Current
27) Sargasso Current
28) Bermuda Current
29) Gulf Stream
30) Sargasso Current
31) Sargasso Coastal Current
32) Azorean Sea
33) Red Sea
34) Bay of Bengal
35) Gulf of Thailand
36) South China Sea
37) Bubu-Cebu Sea
38) Indonesian Sea
39) North Australian Shelf
40) North West Australian Shelf
41) Northwest Australian Shelf
42) Southeast Australian Shelf
43) Southwest Australian Shelf
44) West Central Australian Shelf
45) Northeast Australian Shelf
46) New Zealand Shelf
47) East China Sea
48) Yellow Sea
49) Korea Current
50) Sea of Japan
51) Bering Sea
52) Bering Shelf
53) Western Bering Sea
54) Okhotsk Sea
55) Sea of Okhotsk
56) East Siberian Sea
57) Laptev Sea
58) Kara Sea
59) Barents Sea
60) Greenland Sea
61) Barents Sea
62) Hudson Bay

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4. Use a variety of strategies to hedge against uncertainty in the ecosystem response to EBM approaches.
Unanticipated effects of EBM on ecosystems can come from inherent variability and complexity in food-web dynamics, their interaction with complex socioeconomic systems, and the uncertainty in the effects of alternative management approaches themselves. Regardless of the state of models or analysis used to characterize a system, adopting a management approach that becomes relatively more prescriptive over time as information (and thus certainty in outcomes) increases is one way to explicitly build in learning to strategy development (e.g., Kaufman et al. 2004). Another prudent approach that can be implemented without extensive knowledge of a system is including a diversity of regulation, reward, and other incentive systems for human behaviors that are consistent with EBM objectives (Hutton and Leader-Williams 2003, Hilborn 2007). Where information allows, exploring and modifying alternative approaches through scenario modeling and experimentation, monitoring, and adaptive management also can improve contingency planning (Butterworth and Punt 1999).

5. Use spatial organizing frameworks such as zoning for coordinating multiple management sectors and approaches in EBM.
Marine EBM will require multiple approaches to managing competing uses and authorities in the ocean, such as fisheries, recreation, research, conservation, and shipping. Such activities can be coordinated spatially and temporally through ocean zoning or other spatially specific management approaches (NMFS 1999, POC 2003, USCOP 2004, Young et al. 2007).

6. Link the governance structure with the scale of the ecosystem elements to be managed under an EBM approach.
Management decisions that are matched to the spatial scale of the ecosystem, to the programs for monitoring all desired ecosystem attributes, and to the relevant management authorities are likely to be more successful in achieving ecosystem objectives (Sissenwine and Mace 2003, Rosenberg and McLeod 2005, USGAO 2005). Coordination and decision feedbacks among the governing authorities are a crucial part of successful EBM.

**Figure 1. Simplified food-web diagram of the Southern Ocean (redrawn from CCAMLR’s Management of the Antarctic, available at www.ccamlr.org/pu/E/e_pubs/am/man-ant/toc.htm).**
importance of krill to predators, with the result that the recommended rates of removal are 25% lower than if predators were not considered (CCAMLR 2006).

A second example of the ecosystem-based fishery approach is evident in the CCAMLR’s management of fisheries bycatch. Limits on the incidental mortality of nontarget species have been established, and once these limits are met, the target fishery can be closed, even if the quota for the target species has not been harvested. The CCAMLR’s approach to EBM is iterative, taking into account new information as it becomes available. However, the character of this environment makes data collection and fisheries observation expensive and logistically challenging. If ecosystem metrics were adopted and monitored, information that is missing for specific species would not necessarily mean that they would be removed from management focus. In this way, food-web and ecosystem metrics could themselves become the targets of management (in addition to single-species metrics), and consequently help drive management decisions and feedbacks.

High-latitude environments such as the Southern Ocean may be especially susceptible to the impacts of multiple stressors such as those associated with climate change and with multiple commercial fisheries (e.g., Atkinson et al. 2004). Consequently, the effectiveness of the ecosystem approach currently is limited by insufficient data to understand the biological effects of fishery regulations on food-web elements, potential lack of compliance with fishery regulations, and unknown effects of interactions of fishery management approaches with environmental change. For example, there is no clear mechanism for linking the CCAMLR’s management recommendations regarding catch limits with those developed to manage the seal and whale fisheries. If management objectives, indicators, and strategies for diverse sectors were better coordinated, potential trade-offs would likely become more apparent. Because of the remote and large geographic area covered by the CCAMLR, a mix of regulatory and incentive-based approaches is likely to increase the chances that ecosystem goals will be achievable.

