# Waves of Change:

## Using Science to Inform Policy in an Ecosystem-Based Approach to Ocean Resource Management

Final Workshop Report:
The Ocean Conservation, Education and National Strategy for the 21st Century Act (H.R. 21)

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# Executive Summary

Two blue ribbon commissions recently examined current United States ocean policy and found that the nation's uncoordinated system of ocean governance has proven unsuccessful at sustaining the supply of marine ecosystem services such as climate regulation and food provision. Declines in ocean ecosystem health have been primarily attributed to six major threats: climate change; chemical, nutrient and biological pollution; land use and coastal development issues; habitat damage; unsustainable fishing and invasive species are all having deleterious impacts on marine organisms and habitats.

In response to the commissions' findings and subsequent recommendations, the Ocean Conservation, Education and National Strategy for the 21st Century Act was proposed in early 2006 to address these problems and many others. The bill seeks to promote a coordinated National Ocean Policy, strengthen the National Oceanic and Atmospheric Administration and integrate ocean governance at multiple levels using science to inform policymaking in an ecosystem-based approach to management.

Ecosystem-based management is enabled by coordinated, interdisciplinary scientific study that allows management to operate within ecosystem boundaries and transcend traditional political jurisdictions. It makes use of the precautionary principle to facilitate action in the absence of complete scientific understanding and couples this proactive stance with a commitment to adaptive management in which science informs policy and vice-versa. Ocean policies, including those proponing ecosystem-based management, that avoid the spatial and temporal mismatches inherent in traditional sector-by-sector approaches will be better able to confront the synergistic problems faced by ocean ecosystems in the 21st century.

# Introduction and Historical Context

United States ocean governance has matured iteratively over the past two centuries in response to emerging economic, environmental and political concerns. This history of fragmented development is evident in the plethora of agencies that are today responsible for handling ocean issues. From the Navy and National Oceanic and Atmospheric Administration to the Fish & Wildlife Service and Environmental Protection Agency, a multitude of agencies are charged with overseeing various aspects of ocean policy. This governance system was designed within the constraints and based on the circumstances of evolving U.S. politics, and each piece was created to address a specific issue at a unique point in time. The marine environmental problems facing the ocean today are interrelated and of larger scope than any envisioned by policymakers as they authorized the development of such a disjointed system of ocean resource management. As a result, "the nation is not now sufficiently organized legally or administratively to make decisions, set priorities, resolve conflicts, and articulate clear and consistent policies that respond to the wealth of problems and opportunities ocean users face," according to the final report of the U.S. Commission on Ocean Policy (2004). An integrated and coordinated approach to managing U.S. coastal and ocean resources will provide a strong basis for continued environmental protection, economic development and national security.

The Oceans Act of 2000 mandated a thorough examination of United States marine policy effectiveness by authorizing a U.S. Commission on Ocean Policy to analyze all aspects of ocean resource management. Concurrently, the Pew Charitable Trusts funded a private Pew Oceans Commission to conduct a similar investigation. Using ocean ecosystem health as an indicator of effective ocean policy, both studies came to the same conclusion: the ocean and its component marine resources are experiencing precipitous declines due to diverse threats ranging from overfishing and bycatch to nutrient pollution and coastal development. Impacts of climate change, including ocean warming and acidification, are among the other extant risks to marine ecosystems and the services they provide. The current magnitude of marine environmental problems affecting U.S. ocean resources indicates the existence of serious flaws in marine policy that have allowed these problems to broaden in scope and impact.

The lack of a comprehensive national ocean policy is compounded by weak communication among the numerous federal, state and local agencies responsible for implementing different aspects of ocean resource and marine ecosystem management. Issues such as fisheries management, endangered species conservation, marine transportation and offshore energy extraction are managed independently of one another, and administrators are often uninformed about management activities in other sectors. Because aquatic ecosystem boundaries usually do not correlate with those of agency jurisdiction, additional coordination in management is necessary – even so, this integration is often lacking. The traditional sector-by-sector approach to ocean resource management, where, for example, fisheries are managed independently of marine mammals, often fails to provide coordinated strategies, unified decision-making or effective administration that can enable enhanced ocean ecosystem health.

