4

Governance and Management of Ecosystem Services in Semi-Enclosed Marine Systems

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Introduction

The global ocean faces increasing pressures as human populations grow and demand for marine resources expands. In semi-enclosed marine systems (SEMSs), stressors from human activities are concentrated and numerous pressures overlap in space and time, with complex, interacting effects on coastal and marine ecosystems, and feedbacks into the social realm. Chapter 2 provides greater detail of the stresses that impact SEMSs, and in this chapter we focus primarily on how these stresses affect the ability of humans to govern SEMSs effectively.

Within the last decade there has been significant recognition of the role that ecosystem services play in providing key benefits to human society (Daily 1997; Snelgrove et al. 1997; Millennium Ecosystem Assessment 2005; Duffy and Stachowicz 2006). The importance of ecosystem services of SEMSs, their regional differences, and long-term changes have been reviewed by Lotze and Glaser (Chapter 12, this volume). Moreover, recent experimental work has established the linkages between biodiversity and ecosystem services (Lohrer et al. 2004; Waldbusser et al. 2004). Considered in tandem with global biodiversity losses (Worm et al. 2006), the challenges faced in maintaining ecosystem services in SEMSs are considerable.

The goals of this chapter are threefold. First, we identify important threats to and vulnerabilities of ecosystem services in SEMSs. Second, we describe how SEMSs have been managed to address losses of ecosystem services, and strategies that have been invoked to reverse the losses. Finally, we provide case studies that show how different governance and management strategies have succeeded and failed, and we discuss how these efforts can be used to guide future efforts to maintain ecosystem services in SEMSs around the world.

Threats to Ecosystems Services in Semi-Enclosed Marine Systems

Ecosystem services are the benefits that people obtain from ecosystems (Millenium Ecosystem Assessment 2005; Chapter 12, this volume). For SEMSs, the most important provisioning services include food resources from fisheries, hunting, and aquaculture, as well as genetic resources (the genes and genetic material contained in individuals and within populations that offer potential future benefits to humans, such as novel genes and gene products), biochemical resources, and aesthetic and cultural resources (for more detail see Chapter 12). Important "regulating services" of natural systems include climate regulation, water purification, waste treatment, erosion control, and natural recycling of elements. Key "cultural services" include cultural identification, spiritual enrichment, and aesthetic values. "Supporting services" are those necessary for the production of all other ecosystem services and include photosynthesis and primary production, nutrient and water cycling, and habitat provisioning. While we acknowledge the importance of this diversity of services, we focus here primarily on those services of most direct benefit to humans, including fisheries, habitat, and water quality.

Ecosystem services are subject to many threats or drivers of ecosystem change (Figure 4-1) that operate on different spatial and temporal scales and are often not independent of one another. In order to identify the most urgent threats to ecosystem services in SEMSs, we canvased regional experts to provide a relative comparison of the importance and spatial dimension of different threats within their systems (Figure 4-1). In a general sense, human activities that alter species composition and abundance have the capacity to compromise any of these ecosystem services.

We discuss the major threats to ecosystem services and how they manifest themselves at different spatial scales. The summaries are brief and draw on diverse examples, in order to place some of the more detailed case studies that follow within the context of multiple drivers of change, which often act synergistically rather than additively. Most threats operate at multiple spatial scales, and we therefore focus on the most relevant scale for any specific driver. From a governance perspective, this organizational scheme reflects which threats may be dealt with by local users and which require complex solutions that include international cooperation and management strategies.

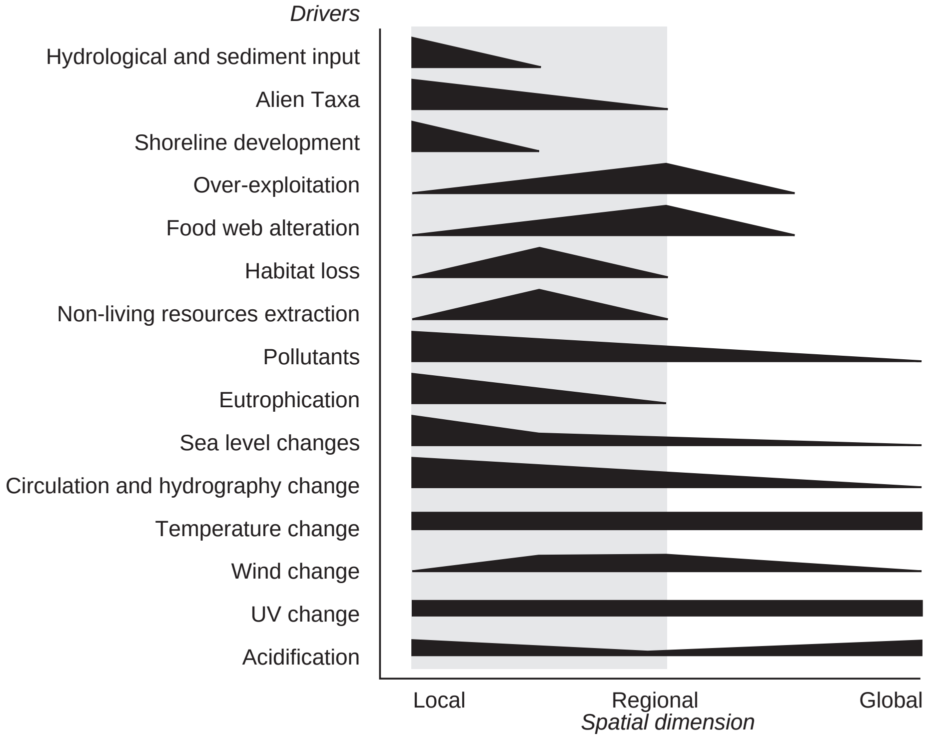

Figure 4-1. Summary of perceived threats to ecosystem services and the spatial scales at which they operate. Wide areas indicate scales at which threat is most predominant. The gray box illustrates the spatial dimension of SEMSs, where *local* is defined as a single bay, *regional* refers to the scale of one SEMS, and *global* is defined as ocean scale. Bar height indicates perceived magnitude of threat at the different scales.

Local (Bay and Coastal Ocean) Drivers

Drivers of changes in ecological services that occur on local scales include changes in inputs of freshwater, nutrients, and sediments; biological invasions and stock enhancements; and development of shoreline and nearshore areas.

HYDROLOGIC CHANGE AND SEDIMENT INPUT

Decreases in freshwater and changes in hydroperiod from the diversion and damming of freshwater sources can affect the amount and timing of freshwater and sediment inputs to SEMSs. SEMSs (including their landward components) can act as filters of material entering the ocean, which is described in detail in Chapter 7.