Finally, the strength of the CCAMLR is in the organization and scope of scientific research underpinning EBM for the Southern Ocean. What is missing is a rigorous link between the scientific recommendations emerging from this process and policies that explicitly incorporate risk management in setting acceptable catch limits for the species harvested in the Southern Ocean. Tighter linkages between governance decisions and scientific information will increase the likelihood of achieving overall ecosystem objectives.

The Bering Sea–Aleutian Islands ecosystem
The fisheries within the Bering Sea–Aleutian Islands (BSAI) ecosystem are managed under a sophisticated multispecies framework that is based on extensive monitoring by both fishers and managers. Similar to the management approach under the CCAMLR, the approach in the BSAI ecosystem can be characterized as an ecosystem-based fishery management approach that is evolving to incorporate broader ecosystem management elements more fully (box 2). Groundfish fisheries in the BSAI ecosystem are among the largest fisheries in the world. They serve as an illustration for the way in which conservative single-species management of multiple species can contribute to an ecosystem approach to fisheries management. About 80 stocks of groundfish are recognized and managed in the BSAI ecosystem (NPFMC 2006); chief among these are stocks of walleye pollock, Pacific cod, and Atka mackerel (box 3). Despite intensive commercial fishing, none of the groundfish stocks is currently overfished according to the technical definition under the regulations (Lauth 2007). Removal levels and biomass of the primary commercial target species, walleye pollock, have been stable for more than two decades, and the average trophic level of the catch (an indicator of sustainable fishing practices) has been stable for at least 15 years (Boldt 2006), which represents approximately one generation for most species involved.

In the BSAI groundfish fisheries, single-species management is implemented by establishing annual or seasonal fishing quotas that are lower than the estimated maximum sustainable yield, which is considered an upper limit on fishing effort rather than a target. Quotas become more conservative as uncertainty about the status of the stock increases. Removals are further restricted by limitations on the total catch of all groundfish species combined. This combined quota is lower than the sum of the individual quotas, thereby providing an extra measure of precaution in management of this system. Additional limits are established for the incidental catch of nontarget and protected species; once these limits are reached, the fishery is closed, even if catch quotas of target species have not been reached. It is common in the BSAI groundfish fisheries for caps on the mortality of protected species to limit fishing on target species in a given area and season (NPFMC 2006).

The simultaneous application of quotas at the level of individual stock, combined total catch, incidental take of nontarget species, and incidental take of protected species substantially reduces the likelihood of long-term impairment of the ecosystem by fishing. Setting such quotas requires an extensive data collection and management system. Data collection includes fishery-independent survey data (i.e., both bottom trawl and acoustic surveys for groundfish and surface trawls for forage fish) that supplement the fishery-dependent data provided by the fishers and observers on commercial fishery vessels (e.g., catch per unit effort, biological samples, bycatch monitoring, etc.). The annual cost of the fishery-independent data currently is on the order of $20 million to $30 million a year, an investment that has been acceptable to the federal government and the fishing industry, given the approximately $1 billion annual value of the fishery (NPFMC 2006).

Other fishery management methods are applied in the BSAI groundfish fisheries to account for some predator-prey interactions and habitat protection (NMFS 2003, NPFMC 2006). Large areas have been closed to fishing, depending on
### Box 2. Summary of current and potential ecosystem-based management strategies for selected marine and coastal management areas.

**Antarctic/Southern Ocean**

**Current strategies:** Spatial boundaries are defined by international agreement through the Commission for the Conservation of Antarctic Marine Living Resources. Clear statements of objectives are defined for fisheries, but not for marine mammals and for only some birds. Human activities (commercial fisheries) are explicitly considered. A zoning framework is applied (as a sectoral framework). The governance structure allows for the ecosystem-based management (EBM) approach, but monitoring and enforcement are difficult.

**Additional components for a comprehensive EBM approach:** Develop indicators of ecosystem status and function (current management relies on the status and trends in some individual species). Diversify approaches and tools to hedge against uncertainty in food-web dynamics, future climate, and so on. Develop spatial strategies for each sector at smaller, ecologically relevant scales using a mix of regulatory and incentive-based approaches. Link the governance structure fully to scientific processes and adaptive management.