Marine science research is fragmented in a way similar to that of marine resource management. Although oceanography and marine biology have grown and spawned numerous specialized sub-fields, experts are often reluctant to integrate their disciplines in ways that could inform policy with more comprehensive analyses of multiple ecosystem components. The health of marine and freshwater ecosystems has not ceased to decline despite a proliferation of research stations, technological innovations and sources of funding. A more integrated, interdisciplinary approach towards marine science research may lead to the increased development of applied science techniques and real-world solutions primed for implementation. Both the Pew and U.S. Ocean Commissions have indicated the need for a more dynamic approach to marine science research that can be flexible in choosing coordinated research priorities to provide a strong scientific foundation for ocean policy and marine resource management strategies.

In addition to the fragmentation within the marine science and management communities, there is a substantial communication gap between the realms of science and policy. This fundamental disconnect must be addressed in order to sustain the health of marine and freshwater ecosystems. Marine policy concerned with ensuring the continued provision of ocean ecosystem services can address the gap between science and policy by promoting a management system in which managers help scientists frame scientific questions so that results are able to inform policy development and implementation.

The Oceans Conservation, Education, and National Strategy for the 21st Century Act (H.R. 21) authorizes a marine resource management system organized to do exactly that: ecosystem-based management considers the convergence of individual threats in ecosystem-scale problems and proposes solutions by using science to continually inform policy through adaptive management techniques. This approach explicitly acknowledges the fundamental scientific uncertainties involved in the characterization of marine ecosystems and uses a proactive approach based on the precautionary principle to suggest potential management actions before problems reach a critical stage. The bill proposes the nationwide implementation of ecosystem-based, precautionary and adaptive approaches to marine resource management by authorizing a comprehensive National Oceans Policy, strengthening the National Oceanic and Atmospheric Administration and implementing novel ocean governance mechanisms on multiple administrative levels. Taken together, these three legislative initiatives will allow for a better-integrated system of ocean resource management pursuant to the recommendations of the Pew and U.S. Ocean Commissions.

The need for large-scale national reorganization of ocean governance has been indicated by the magnitude of serious marine environmental problems as outlined in two key reports from the U.S. Commission on Ocean Policy and Pew Oceans Commission. Consequently, H.R. 21 promotes an ecosystem-based approach to management in order to address varied threats to the health of marine organisms and habitats. An in-depth examination of the scientific core of these threats provides the foundation upon which effective and integrated ocean policies can be created within the framework of H.R. 21.

# Scientific Understanding of Marine Ecosystem Problems

Our understanding of the ocean has traditionally been based on oceanography and marine biology, which have together allowed for an understanding of the physical and biological components of ocean ecosystems. As marine science continues to evolve, the need for interdisciplinary study is becoming more and more evident. The following summarizes the six major threats to marine and freshwater ecosystems to be addressed by the new governance mechanisms of H.R. 21.

## Climate Change

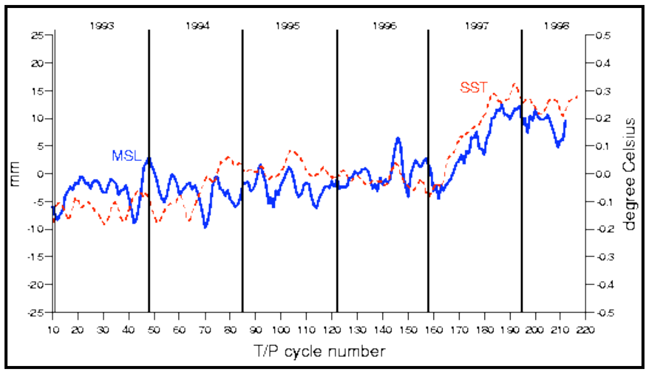



**Figure 1: Increasing sea surface temperatures (red) and sea level (blue) will be among the many marine impacts of climate change.** (www.jason.oceanobs.com)