CHANGES IN SEDIMENT INPUTS

Decreased sediment inputs can lead to erosion of delta systems (Barmawidjaja et al. 1995), marshes, and beaches, reducing the protection these structures provide against storms, their usefulness for tourism, their aesthetic appeal, and their use by indigenous populations. Coastal habitats also disappear when sediment inputs decrease, decreasing associated services such as water purification or waste treatment, production of commercial fish species, and maintenance of marine biodiversity. Increases ~~of~~ sediment inputs can decrease water clarity, with potential effects on phytoplankton, sea grasses, kelp, and coral with cascading effects through their ecosystems.

CHANGES IN FRESHWATER INPUTS

Most species are adapted to specific salinity ranges, and salinity levels limit the spatial and temporal distributions of species. The reproductive activity, egg and larval transport (e.g., cod eggs in the Baltic Sea; MacKenzie et al. 1996), and growth and survival of larval and adult organisms are affected by salinity changes. Fish kills can result from freshwater release from dams. Changes in input of freshwater to SEMSs can also affect the stratification of the waters in SEMSs, which can change their biological productivity.

CHANGES IN NUTRIENT INPUTS

Dams can reduce silica supply to SEMSs by trapping silica-containing sediments behind dams, which changes phytoplankton species composition (Dortch et al. 2001) and productivity (Turner et al. 1998). Reduced flow from damming and diversion can also reduce nutrient supply to estuaries and thus the primary and secondary production capacity, including commercial fisheries (Nixon 2003, 2004). In contrast, increases in nutrients can influence food web structure and exacerbate toxic blooms that can limit fish and shellfish harvesting (Rabalais 2004). Changes in freshwater and associated nutrients reaching SEMSs also can eliminate wetlands (Levin et al. 2001) if conditions are too saline or fresh or if nutrient supply decreases or increases.

INVASIVE SPECIES AND STOCK ENHANCEMENT

Human activities (e.g., shipping, aquaculture, deliberate introductions) have rapidly promoted the dispersal of nonnative marine organisms (Carlton 1996; Ruiz et al. 1997), especially in SEMSs. Invading species can change the structure and function of ecosystems in SEMSs. Invasive predators can suppress populations of native species more than native predators (Salo et al. 2007) and have other negative effects on natural and aquaculture systems as trophic competitors, predators, or disease vectors (Decottignies et al. 2007). Typically, invasive species expand their ranges until they reach environmental and/or ecological conditions that limit their growth or reproduction, and they become nearly impossible to eradicate. Deliberate introductions to increase productivity have led to invasions of the seaweed *Caulerpa taxifolia* in the Mediterranean Sea and the Pacific oyster (*Crassostrea gigas*) in the North Sea (Van der Weijden et al. 2007). Some native species have been cultured and reintroduced to the wild to help in the recovery of endangered species and boost natural production. For example, off the Zhejiang coast, jellyfish that are a traditional dish are seeded from captive populations each year (Qu et al. 2005; Zhang et al. 2006). By introducing large numbers of individuals with a limited number of parents, such activity can change the genetic structure of wild populations.

Rapid warming (and presumably ice loss in the Arctic) can accelerate invasion and establishment of nonindigenous species, many of which have fared better under recent warmer conditions (Stachowicz et al. 2002). Recent observations indicate that the Atlantic Ocean has already been invaded by a Pacific plankton species through the Arctic Ocean (Reid et al. 2007).

SHORELINE AND NEARSHORE DEVELOPMENT

Shore development, including industrialization, urbanization, dike building, and a range of other activities, is often driven by economic forces. It can reduce a wide array of provisioning services, including fish harvests or shrimp aquaculture, when habitat destruction removes areas used for fish and shrimp spawning and/or larval development. Oil and gas extraction from coastal seabeds cause disturbance through drill cuttings and produced water, associated transport issues (tanker traffic and pipelines), and spills. All have potentially negative effects on fisheries. Shore development can also disrupt regulating services that would result from natural habitats, such as climate regulation, water regulation, water purification and waste treatment, and erosion regulation. Cultural services such as heritage, artistic, and aesthetic values in recreation and ecotourism are particularly vulnerable ~~from~~ shoreline and nearshore development, because it is so visible to humans. Such development can also change sediment, water, and nutrient inputs, with the negative impacts described earlier.

Medium-Scale (Regional) or Semi-Enclosed System Effects

Changes that are manifested at regional scales (i.e., beyond individual bays) include living resource overexploitation, food web alterations, habitat loss, and nutrient loading.

OVEREXPLOITATION

Overexploitation of fish populations by recreational, subsistence, and commercial fisheries has become a major problem at global spatial scales. Many fisheries are in major decline from historic baseline levels or have collapsed (Myers and Worm 2003), and many areas have experienced "fishing down the food web" (sequential reduction of the largest species in an ecosystem) (Pauly et al. 1998). Marine living resources are harvested usually for human consumption (including fish oils) but also for animal feeds (e.g., fish meal), aquariums, and clothing (e.g., furs, shark and eel leathers). Bycatch (incidental catch of unwanted species) can reduce populations, as well as genetic and species diversity.

Suspension-feeding organisms, such as oysters, purify water in estuarine and mangrove environments by removing particulate matter, thus improving water clarity, biogeochemical regulation (e.g., cycling of organic carbon and particle-associated elements and compounds), and sedimentation. Reduction of suspension feeders can increase turbidity, decrease submerged aquatic vegetation, change zooplankton populations, and increase ctenophores (Newell 1988).

Spiritually symbolic species (e.g., sharks, whales, and dolphins) represent cultural services that are lost to indigenous cultures (e.g., Inuit in Hudson Bay) when stocks collapse and when conflicts develop among subsistence, recreational, and commercial fisheries. Overexploitation and fisheries closures can lead to loss of cultural traditions, aesthetic values, recreational fishing and (eco)tourism (e.g., bird and whale watching, diving).

Overexploitation of living resources can affect the supporting service of primary production. For example, overexploitation of menhaden and other algal grazers may increase the amount of particulate carbon in the pelagic system, whereas removal of predators may allow grazers to increase, and thus reduce phytoplankton.

FOOD WEB ALTERATION

Overexploitation can alter food webs, with cascading effects through the food web that can have dramatic consequences on production services (e.g., Frank et al. 2007). From a human perspective, effects may be positive or negative. For example, Myers and colleagues (2007) describe cascading declines in shellfish through removal of top predators, whereas Worm and Myers (2003) document a widespread positive effect of cod decline on shrimp. Fishing down the food web (Pauly et al. 1998) reduces populations of large fish but can increase populations of smaller (usually less valuable) fish. Diversity changes may reduce the resilience of estuarine ecosystems (Cohen and Carlton 1998; Stachowicz et al. 1999), especially when entire functional groups (multiple species that perform a specific ecological function, such as nitrogen fixation) are lost. Blooms of gelatinous zooplankton or other undesirable species can result from trophic cascades, yielding negative and unexpected consequences on recreation and ecotourism.