**Bering Sea/Aleutian Islands**

**Current strategies:** Spatial boundaries are defined as large marine ecosystems on the basis on hydrographic, bathymetric, and biogeographic criteria. Fishery-based management objectives are based on allowable catch for targeted and nontargeted species caught as bycatch. Indicators for fished part of food web and some habitats are well monitored. Quotas for nontarget species reduce risk for the overall food web, some food-web experiments are being conducted, and uncertainty is explicitly included in stock assessments for pollock, a primary fished species. Spatially explicit fishery regulations are used. Governance is relatively simple because few management sectors are relevant (i.e., federal and state governments, the fishing community).

**Additional components for a comprehensive EBM approach:** Identify ecologically and politically relevant subregions of the ecosystem for more targeted management. Adopt broader ecosystem objectives, taking into account socially valued habitats and species in higher and lower trophic levels. Include indicators for larger marine mammals, climate-mediated processes for better predictions of ecosystem responses to management. Incorporate future scenarios of climate change into fishery and habitat management strategies to increase the certainty of ecosystem response. Broaden governance to include other managed parts of the ecosystem (e.g., marine mammals, watershed influences).

**Great Barrier Reef Marine Park**

**Current strategies:** The boundary of the managed area is defined by the extent of the Great Barrier Reef (GBR) and adjacent waters. The objectives adopted by a broad group of users explicitly include ecological sustainability, through protection of natural resources and human use and enjoyment of the Great Barrier Reef. There is monitoring of biophysical and some socioeconomic attributes of the GBR Marine Park and no single report card for reef “health.” A 25-year strategic plan outlines eight broad strategy areas; education of the public is key. Clear zoning maps specify the uses of the GBR Marine Park (e.g., commercial uses, tourism, recreation, traditional uses, research) and the degree of protection (“general use” or “preservation,” e.g.). The GBR Marine Park Authority has an explicitly stated relationship with Commonwealth and Queensland governmental organizations, roles are spelled out in governance documents, and Australia’s 1998 oceans policy provides a framework for EBM in marine waters.

**Additional components for a comprehensive EBM approach:** Advance work on performance indicators and identify clear paths for monitoring feedback into strategies. Emphasize social and economic aspects of research and adaptive management, in addition to the biophysical aspect. Develop a plan for dealing with external factors affecting the quality of resources within the GBR Marine Park, such as water quality, climate change, coastal development, and fisheries. Education about the 2004 zoning plan, and enforcement of it, are critical. Improve coordination between commonwealth and state laws in managing the GBR Marine Park.

**California coast**

**Current strategies:** Spatial boundaries are defined by state statute. The marine protected area and general coastal ocean management objectives are stated. Human activities (e.g., commercial fisheries) are explicitly considered. A zoning framework is applied (within the context of marine protected area networks).

**Additional components for a comprehensive EBM approach:** Adopt specific objectives for multiple natural and human ecosystem components. Identify a set of natural and human system indicators for tracking progress. Identify and get commitments for the role of different management sectors in contributing to ecosystem objectives. Link the governance structure to management and scientific processes.
gear type and season, for the protection of habitat and important prey species. For example, areas around Steller sea lion rookeries are closed to some types of fishing when pups are present, in order to preserve the prey items required for pup survival and growth. Experiments to determine how fishing levels affect the prey field for Steller sea lions are testing these impacts explicitly (Wilson et al. 2003).

In 2006, the Regional Fishery Management Council responsible for developing recommendations to the federal government on acceptable catch levels created an ecosystem committee for the purpose of developing a fishery ecosystem plan for the Aleutian Islands region. This ecosystem plan will be an overarching guide for the implementation of EBM of fisheries in this area, which is a subregion of the BSAI ecosystem. This work is considered a pilot effort and its effectiveness will be evaluated as it is implemented. Whether other subregions of the BSAI ecosystem should be managed more precisely will depend in part on the distinctness of ecosystem responses in different parts of the system. For example, Ciannelli and colleagues (2004) used food-web energetic models and information on species’ dispersal distances to define the spatial scales over which there are predator and prey feedbacks for some of the species in the Pribilof Islands portion of the BSAI ecosystem.