The major climate change impact on marine ecosystems will be rising temperatures (Wu 2007). These changes will in turn cause altered surface-driven wind circulation, coastal stability, formation of storm bodies, thermohaline flow, risks to coastal infrastructure and threats to biodiversity (Lomas, *et al.* 2002; Collins, *et al.* 2007; IPCC 2007). Even the most optimistic IPCC projections for the next century predict that sea level will rise by .18 meters; sea surface temperatures are predicted to rise by 1.8 °C (IPCC 2007). Sea level rise associated with the thermal expansion of seawater and melting of the Greenland and Antarctic ice sheets will inundate wetlands, mangroves and other coastal ecosystems (IPCC 2007). Increasing sea surface temperatures will alter phytoplankton nutrient uptake processes, cause the destruction of coral reefs via bleaching events, extend the ranges of invasive species and aid the proliferation of bacteria and other disease-causing organisms in the oceans (Colwell & Anwar 2001; Pew Oceans Commission 2003). Moreover, marine species will shift their ranges as isotherms move poleward in response to global warming (IPCC 2007). The economic impact of climate change effects on marine resources will be severe: coastal damage and restoration costs linked to climate change are predicted to reduce the U.S. national GDP by up to twenty percent (Pew Oceans Commission 2003).

## Chemical, Nutrient and Biological Pollution

The production of toxic chemicals, offshore spillage of petroleum, introduction of invasive species and poor management of coastal water resources have all caused considerable damage to ocean and Great Lakes ecosystems (Worm, *et al.* 2006). The proximity of these ecosystems to heavily populated areas makes them susceptible to influxes of nutrient, chemical and biological pollution.

Increasing usage of nitrogen and phosphorous fertilizers has elevated the amounts of these nutrients delivered to aquatic ecosystems. Nutrient influxes can initially support the proliferation of phytoplankton, which use the extra nitrogen and phosphorous, along with solar energy, to fuel rapid reproduction (Caffrey, *et al.* 2007). One byproduct of increased productivity is an accumulation of dissolved oxygen, a product of photosynthesis, in the water column and the subsequent proliferation of organisms that eat phytoplankton. The oxygen used to decompose the phytoplankton and their consumers sometimes balances the amount of oxygen generated by increased primary productivity, but the nocturnal respiration of primary producers often combines with other causes of oxygen depletion to produce anoxic conditions. Too much decomposition under these conditions can create zones of hypoxia – 'dead zones.' When this occurs, larger organisms are unable to respire and must either migrate or die. Major build-ups of nutrients have occurred in areas such as the Gulf Coast, Mississippi River and Great Lakes where agricultural runoff is plentiful and full of nitrogenous fertilizer (Rabelais, *et al.* 1996; Nordby, *et al.* 1991; Hu, *et al.* 2003).

Anthropogenic waste in the form of sewage is another form of nutrient input to aquatic systems. An analysis of U.S. beach closings reported that sewage spills and overflows caused or contributed to 25% of beach closing or advisory days during 2004 (NRDC 2005). Sewage loading can lead to high fecal coliform bacteria concentrations, increased biochemical oxygen demand and severely hypoxic conditions. In 2005, 3 million gallons of raw sewage spilled into a small tidal tributary in North Carolina and caused widespread oxygen depletion and fish kills (NRDC 2005). In Delaware, sewage runoff has been shown to alter estrogen levels in coastal fish and compromise their ability to reproduce (Atkinson, *et al.* 2003).