HABITAT LOSS

Habitat loss can influence production services by reducing critical habitat for potential food resources. Loss of species that create physical structure (e.g., coral and oyster reefs, mangroves, kelp forests) can cascade to species that depend on those habitats as adults, juveniles, or larvae. For example, loss of cold-water corals (e.g., Costello et al. 2005) and sea grasses (Gonzalez-Correa et al. 2005) as a result of bottom-trawl fisheries has cascading effects on other species. Loss of biodiversity is often linked to specific habitat loss, and declines in specific habitat such as wetlands may affect climate-regulating services, as discussed earlier.

NUTRIENT LOADING

Increasing human populations and associated agricultural needs have significantly altered global nutrient cycles over the last fifty years and increased nitrogen and phosphorus flux to the coastal ocean (Vitousek et al. 1997; Bennett et al. 2001). Widespread coastal eutrophication (Rosenberg 1985; Nixon 1995; Cloern 2001; Schindler 2006) has resulted in poor water quality, noxious algal blooms, oxygen depletion, and in some cases, loss of sea grasses and fisheries production (Rabalais 2002, 2004; see Chapter 11); much effort has therefore been devoted to reducing nitrogen and phosphorus discharges (National Research Council 2000; Boesch 2002).

The reduced flushing and smaller size of SEMSs often exacerbate effects of nutrient loading, so impacts may prolong effects (see Chapter 3, this volume). For example, following the collapse (circa 1990) of agriculture in the former Soviet republics of Estonia, Latvia, and Lithuania, although fertilizer application fell to 1950s levels, downstream concentrations of inorganic phosphorus and nitrogen were similar in 1994 and 1987 (Löfgren et al. 1999), presumably because nutrients stored in sediments continued to leach out.

Eutrophication can influence the atmosphere by stimulating growth of algae such as *Phaeocystis* species that emit dimethyl sulfide (DMS), which can enhance cloud production. Similarly, methane and other greenhouse gases are produced in larger amounts in anoxic conditions like those that develop during eutrophication. Nutrient loading can also enhance disease organisms such as *Vibrio cholerae* (National Research Council 1999). Aesthetic values are compromised by algal blooms and oxygen depletion that cause foul odors, fish kills, foam accumulation, algal debris on beaches, and "dead zones" (see Chapter 11). All of these outcomes compromise recreation and tourism opportunities.

Large-Scale (Ocean Basin and Global) Effects

Sea level change and ocean acidification are stressors on drivers of ecosystem services that operate at global scales, and thus they represent major challenges for management.

SEA LEVEL CHANGE

Production services in low-lying coastal areas are particularly vulnerable to sea level rises, in that storm surges, salinity increases in estuaries, and rising water tables can cause salt poisoning of terrestrial plants and agricultural land. Loss of wetlands as sea level rises will also impact fisheries for species that depend on wetlands for critical habitat. Rising sea levels alter the extent of wetlands in SEMSs and associated net greenhouse gas sequestration/production, a climate-regulating service. Loss of wetlands with sea level rise could also compromise water filtration and protection from natural hazards such as storm surges and tsunamis. Inevitably, sea level rise will alter natural shorelines and the many recreational and tourism economies they support. The loss of wetlands will also compromise the multiple supporting services that they contribute.

ACIDIFICATION

Ocean acidification has broad-scale ramifications for production services, especially for organisms with calcium carbonate structures that are particularly sensitive to pH changes. Photosynthetic coccolithophores, larval (and even adult) bivalves (Gazeau et al.

2007), and corals are all vulnerable to acidification, with possible direct effects on bivalve and coral reef fisheries and indirect effects on food webs. Genetic, biochemical, and ornamental resources are potentially vulnerable to pH change, which will decrease biodiversity and population levels. Acidification of seawater and seafloor sediments can also alter the chemical reactions that control trace metal cycling, with ramifications for primary production and toxicity to humans and other organisms. Decreasing pH can shift phytoplankton composition, with effects on oceanic CO_2 and subsequent sequestration into seafloor sediments. Shoreline protection by corals and carbonate sands would also be compromised by pH decreases, with negative ramifications for recreation, ecotourism, and habitat provisioning.

Case Studies

Below we present a series of case studies on how human activities have resulted in losses of ecosystem services, on governance strategies to address these dynamics, and on lessons that can be derived from these examples. We have organized these case studies around scales of effect and response, in order to illustrate how different scales of change may require very different types of response in terms of actions and governance bodies. We recognize, however, that the scales of drivers represent a continuum and that threats that are initiated at one scale may manifest themselves at smaller or larger scales, depending on management response.

Small-Scale (Individual Bays and Beyond) Examples

HYDROLOGIC CHANGE AND SEDIMENTATION

The East China Sea provides an excellent example of the complex problems that arise with changes in hydrologic input and sedimentation. The Changjiang (Yangtze) River accounts for 90%–95% (1.0×10^{12} m^3 y^{-1}) of freshwater input to the East China Sea, representing the world's largest river discharging directly into a SEMS. The Changjiang watershed has been affected by accelerating human activities over the last century, particularly through damming that has reduced sediment loading and freshwater flow. The amount of sediment discharged from the Changjiang into the East China Sea in the 1990s was 30%–40% lower than that discharged in the 1960s, and the building of the Three Gorges Dam has reduced that loading by an additional factor of 2 (Yang et al. 2006).

These discharge changes have starved the Changjiang delta region of sediment over the past fifty years, especially since 2000, when changes in the seaward extension of the delta reversed, to retreat and erosion, with profound consequences for the ecosystem and the socioeconomics of the region (S.L. Yang, unpublished data). Examples of deteriorating ecosystem services include major loss of critical habitat, such as salt marshes, that once represented an important spawning ground for commercial species and a key habitat for migratory birds and associated tourism activities (Zhang et al. 2006), as well as

Lessons Learned

Upstream effects can have dramatic consequences for downstream environments and human populations, and managers must consider potential impacts of decisions that extend beyond their immediate geographic locales.

Restoration efforts are expensive and complex because they can add problems such as movement of contaminants, spreading of diseases and invasive species, and loss of genetic diversity.

increased seawater intrusion into freshwater supplies in urban areas that may be exacerbated in drought years associated with climate change (Yang et al. 2006).