Although parts of the BSAI ecosystem are subject to an ecosystem-based fishery approach, unknown effects of other factors within the ecosystem reduce the certainty of predicting future states. Some drivers in the system are poorly studied, such as food-web interactions and relationships between habitat quality and productivity of target and nontarget species. For example, the implications of potential food-web interactions among whales, pinnipeds, sea otters, urchins, and kelp forests (Springer et al. 2003, DeMaster et al. 2006) for fishery management are not well understood. In addition, the impacts on the ecosystem of rising water temperatures, loss of sea ice, and changes in pH and carbonate saturation are just beginning to be examined. A five-year, $30-million research program, which will begin in 2008, is designed to provide an initial understanding of some of these key processes and interactions associated with increasing concentrations of greenhouse gases.

An improved understanding of all elements of the ecosystem within a management strategy evaluation framework (e.g., Butterworth and Punt 1999) will better allow commercial and subsistence hunters and fishers in the region to prepare for likely changes in the Bering Sea over the next 20 to 50 years. Including management objectives for a broader scope of species or habitat types within the ecosystem will require the difficult work of engaging representatives from more sectors (e.g., Alaska native subsistence whaling interests). The relatively low density of the human population in the BSAI ecosystem makes such governance challenges relatively minor, compared with systems such as California’s coast, where many more stakeholders are involved.

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**Box 3. Types of species in the fishery management plan for the Bering Sea–Aleutian Island ecosystem.**

**Prohibited species**

Prohibited species are those species and species groups that when caught must be returned to the sea with a minimum of injury, except when their retention is authorized by other applicable law. Foreign fisheries must maintain catch records for each of these species. All bycatch of marine mammals must be reported to the appropriate agency. Examples of prohibited species include Pacific halibut, Pacific herring, salmonids, king crab, and Tanner crab.

**Target species**

Target species are commercially important and generally targeted upon by the groundfish fishery. Sufficient data exist to specify total allowable catch (TAC) and to manage each species or species group separately. Catch records must be kept for each of these species. Target species, or species groups, may be combined or split by regulatory amendment. Examples of target species defined in the regulations include atka mackerel, arrowtooth flounder, flathead sole, Greenland turbot, Pacific cod, Pacific Ocean perch, rock sole, sablefish, squid, walleye pollock, and yellowfin sole.

**Other species**

Other species have little economic value and are not usually targeted, but they may be significant components of the ecosystem or have economic potential. A single TAC applies to this category as a whole. Catch records must be kept for each of these species. Other species include sculpin, eulachon, capelin, shark, skates, smelt, and octopus.

**Nonspecified species**

Nonspecified species are those species and species groups of no current economic value taken as incidental catch in the target fisheries. Virtually no data exist that would allow population assessments. No record of catch is necessary. No TAC is established for this category; the allowable catch is the amount that is taken incidentally during fishing for target and other species, whether retained or discarded. Nonspecified species include numerous fish and invertebrates such as grenadiers, eelpouts, sea urchins, and mussels.

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**The Great Barrier Reef Marine Park, Australia**

The Great Barrier Reef (GBR) ecosystem boasts a system-wide spatial management approach that is arguably the world’s most sophisticated and extensively implemented example of marine zoning. Stretching more than 2300 kilometers along the northeastern coast of Australia and comprising 70 bioregions, the GBR is the largest and most famous reef system.
in the world and the largest World Heritage Area. Coral reefs in general are both the most diverse of all marine ecosystems and among the most threatened (Pandolfi et al. 2003). Threats include not only the loss of intensively harvested species (including elimination through fishing of spawning aggregation sites) but also the loss of the coral reef framework itself because of destructive fishing practices, coral disease, coral bleaching, algal overgrowth, and now ocean acidification.

Although the GBR often is assumed to be in relatively good condition, recent analyses indicate that it too has suffered substantial degradation (Pandolfi et al. 2003).Fortunately, the GBR has the benefit of being almost entirely within the jurisdiction of the Great Barrier Reef Marine Park Authority (GBRMPA; www.gbrmpa.gov.au/) of Australia. The GBRMPA was established in 1975, and concerns about oil drilling drove its early development. Over the years, however, other threats were recognized, and comprehensive management of this reef system has now evolved to the point where multiple uses and protection of marine biodiversity are addressed directly. The GBRMPA management philosophy explicitly emphasizes management at the ecosystem level, conservation and reasonable use, public participation and community involvement, and monitoring and performance evaluation.