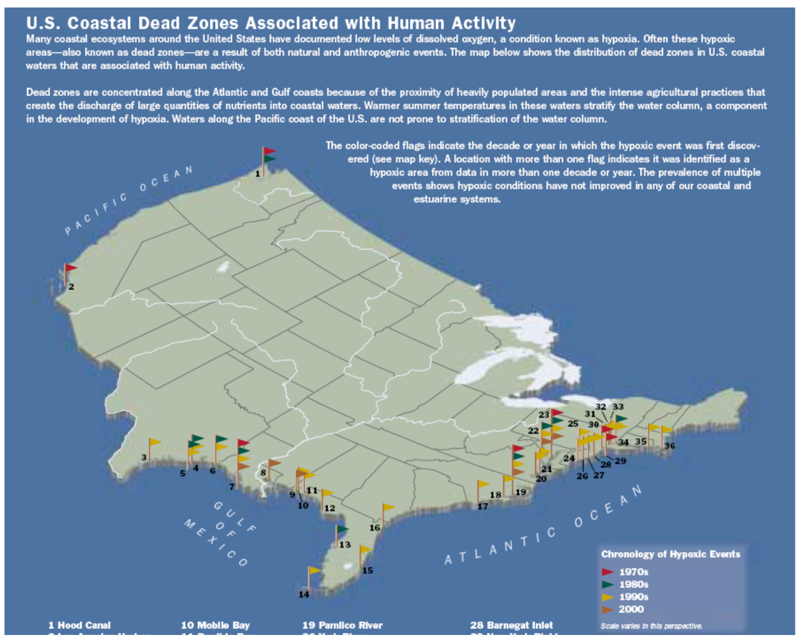



**Figure 2: US Coastal Dead Zones by Decade** **(Pew Oceans Commission 2003)**

Chemical pollution from industrial activities has additional damaging effects. In the Great Lakes, industrial chemicals have disrupted endocrine function in fish and other freshwater organisms (Leach 1993). Immediate effects of this disruption included reproductive or gonadal mutations, diminished resilience in the face of environmental change and reduced growth and development (U.S. EPA 2006). Across the country, mercury, PCBs and organochlorine are present at high levels throughout the San Francisco Bay (Morell, *et al.* 1998; U.S. EPA 2006). All of these contaminants are lipid soluble and can bio-accumulate in fish tissues where they pose a health risk to catch-and-eat anglers.

Biological pollution in the form of harmful algal blooms and invasions of exotic species can also have serious impacts on freshwater and marine ecosystems. Escaped farmed species or non-natives discharged in ballast water can sometimes rapidly overcome endemic species or consume scarce resources to the detriment of native populations. Harmful algal blooms cause respiratory distress among human and marine mammal populations alike, polluting the shorelines with toxic vapors (Rabelais, *et al.* 2002).

Taken together, these three types of pollution pose a great threat to the stability of marine and Great Lakes ecosystems. Although coastal habitats located near developed areas face the greatest risk, the entire ocean can be affected by nutrient, biological and chemical pollution (U.S. Commission on Ocean Policy 2004).

## Unwise Land Use and Coastal Development

The intense development pressure from human population increases in coastal areas is the main contributor to habitat loss and subsequent species extirpations (MEA 2005). More than half of all Americans live in coastal counties, and the coastal population is predicted to continue increasing throughout the next century (Pew Oceans Commission 2003). Major problems include development proceeding at rates up to ten times faster than at inland sites, excessive use of transport fuels and clearance of wetlands, mangroves and other sensitive coastal habitats (Platt 1994; Wilkinson, *et al.* 1997; Wilson 1999).