Management efforts to protect the Changjiang delta, its human population, and natural resources include relocation of sediments dredged from navigation channels to tidal flats in order to offset sediment loss, establishing protected areas in the delta region (e.g., near Shanghai) to limit further habitat loss to urbanization, and transplanting of marsh plants to shallow areas in order to reduce sediment loss from the delta and to restore habitat. Other projects have focused on enhancement of endangered stocks (e.g., the Chinese sturgeon *Acipenser sinensis)*, by releasing cultured larvae or juveniles into the wild.

Since the mid-1990s these efforts have improved substantially the number of species and populations of migratory birds that utilize the coastal wetlands, but new problems have appeared, such as the movement of contaminants in dredged sediments and loss of genetic diversity in stocking programs that utilize offspring of captive populations to seed wild populations.

INVASIVE SPECIES

In the early 1980s, an unknown ship dumped tons of ballast water into the Black Sea. That water, picked up in a distant ocean, contained the comb jelly (ctenophore) *Mnemiopsis leidyi*, which reproduced rapidly, feeding on fish eggs and larvae as well as crustaceans and other food previously eaten by finfish. By 1990, the total biomass of *Mnemiopsis* in the Black Sea was estimated at 2 billion tons, peaking at an average of about 4.5 kg m^{-2} in 1989/1990 and August 1994 (Shiganova et al. 2001). Another gelatinous carnivore, *Beroe ovata*, which preys mainly on *Mnemiopsis* and was introduced into the Black Sea with ballast waters in 1998, contributed to recovery of the ecosystem at the end of the 1990s. Its introduction was immediately followed by a two- to threefold increase in mesozooplankton biomass, ichthyoplankton biomass, and fish stocks (Kideys 2002; Shiganova et al. 2003). *M. leidyi* has now reached high biomass levels in the most important commercial areas of the Caspian Sea and is jeopardizing fisheries by altering the entire food chain, particularly pelagic fish (Ivanov et al. 2000). Very recently, this species has also been observed in the Baltic Sea (Hansson 2006) and the southern North Sea (Faasse and Bayha 2006).

Lessons Learned

Ballast water should be treated as already advocated by the International Convention for the Control and Management of Ships Ballast Water & Sediments, adopted by consensus by the IMO in 2004.

Deliberate introductions should be considered with extreme caution, even where they appear to be safe and beneficial, because adaptation and changing environments may produce unexpected negative results.

Some marine nonindigeneous species have been introduced deliberately in an attempt to improve ecosystem services. For example, Dutch oyster farmers imported spat of the Pacific oyster (*Crassostrea gigas*) from British Columbia to the coastal North Sea for aquaculture in 1964 after the indigenous oyster (*Ostrea edulis*) was wiped out by diseases and overfishing. At that time, *C. gigas* was not considered to be potentially invasive because water temperatures were too cold for its reproduction. However, the combination of warming waters and local adaptation has resulted in the spreading of Pacific oysters and a subsequent decline in indigenous bivalves (mussels and cockles). The oyster also provided a conduit for other invasive species (Wolff and Reise 2002; Nehring 2006). Recently, several studies have been funded to advise state regulators in Maryland and Virginia (USA) on the costs and benefits of introducing *Crassostrea ariakensis* to the Chesapeake Bay to reestablish oyster fisheries decimated by disease, habitat destruction, and overfishing (e.g., National Research Council 2004). Considerable controversy remains regarding the desirability of this introduction, in view of previous unintended consequences that have resulted from other introductions.

On February 13, 2004, the International Maritime Organization (IMO) adopted the International Convention for the Control and Management of Ships Ballast Water & Sediments by consensus at a diplomatic conference in London. The convention's goal is to prevent, minimize, and ultimately eliminate the transfer of harmful aquatic organisms and pathogens through the control and management of ships' ballast water and sediments (International Maritime Organization 2008). There are discussions on whether to introduce the predatory comb jelly *B. ovata* to the Caspian Sea, in order to reduce the invasive *M. leidyi* (Volovik and Korpakova 2004), as occurred fortuitously in the Black Sea.

Medium-Scale (Regional, Semi-Enclosed System) Effects

OVEREXPLOITATION

Overexploitation (including bycatch) of many fishery resources in SEMSs has occurred over the last four decades as a result of growth in commercial fishing and destructive fishing practices. In the Bay of Bengal, the operation of about 4,000 mechanized boats and 26,000 traditional craft has contributed to overfishing (Vijayan et al. 2000), which has been compounded by destructive fishing methods that include bottom trawling, blast fishing, and fishing with poisons. Collectively, these activities have contributed to significant declines in fish and shrimp populations. Gill nets with finer mesh to collect smaller fish also capture juveniles of some taxa, leading to depletion of fish stocks such as the frigate tuna (*Auxis thazard*) (Jude et al. 2002). Overfishing results in significant impacts on marine biodiversity, reducing human food resources. At least 20% of coastal communities in Bangladesh depend on living resources from the Bay of Bengal for their livelihood (Roy 2001) and as a primary source of animal protein. Open-access management schemes in the countries that surround the Bay of Bengal have contributed to overfishing. Developing mariculture will probably worsen rather than solve the problem in the near future, given that production of 3 metric tonnes of finfish require 5 metric tonnes of fish meal (Tacon and Barg 1998), though there have been some developments in feeds that have the potential to reduce waste and utilize nonfish protein.

Until 2003, Bangladesh, India, and Sri Lanka did not apply principles of participatory management and sustainability in their fisheries policies, and funding was not available to implement sustainable fisheries management. In response to declining fisheries, the Food and Agricultural Organization (FAO) developed the Bay of Bengal Programme (BOBP), which employs an innovative participatory approach to resolving fisheries management issues. The BOBP is an intergovernmental program that includes eight countries around the Bay of Bengal and focuses on the development of sustainable fisheries and capacity building (Bay of Bengal Programme 2008). The program evaluates the needs of countries that depend on Bay of Bengal resources and involves member countries in management. Through the BOBP, the countries that surround the Bay of Bengal will consider policies to ensure sustainable use of the coastal zone and marine resources without compromising the integrity of the natural environment.

In 2005, the government of Bangladesh developed a Coastal Zone Policy, in which it declares its intention to develop integrated coastal zone management and to contribute to the sustainable utilization of fishing resources in the Bay of Bengal (Ministry of Water Resources 2005).

HABITAT LOSS

Regional seas provide a variety of habitats to species or groups of species, and the loss of area or function of these habitats represents a major threat to ecosystem services in SEMSs. We summarize contrasting examples from the Wadden Sea in the North Sea, the *bodden* areas in the Baltic Sea, and the mangrove forests along the Bay of Bengal to illustrate different solutions to habitat loss at different scales.