Protection recently took an enormous step forward with the establishment of a new zoning plan on 1 July 2004. As a consequence, the proportion of no-take zones increased from less than 5% to more than 33% of the total area of the park (figure 2). These no-take zones protect representative examples of each of the broad habitat types in the GBR and represent the world’s largest such network in operation today. Although increasing the protection of biodiversity was a top priority, a further aim was to minimize impacts on the existing users of the GBR Marine Park, including commercial and recreational fishers. Both these aims were achieved by a comprehensive program of both scientific input and community involvement; the participatory planning was the largest such exercise for any environmental issue in Australia’s history. The rationales for the decisions made are summarized in a series of biophysical operational principles and in a set of social, economic, cultural, and management feasibility operational principles (Fernandes et al. 2005). Managing for resilience is explicitly mentioned in GBRMPA documents.

There is also a clear awareness that no-take areas in isolation cannot achieve all conservation aims, and management of land use is therefore considered a critical component of successful reef management. This is facilitated by legislation that allows regulation of activities outside the GBR that could have adverse impacts (Day 2002) and by prioritizing marine areas that lie adjacent to protected land (Fernandes et al. 2005); the Reef Water Quality Protection Plan of 2003 is an example of this approach. Global temperature rise and acidification cannot, of course, be managed directly on a local scale, but some evidence exists that reducing local impacts improves reef resilience to global stressors (Hughes et al. 2007). Thus, although the ecosystem outcomes remain to be documented, the GBRMPA is arguably the best example we have of EBM in place today.

A thorough review of the management of the GBR Marine Park was completed in 2006 (DEH 2006), and the recommendations include a sophisticated list of the next issues to address. Relatively speaking, the management of the GBR area is mature enough that detailed implementation of many
EBM principles already are under way. The review highlighted the need for greater attention to social and economic issues in research, reporting, and governance, and pointed out that relatively more attention has been focused on understanding and managing the biophysical aspects of the ecosystem. For example, there has been no assessment of cumulative regional, social, and economic impacts of the 2004 zoning plan on the viability of businesses. Management of the park’s resources also would benefit from careful consideration of external factors affecting the status of the ecosystem—such as impacts from climate change, land-based inputs of sediments and nutrients from development, and the way in which fishery management on highly migratory species affects the ecosystem’s functioning. Finally, better coordination among many state and commonwealth laws (e.g., there are six laws regulating fisheries alone) will help to protect the environmental and cultural values that are part of the GBRMPA’s ecosystem objectives.

**Ecosystem-based management approaches in coastal California**

California is a leader in promoting marine EBM approaches through legislation. California’s Marine Life Management Act (MLMA) became law in early 1999, and it represents an ecosystem-based approach to managing all marine wildlife in the state’s waters (CDFG 2007). The goals of the MLMA include conservation of nonconsumptive values of marine resources, sustainability of fisheries and reduction in bycatch, habitat conservation and restoration, and consideration of socioeconomic benefits to fishing communities from changes in management of marine resources. The fishery management plans included under the law’s umbrella must be linked in a master plan, which defines the ecosystem-based management principles, prioritizes fisheries for plan development, and incorporates interactions among management plans for individual fisheries. The 29 species included in the prioritized list are diverse taxonomically, including surfperches, sharks and rays, sea basses, halibut, sea urchins, lobster, sea cucumbers, subtidal snails, intertidal invertebrates, and two species of kelp.

One of the key fishery management plans for California is the nearshore fishery management plan, which must contain fishery management objectives for 19 species of finfish while also meeting the ecosystem and nonconsumptive use provisions of the MLMA. A unique feature of the nearshore fishery management plan is its inclusion of an adaptive management framework for setting biological objectives that explicitly adjusts for the quality of information over time (Kaufman et al. 2004). A so-called control rule in the plan guides the establishment of total catch limits for each species, and the rule is designed to evolve over time as data availability increases on the ecosystem effects of harvest. The design of the control rule encourages data collection and analysis as the EBM approaches to setting harvest levels are implemented, and acknowledges that such approaches are likely to be experimental in the early stages. As more information is gathered over time, the precautionary approach to setting harvest limits can be moderated and replaced by more informed catch limits that incorporate knowledge of ecosystem relationships and interactions among species.