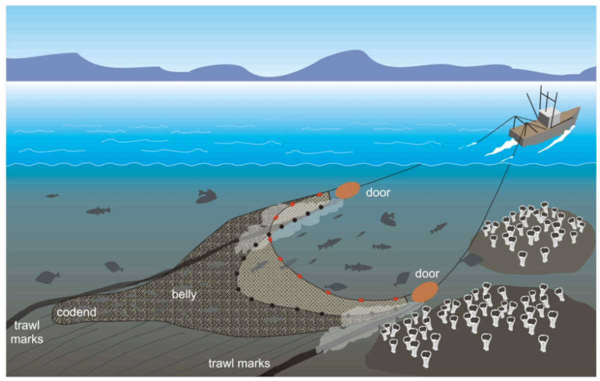
When explaining the effects that environmental problems have on habitats, coastal zones are often used as examples. This is they provide numerous ecosystem services (Ray 2005; Byrd 2007). Some of these services include providing oxygen to waters and sediments, sequestering atmospheric carbon, exporting organic carbon to adjacent ecosystems, stabilizing sediment, preventing sediment re-suspension, improving water transparency, attenuating waves, protecting shorelines and providing habitat for microbes, invertebrates and vertebrates that are either endangered or commercially exploited (Smith, *et al.* 1996; Lomas, *et al.* 2002; Worm, *et al.* 2006). The loss of productive coastal ecosystems and the services they provide will have immediate consequences for humans – every acre of wetlands given over to development reduces the floodwater mitigation potential of the coastal zone (Dickert & Tuttle 1985).

**Figure 3: Rapid coastal development and population density increases threaten fragile coastal ecosystems. (www.noaa.gov)**

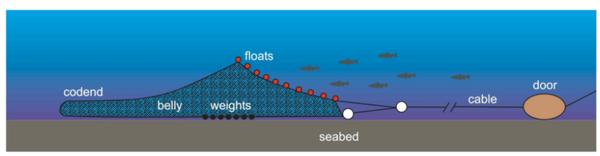
One example of unwise land development comes from the Tijuana Estuary in Southern California, which has experienced an increase in human disturbances over the past 15 years (Nordby, *et al.* 1991). As beach patronage increased, trampling of sand dunes eventually led to sand filling the estuary and closing the inlet to the Pacific Ocean. Eight months passed before dredging could remove the sand. In the meantime, evaporation and a lack of ocean mixing caused the blocked estuary to become very salty. Consequently, three fish species, the longjaw mudsucker (*Gillichthys mirabilis*), California halibut (*Paraicthys californicus*) and diamond turbot (*Hyposopsetta guttulata*), declined in abundance; and the dominant bivalve, the purple clam (*Nutallia nuttallii*) became extinct (Nordby, *et al.* 1991).

## Habitat Damage

One striking example of marine habitat damage is bottom trawling. This destructive fishing practice involves scraping a large net across the seafloor in order to catch fish and has an ecological impact comparable to clear-cutting in terrestrial forests (Jennings, *et al.* 2001). In addition to decimating fish populations, bottom trawling levels seafloor topography, rips coral from the seabed and destroys essential fish habitat (Jennings, *et al.* 2001; Robinson 2004).




(after Christen, 1999)




(after Messieh et al., 1991)

**Figure 4: Schematic Diagram of Bottom Trawling** (www.livingoceans.org)

Marine aquaculture can also result in significant damage to ocean ecosystems (Vecchione & Collette 1996). For example, aquaculture can decrease water and sediment quality by inducing high organic and nutrient loading in surrounding waters. When this input accumulates in the sediment, hypoxic conditions prevail (Delgado 1999). This phenomenon, coupled with accelerated siltation, sedimentation and turbidity due to land use-related erosion, can cause serious damage to benthic habitats (Rabalais, *et al.* 2002; Wilson & Carpenter 1999).

## Overfishing and Bycatch

Commercial fishing is a multi-billion dollar global industry with strong historical ties to many coastal communities in the United States. Scientific uncertainty used to justify risky fishery management decisions has led to long periods during which overfishing, i.e. removing more fish from the sea than can be replaced by reproduction amongst the remaining individuals, has been the norm (Pontecorvo 2003). This process has led to the overexploitation of nearly one-third of global fish stocks (U.S. Commission on Ocean Policy 2004). A notable example of this overexploitation occurred on Georges Bank (off the coast of New England), where stocks of commercial fish were reduced by over fifty percent in less than four decades of intensive fleet fishing (Fogarty and Murawski 1998). The cumulative impact of overfishing and other factors on fish stocks has serious consequences for ecosystem structure. In addition to the removal of targeted species, overfishing can impact additional species through ecosystem interactions including top-down and bottom-up effects (Pontecorvo 2003). In these scenarios, species are affected indirectly through food web impacts via loss of overfished prey or predator species. Overfishing can also affect the genetic makeup of species (Conover 2002). The selective extraction of large fish confers evolutionary success on genotypes that produce smaller individuals, which increases the proportion of small individuals in the population and results in decreased stock biomass over several generations (Conover 2002).