The Wadden Sea, which comprises the southern and eastern coast of the North Sea, with adjacent estuaries, is an important area for recruitment of commercial fishes. Other important ecosystem services include an extensive filtering function for nutrients and other material exported from land and acting as a store or sink for metabolic products.

Lessons Learned

Because of the novelty of the BOBP, it is difficult to predict whether it will be successful. Nonetheless, the failure of past practices suggests that independent management of shared ecosystems is problematic and that the needs and goals of user countries must be considered if an effective and sustainable management scheme is to be developed. To date, the BOBP has not succeeded in establishing any form of transnational governance or management of the Bay of Bengal. Beyond the clearly pressing need to achieve an agreement on maritime boundaries among India, Bangladesh, and Myanmar, the needs and priorities of the different user groups and other stakeholders in and adjoining the bay must be considered if effective and sustainable management of this SEMS is to be developed.

In developing countries, in particular, the scarcity of financial resources creates an additional challenge for the development of sustainable fisheries. Independent bodies that receive outside funding provide a potential tool for cooperative and participatory governance.

The system is dominated by tidal currents and high turnover rates that create a very productive and efficient system for water purification and food production. Increasing activities—such as shipping, dredging for sand mining and navigation, dumping of dredged material, and emplacement of man-made devices for shoreline protection—influence nearshore currents and bottom characteristics that can lead to habitat loss for flatfish and brown shrimp.

The *bodden* areas of the Baltic Sea are similar in function to the Wadden Sea; however, tidal influences are minimal in the former. Shallow, sheltered areas provide habitat for young fish and a productive benthic community, and sea grass and reed meadows also serve as filter systems that improve water quality. Like the Wadden, the *bodden* area supports tourism activities such as boating, sailing, fishing, and swimming, resulting in potential conflict with other uses and maintenance of ecological function such as spawning grounds, nursery areas, or shelters from predation.

Mangrove forests such as those in coastal areas of the Bay of Bengal represent tropical counterparts to the Wadden and *bodden* seas. These tidal forests and associated tidal mudflats provide fisheries, recruitment areas for food fishes, filtering function for water purification, and a sink for land-derived sediments and organic and inorganic matter. Although of no direct importance for tourism, mangroves compete for space with tourism (hotel and resort developments) and other land-based activities such as aquaculture. The genetic resources of mangrove forests are potentially very valuable (e.g., for pharmaceuticals) but are poorly assessed and understood. Future loss of many services in these systems is expected if they are destroyed.

Lessons Learned

Governance of similar resources may sometimes occur most effectively at very different spatial scales, and in instances where relatively few countries share a resource, it may be possible to develop effective comanagement schemes in which resource users are involved in the management.

Although certainly fraught with difficulties, the inclusion of upstream countries that share an SEMS's watershed, but not its coastline, in its governance and management is needed (e.g., Hungary for drainage to the Black Sea or Laos for drainage to the Gulf of Thailand/South China Sea), to ensure comprehensive management of factors such as sediment load, harmful substances, and freshwater inputs.

Restoration efforts can help to offset habitat loss, but if loss exceeds replacement, then decline in ecosystem services can be expected.

Management of these ecosystems works on different scales. In the North Sea, regional conventions and agreements (e.g., the North Sea Conference, Wattenmeerforum, Aktionskonferenz Nordsee, OSPAR) attempt to manage the Wadden Sea as a whole and include representation from the countries that surround it (Germany, The Netherlands, Denmark, the United Kingdom). Problems in the *bodden* areas occur on a smaller scale and can therefore be managed at a local level. Bilateral projects between Germany and Poland, such as Research for an Integrated Coastal Zone Management in the German Oder Estuary Region (IKZM-Oder 2008) have been established to improve the management of areas in the fragile border zone. Research institutes and nongovernmental organizations (NGOs) are active in both regions and attempting to establish integrated management tools and programs.

Mangrove problems in the Bay of Bengal are mainly dealt with on national levels, and management typically operates on relatively small scales. Reforestation programs are underway in Bangladesh to counteract degradation and loss of mangrove areas. Driven by governmental programs and supported by international funds (e.g., the Maturing Mangrove Plantations of the Coastal Afforestation Project and the FAO/UNDP Project; Drigo et al. 1987), the Forest Research Institute in Chittagong runs a reforestation project that has replanted approximately 170,000 ha of mangrove since 1966. Unfortunately, this effort is sometimes offset by clearing of mangroves over the same time period at other places, and the overall area of mangroves in Bangladesh has changed little during the last decades (average = 6,000 km^2; Wilkie and Fortuna 2003). Intergovernmental organizations such as the BOBP have had some success in promoting regional initiatives on sustainable resource use. By contrast, an initiative in Thailand begun in 2003 to frame the management of the Thai waters in the Gulf of Thailand by formulating a national marine policy has been stalled indefinitely by internal political changes.

NUTRIENT LOADING

Nutrient enrichment is becoming increasingly widespread in the scales of impact and the regions affected. We summarize below the effect of nutrient loading on the North Sea, coastal Florida, and the Baltic Sea and the progress in efforts to reduce those loadings. Although it is possible to reduce nutrient loading to pre-eutrophied levels, changes in coastal nutrient concentrations have seldom resulted in the intended management goals (i.e., improvement of particular ecosystem services).

The coastal waters of the North Sea have been subjected to many decades of nutrient enrichment followed by subsequent efforts to reduce nutrient loading. Changes in nitrogen and phosphorus concentrations in coastal waters during these periods were reflected in phytoplankton biomass, production, and community structure. Enrichment and subsequent reduction of phosphorus was followed by corresponding shifts in other coastal ecosystem components (i.e., macrozoobenthos and birds). Although phosphate concentrations are now substantially lower than they have been in the recent past, the ecosystem has not reverted to its previous state. This shift may be a result of nitrogen and silicon concentrations that have remained relatively high or a result of compound effects of overfishing and climate change. These changes may have shifted threshold values for restoration, thereby altering relationships between nutrient loading and ecosystem services (Philippart et al. 2007).

During the 1980s, nitrogen loading in Tampa Bay and Sarasota Bay (Gulf of Mexico), primarily by domestic wastewater, was reduced by 57% and 46%, respectively, as a result of decisions made primarily at state and municipal levels. In 2002, both bays had lower phytoplankton concentrations, greater water clarity, and more extensive sea grass coverage than in the early 1980s (Tomasko et al. 2005). Given that storm water runoff is currently the primary source of nutrient input, year-to-year variation in nitrogen loads will be strongly related to annual rainfall. Phytoplankton abundance, rainfall, and nitrogen loads in southwest Florida's estuaries will all influence water clarity and therefore sea grass growth (Tomasko et al. 2005). Atmospheric nitrogen now represents a major source of nutrients into these coastal waters and also needs to be monitored.