The MLMA also requires that a plan for a network of marine protected areas be developed as a means to achieve the objectives of the act. The Marine Life Protection Act Initiative is designed to use scientific, policy, and public input to identify networks of MPAs along the California coast. After a thorough two-year science-stakeholder-policy process, the first of the regional networks—along the central coast—was approved in April 2007 by the California Fish and Game Commission (CDFG 2007). The science-policy process will begin anew for adopting an MPA network along the northcentral California coastal region. Previous to the MLMA enactment, a network of marine reserves in the Channel Islands in southern California waters was developing, and after a rigorous science-policy process to identify scenarios of protected areas, the network currently contains 453 square kilometers of state-managed reserves within the existing federal Channel Islands National Marine Sanctuary (Airame et al. 2003; www.dfg.ca.gov/mrd/channel_islands/index.html).

More recently, the California state legislature passed the California Ocean Protection Act, which creates a state Ocean Protection Council (OPC) composed of the state agencies that have responsibility for ocean issues. The California Ocean Protection Act also establishes a $10 million Ocean Protection Trust Fund, which is designed to reduce threats to marine ecosystems through incentives for sustainable fisheries, improved management, and monitoring. As part of implementing the new act, the OPC created a five-year strategic plan that identifies goals for the California marine ecosystem and outlines measurable outcomes and key actions for achieving these goals (COPC 2006). The goals laid out in the plan discuss explicitly that an EBM approach is needed to maintain ocean and coastal ecosystems, including coordinating governing bodies; learning about the system through monitoring and research; maintaining water quality, physical processes, habitat structure, and wildlife; and conducting education and outreach.

A more comprehensive EBM approach in California’s coastal region, at the scale of the entire California coast, could be achieved through application of many of the EBM principles that already have been implemented at local scales for more focused issues (e.g., Channel Islands and Central Coast MPA network processes). In particular, using public participatory processes to adopt specific objectives for multiple natural and human ecosystem components for coastal California would help greatly in coordinating ongoing and future work across many sectors. Such work could guide actions affecting the ecosystem beyond establishing MPA networks or setting fishery catch limits, such as land- and water-use regulations, shipping practices, and oil and gas development. Once the ecosystem objectives are broadly agreed upon, different management sectors can identify ac-
tions (and expected ecosystem responses) to which they will contribute under an accountability system.

Conclusions
The case examples we highlight in this article illustrate the current, relatively young state of marine EBM in practice. Evaluating the success of something as complex as EBM will take diligent monitoring and evaluation of strategies and desired ecosystem components—such data are just beginning to emerge. In the meantime, strategies in each case are evolving as managers slowly expand the components of the ecosystem included within their evaluations and the EBM principles they include in management approaches. The examples we highlight differ in the particular aspects of EBM that have been applied, yet each suggests several promising next steps that could advance EBM approaches and improve ecosystem prospects.

Fishery-based ecosystem management approaches in the Antarctic and BSAI ecosystems provide good examples of how explicit adoption of objectives and monitoring of indicators can drive management decisions through governance bodies charged with meeting those objectives. The multispecies fisheries objectives in those two regions are mostly being met through evolving management approaches, but components of those ecosystems that are peripheral to the managed portions are not getting the same level of attention as target species. More work to expand ecosystem objectives and management sectors beyond fishing interests could bolster fisheries and support broader ecosystem functions, such as persistence of migratory marine mammals, sea birds, and habitats, in both of these regions. Both of these ecosystem-based fishery management examples also would benefit from broadening their strategies to include a combination of regulatory and socioeconomic incentives as a way to meet more comprehensive ecosystem objectives.

The GBRMPA is the current gold standard for EBM in the oceans, and its success thus far in applying EBM principles is in large part because of its equal attention to both the human and natural systems parts of ecosystem management. Tracing the evolution of management of the GBR from one largely driven by concerns about oil extraction to one guided by full ecosystem objectives and management of multiple threats is instructive for the younger regional EBM efforts. Managers in the GBRMPA clearly recognize the potentially significant ecosystem benefits that arise from involving stakeholders in identifying and adopting strategies to achieve ecosystem goals. The ecosystem work through the GBRMPA benefits from clearly identified entry points for all elements (natural, social, political) of the decision framework. How such an approach ultimately will succeed in achieving the biodiversity and socioeconomic objectives to which they aspire will become clearer over time.

Finally, the sort of adaptive approach adopted in California, which will require many years for ecosystem-dynamic properties to emerge, will very likely be fruitful in most approaches to EBM. EBM is in the early stages of imple-


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