Between 1970 and 1985 there was a threefold increase in surface nitrate and phosphate concentrations in the Baltic Sea (Nehring and Matthaus 1991), resulting in increased toxic or noxious algal blooms. One major problem is cyanobacterial blooms in the open sea, particularly of the toxic, nitrogen-fixing genus *Nodularia*. In addition, multiple fish kills by the phytoplankton *Prymnesium parvum* have been reported from the Baltic coastal zone. In order to mitigate the problem of nutrient loading in the Baltic Sea, the countries with significant riparian loading agreed to reduce river nutrient loads by 50% (Neumann et al. 2002). Modeling studies indicated that most countries would gain net economic benefits from the 50% nitrogen and phosphorus reduction policy (Turner et al. 1999).

Lessons Learned

Reduction of riverine inputs of nutrients in overloaded systems will not likely result in "pristine" conditions, because SEMSs have compounding factors such as overfishing, atmospheric deposition, climate change, habitat destruction, and nutrients stored in bottom sediments that slow down or even make impossible restoration of pre-impact ecosystem services.

Nutrient reduction is often easier (more affordable) for any one nutrient than for all; this results in changes in nutrient ratios that affect phytoplankton species composition and subsequently ecosystem services. Closer attention should be paid to the importance of balanced nutrient composition, as well as nutrient supply dynamics, for the development of eutrophication versus efficient trophic transfer and fish production in nutrient-enriched systems.

When nutrient management measures such as reduction of loads are taken, all ecosystem services that are likely to be influenced by intervention (e.g., food, oxygen production through photosynthesis, primary production, nutrient cycling, and habitat provisioning) should be considered.

POLLUTION WITH INDUSTRIAL WASTES

The Gulf of Thailand (GOT) is part of the Sunda Shelf, with water depths that vary between 45 m and 85 m and a shallow sill that limits water exchanges with the South China Sea. Twenty-three rivers drain large amounts of freshwater and pollutants into the gulf. Major land uses of the catchment are agriculture and related agro-industries, and there has been increasing oil and gas production in the last decade, along with new deep-water ports to accommodate these activities. Untreated municipal and industrial organic wastewater from large cities is causing harmful algal blooms and oxygen depletion~~s~~. The major pollutants of the estuaries and GOT include nitrate, phosphate, and silicate, but heavy metals are also a problem. Pollution includes, for example, mercury loading, small oil tanker spills, and industrial waste from coastal development to accommodate tourism demands.

These threats have reduced the quality and availability of seafood in Thailand. Monitoring by the Pollution Control Department (PCD) of Thailand during 1995–1998 indicated risk imposed on humans from seafood consumption, and there have been incidents of food poisoning and illness associated with seafood consumption. Though mercury is elevated, a public health threat from seafood contamination does not yet appear to be significant. Pollution has also resulted in deterioration of coastal water quality (e.g., from fecal coliform bacteria)~~ and beach appearance~~.

Thailand is working to alleviate the pollution problem and to restore ecosystem services in the GOT. Water treatment facilities are being built in more and more communities, funded initially by the Asian Development Bank and later by the Thailand Environ-

Lessons Learned

Carefully designed monitoring programs are essential for effective management, but enforcement is challenging. International support to kick-start new monitoring programs and provide proof of concept can lead to expansion through domestic programs.

mental Fund. The Thai PCD also monitors water quality twice a year along the entire coastline of Thailand, including monitoring of mercury levels in fish.

The Thai government has also established regulations such as the Swine Effluent Standard, Pier Effluence Standard, and Shrimp Farm Effluence Standard. Operators of coastal aquaculture, fishery activities, pig farms, and factories are now required to treat wastewater to these standards before releasing it. More measures have to be established and enforced effectively to solve the industrial water pollution problem. New standards for mercury emissions have been established, and a collaborative working group has been established between government agencies and university scientists to ensure that an appropriate strategy is developed to resolve the mercury problem and to carry out capacity and risk assessment analyses. There has also been development of Association of Southeast Asian Nations (ASEAN) marine water quality criteria (for oil, grease, and metals such as zinc) as part of the ASEAN–Canada Cooperative Programme on Marine Science. The PCD has organized workshops to accelerate implementation of an action plan on water quality and established an Environmental Quality Index for Tourist Beaches and Islands to evaluate suitability for swimming.

These actions have yielded positive results. Coastal water quality in the GOT and Andaman Sea has generally improved in recent years. Surveys of solid waste found on beaches, land use, conditions of sand dunes, erosion, and coral reef health show that environmental quality is "good," with slight improvement in some tourist areas. Because of its importance, the coastal water quality monitoring program will continue in the future. Finally, recent surveys (2001–2003) showed declines in total mercury concentrations in coastal water, and all areas were in compliance with the national standard.

Large-Scale (Ocean Basin to Global) Effects

ACIDIFICATION

The uptake of atmospheric CO_2 by the ocean helps to reduce greenhouse effects but this "service" of the ocean in global temperature regulation also lowers the pH and thus acidifies the surface ocean. This is an example of a global environmental issue that will be expressed in different ways in different regions. The biological effects of ocean acidification are only beginning to be studied (see Orr et al. 2005b; Royal Society of London 2005), although it is predicted that decreasing ocean pH will damage (and potentially eliminate) warm-water corals in SEMSs and other tropical coastal areas. Ocean acidifica-

Lessons Learned

Because of the large scales involved, efforts to mitigate problems such as ocean acidification will require substantial proactive measures through international initiatives such as the Kyoto Protocol. The large scale of the problem also creates a strong momentum in which reversal will be difficult and slow to achieve.

In the absence of clear scientific consensus that a given activity will not cause harm, the burden of proof falls on those advocating it (Raffensperger and Tickner 1999). Precautionary approaches are recommended in areas such as management of marine fisheries and coral reefs because specific responses of ocean ecosystems to acidification are difficult to predict.

Careful and integrated monitoring of particularly vulnerable systems, such as coral reefs, is recommended.

tion will add to several other human impacts on corals, the most important of which is increased ocean temperatures. Ocean acidification also will affect the production of calcareous plankton, including coccolithophores and pteropods (Riebesell et al. 2000; Feely et al. 2004), which form the base of some ocean food webs, resulting in changes in the quantity and quality of food for commercial fish and marine mammals. Because the solubility of CO_2 in seawater increases in colder water, ocean acidification effects are expected to be particularly serious and to occur sooner in high-latitude areas (Orr et al. 2005a) including, potentially, Hudson Bay, the Laptev Sea, and the Kara Sea. Ocean acidification may seriously affect the development of larval marine organisms because many larvae in the ocean surface layer form calcium carbonate skeletons.

Management options to cope with ocean acidification are limited. Large-scale preventive measures, such as global treaties to limit human inputs of CO_2 (most notably the Kyoto Protocol) and CO_2 emission–trading systems, are most likely to be effective because of the global nature of the problem. Mitigative management is untried but might focus on reducing other human pressures on coral systems and fisheries stressed by ocean acidification. Research on biological effects of ocean acidification and on management approaches is urgently needed (Cicerone et al. 2004; Kleypas et al. 2006). Specifically, national and international fisheries management in coral reef and high-latitude areas likely to be affected by ocean acidification need to incorporate the effects of all stressors. Presently (at least in the best single-species management systems), total allowable catch (TAC) levels are set each year, based on the fishing level that managers believe will sustain fish populations at desirable levels. TAC levels regulate future fishing efforts and are mostly derived from past population and harvest levels. Under increased climate change, fisheries management could be more effective if it builds in a precautionary cushion to account for the fact that stocks will be increasingly stressed by warmer water temperatures, changing pH, and, potentially, changes in food supply and recruitment failure.

Governance and Management of SEMSs

Multiple human threats in SEMSs require an integrated management approach over different spatial scales (e.g., watershed, coastal zone, and adjacent ocean), temporal scales (e.g., historical changes, current and future threats), and ecosystem aspects (e.g., the major physical, chemical, and biological variables). Multiple threats also put new demands on the larger governance framework, that is, the institutional structures through which diverse social actors, including public authorities, influence and enact policies and decisions in public life (Risse 2007).

Past attempts to manage coastal and marine ecosystems have often been fragmented and ineffective. More recently, broad, integrated management plans have developed from the 1960s and strengthened over the past two decades (Sorensen 2002; Millennium Ecosystem Assessment 2005). A recent survey counted 698 such initiatives in 145 countries, including 76 initiatives at the international level (Sorensen 2002). Still, many countries with long-established and well-designed coastal management plans cannot halt or even reverse overexploitation, habitat loss, and pollution (Millennium Ecosystem Assessment 2005), in part because degradation processes started centuries ago and underlay current ecosystem states (Jackson et al. 2001; Lotze et al. 2006). Moreover, degradation often occurs faster than management and governance can respond, and efforts are undermined by conflicts among multiple stakeholders (Millennium Ecosystem Assessment 2005).

Ideally, integrated management would address human threats at different spatial scales and place management in a comprehensive governance framework that defines the fundamental objectives, policies, laws, and institutions. For example, nutrient loading through watersheds and the coastal zone results from land runoff, groundwater discharges, sewage outflows, and municipal and industrial discharges. Thus, a range of actors and institutions would be involved in integrated management, each with different interests, perspectives, and knowledge. Nutrient loading via atmospheric deposition ultimately requires a larger, supraregional, or even global-scale approach.

Scale-related management issues also occur with overexploitation. Management must address problems ranging from diadromous fish populations to major commercial species (fish, invertebrates, and plants) that inhabit coastal waters and continental shelves. These areas often straddle or fall within national exclusive economic zones or areas subject to regional multilateral agreements, while the high seas mostly extend beyond national jurisdictions and require international or even global coordination efforts.

On the supranational level, a set of important framework instruments, including the following, has developed over recent decades:

- the Ramsar Convention on Wetlands (1971)
- UNEP's Regional Seas Programme (1974) and its Action Plans
- the UN Convention on the Law of the Sea (UNCLOS 1982)

- the UN Conference on Environment and Development's Agenda 21, particularly Chapter 17 (1992)
- UNEP's Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities (GPA 1995)
- the Convention on Biological Diversity (CBD 1992) with its Jakarta Mandate on the Conservation and Sustainable Use of Marine and Coastal Biological Diversity (1995)
- the Plan of Implementation of the World Summit on Sustainable Development (2002)

These global treaties and nonbinding multilateral agreements set the stage for national and regional management efforts, and they are often complemented by more specific protocols, annexes, or action plans, such as the UN Environment Programme Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities (see UNEP/GPA 2008).

The development of these international framework agreements confirms two recent trends in coastal and marine governance (Figure 4-2). First, there has been a long-term shift from top-down, centralized approaches, in which national authorities (advised by scientists) develop and enact rules, to decentralized and more participatory forms of management ("community-centered management"). This trend has problems, such as an often limited knowledge base, an embedding in local power structures, and a lack of reliable financing. In addition, bottom-up approaches are often ill equipped to handle major infractions and macro developments whose social and economic drivers are far beyond their reach. Thus, the pendulum has begun to swing back to hybrid forms of comanagement that involve national and regional authorities, local participants and structures, and often international civil society players.

The second trend is an emerging shift from single-issue or single-species, yield-oriented approaches to ecosystem-based management that aims to maintain the continued functioning of whole ecosystems. Earlier versions of ecosystem management, such as the U.S. Federal Ecosystem Management Initiative, focused largely on the natural components and their scientific management. More recently, integrated ecosystem approaches, as promoted under the CBD—in the context of Integrated Marine and Coastal Area Management (IMCAM))—are characterized by their inclusion of stakeholders, their iterative procedural setup, and their commitment to adaptive management.

Available evidence suggests that resource management strategies that consider the consequences of resource removal on ecosystems and human well-being are more effective than sectoral or single-species management (Kay and Alder 2004). Fisheries management agencies and NGOs increasingly promote ecosystem-based fisheries management that addresses multispecies interactions as well as habitat and environmental (e.g., water quality) requirements for survival and reproduction (Pikitch et al. 2004). These approaches call not only for more-effective regulations of exploitation, but also for pol-

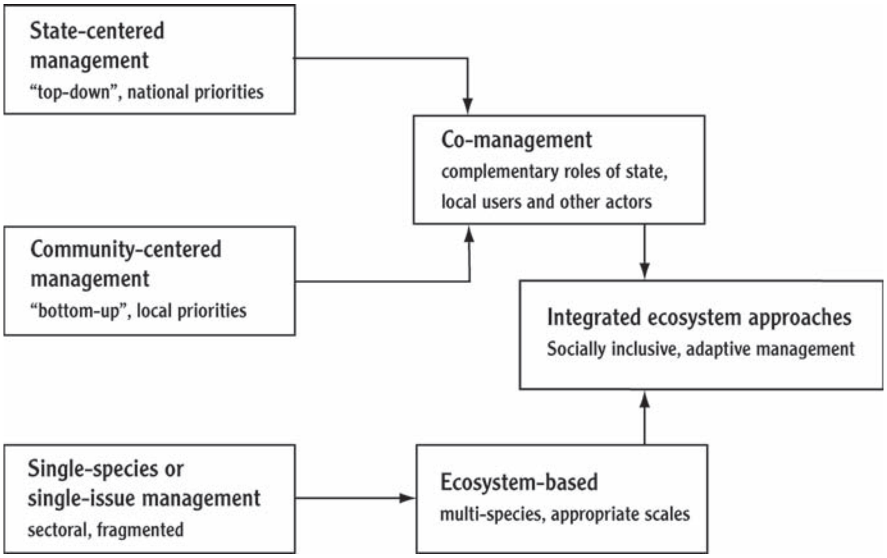

Figure 4-2. Flowchart of the development of management approaches.

lution controls and the protection of coastal and marine habitats. Examples of successful pollution control include wastewater treatment to reduce nutrients and pollutants from point sources such as municipal and industrial outflows, changes in land-use practices that include buffer strips to prevent non-point land runoff, and restoration or construction of new wetlands to enhance filter and storage capacity. However, management interventions to control pollution have often failed, and no country has succeeded in comprehensively limiting pollution of nearshore environments (Millennium Ecosystem Assessment 2005). Costs for habitat restoration can be extremely high and thus unrealistic for developing countries (Millennium Ecosystem Assessment 2005), and not all habitats can be effectively restored.

In the framework of ecosystem-based management, there is increasing interest in marine protected areas as a tool for halting the overexploitation of resources (U.S. Commission on Ocean Policy 2004). Worldwide, there were an estimated 4,116 coastal and marine protected areas in 2003 (Spalding et al. 2003), but despite the large number of individual sites, their coverage accounted for < 1% of the global ocean (Millennium Ecosystem Assessment 2005). Current marine protected areas range from many small fisheries reserves to a few larger networks of marine reserves such as the Great Barrier Reef Marine Park in Australia (Murray et al. 1999; Day 2002; Pauly et al. 2002). A recent analysis of the effects of forty-eight marine reserves worldwide showed that compared with unprotected areas, average diversity, productivity, and resilience are enhanced and variability is reduced in protected areas (Worm et al. 2006). However, the effectiveness of many protected areas is limited because cooperation and enforcement are lacking at local and regional scales, and most protected areas are only partially protected. Thus, marine protected areas as a tool have not been used to their full potential so far (Agardy et al. 2003).

Recommendations

SEMSs are especially vulnerable to human disturbances because of their limited exchange with the open ocean, and many also support dense human populations. As in many other natural systems, the interacting effects of multiple drivers further complicate management strategies. As the examples above illustrate, management of drivers that operate at smaller spatial and temporal scales is relatively easier to achieve than management of drivers that operate at large scales. As many problems in SEMSs are associated with intermediate spatial and governance scales, their management is particularly dependent on successful regional and sectoral integration but may also hold particular chances for creative, regionally specific approaches.

Local intervention at the level of communities and local stakeholders can be effective in reducing some drivers of ecosystem service loss. With the exception of large-scale trawling disturbance, many types of habitat destruction can be managed through sets of rules at the local level or habitat restoration initiatives. Restoration, however, can rarely bring back all the lost services. Moreover, restoration has to outpace rates of habitat loss, which does not always happen. Restoration can be expensive, and it runs the risk of introducing invasive species, spreading disease, and reducing genetic diversity. Clearly, reducing habitat destruction is a more effective and promising strategy for preserving ecosystem services.

Prevention and coordinated national-level intervention are the best strategies for dealing with invasive species, even though invasive species typically cause local problems initially. Given the modes of transit for invasive species and the mobility of the ships involved, local initiatives are unlikely to be effective. Because invasive species are extremely difficult to manage once they have become established, efforts to prevent transport must be prioritized. National laws that regulate ballast water disposal represent one of the best tools to reduce invasions, but because SEMSs are typically bordered by multiple countries, cooperation and parallel regulations are necessary for real effectiveness. Because the full impacts of invasive species are very difficult to predict in advance, deliberate introductions should be avoided until all other potential solutions have been examined.

Scale is also important to consider in managing pollution. Point source pollution can be resolved by local governance where individual polluters (e.g., industries) are induced to reduce emissions by legal bans or economic incentives. Problems such as nutrient enrichment, however, often involve diverse stakeholders who may live long distances from the coastal zone where impacts are most severe. In this instance, nutrient sources may come from another city, county, or even country, and stakeholders from those sources must be made aware of the consequences of their actions and assisted in finding alternative, less destructive approaches. These types of problems require regional cooperation that may include multiple nations, demonstrating that independent management of shared ecosystems is problematic, and the needs and goals of user countries must be considered if an effective and sustainable management scheme is to be developed.

The problem of shared resources is common in marine fisheries because resources often straddle and move across regional and international boundaries. Management of these types of fisheries without consultation among stakeholder groups is doomed to fail, and establishment of an independent body that comanages the resource, taking the interests of all stakeholders into account, is the most promising solution.

Problems manifested at global scales are particularly challenging as they require cooperation and initiative by many countries and stakeholders around the world. These needs are pressing because large-scale disturbances have a strong momentum that is very difficult to reverse, or even slow down. Efforts to mitigate problems such as ocean acidification will thus require substantial proactive measures through international initiatives such as the Kyoto Protocol, but lack of cooperation from a few key nations will reduce the likelihood that disturbing trends can be reversed.

In summary, effective governance and management of SEMSs require an integrated approach that considers all ecosystem services and their interaction. The development of ecosystem-based management in fisheries that is gaining support in many areas of the world is promising in that it aims at ecosystems as a whole. This is also one of the central tenets of the ecosystem approach as it is being developed under the Convention on Biological Diversity. In a similar vein, there is growing recognition of the necessity to couple coastal zone management with watershed management, as under the European Water Framework Directive, aided by recent research initiatives (e.g., Land–Ocean Interactions in the Coastal Zone, LOICZ).

Carefully designed monitoring programs (e.g., for pollution, overfishing, ballast water) are also essential for effective management, despite the challenges of cost and enforcement. International programs that can help to fund establishment of comanagement bodies and related capacity-building measures are particularly important for developing countries that may need funding to kick-start new monitoring programs and establish domestic management. Given the many losses of ecosystem services that have occurred over the last century, a precautionary approach is recommended. SEMSs provide vital resources to many people, and their continued functioning must be a top priority for the many stakeholders who benefit from them.

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