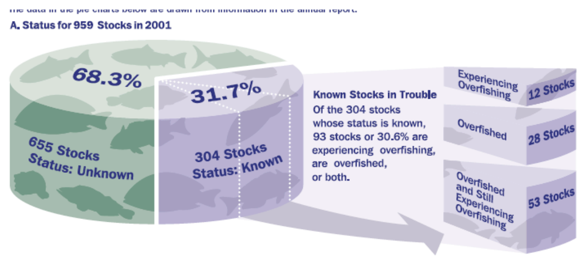



**Figure 5: Almost one-third of measured stocks are overfished, subject to overfishing or both.** (Pew Oceans Commission, 2003)

Bycatch is another marine ecosystem impact of fishing that occurs when non-targeted species are caught in addition to targeted fish. Species that are mistakenly caught can sometimes be sold but are usually thrown overboard either dead or after suffering severe trauma. Bycatch is a severe problem for marine mammals, sea turtles, sharks and seabirds such as albatross (Campbell 2002).

**Figure 6: Sea turtle caught on a longline** (www.oceana.org)

## Invasive Species

Invasive species impact both ocean and freshwater ecosystems. Increased levels of trade over the past several decades have increased the numbers of exotic species reaching US shores (Maki & Galatowitsch 2004). Coastal waters experience a heightened susceptibility to invasion and represent one of the most invaded systems on the planet (Everett 2000).

Invasive species are able to flourish by not having a natural predator within the region into which they are introduced. As a result, predation pressure is removed from the invasive species, while native species are still being preyed upon (Wasson, *et al.* 2005). This enhances invasive species' ability to out-compete native species, which usually results in the decreased abundance of native species. Furthermore, studies have shown that invasive species can evade predation by propagating in areas that have temperature and salinity gradients unfavorable to native predators (Xipling & Purcell 2005).

One prominent freshwater invasive exotic species is the zebra mussel. Beginning in the mid-1980's, zebra mussels were inadvertently introduced into the Great Lakes via ballast water discharge (Leach 1993). They have now spread and established extensive populations in the rivers and freshwater ecosystems of twenty U.S. states and two Canadian provinces (Leach 2003). Due to the very large filtering capacity of these mussels, they are responsible for the reduction of chlorophyll levels and phytoplankton population densities in these ecosystems. Studies have shown that zebra mussels can also play a negative role by changing the dynamics of nutrient and contaminant cycling and the manner in which PCBs bio-accumulate in the marine food web (U.S. EPA 1999).

**Figure 7: Zebra Mussels** (http://biology.usgs.gov)

Other prominent invasive species include *Moerisia lyonsi,* a hydrozoan native to the Black Sea and Middle East that has established itself in low salinity areas of the Chesapeake Bay, and species of weeds and grasses such as *Arundo donax* that exacerbate coastal erosion by blocking the natural flow of sediments (Wagner, *et al*. 1990). *M. lyonsi* was able to survive in the Chesapeake for two reasons: populations do not appear to be limited by temperature and salinity conditions, and there are very few predators who inhabit the low salinity areas favored by *M. lyonsi*, which enabled populations to grow quickly (Xiping, *et al*. 2005).

The continued introduction of exotic species into new environments alters ecosystem structure by creating new inter-species dynamics and shifting crucial ecological relationships (Robinson 1999).

# Ecosystem-Based Management

To mitigate the environmental problems listed in the previous section, complex geological, chemical, biological, atmospheric and ecological relationships must be understood as an integrated whole (Robinson, *et al.* 1999; Pew Oceans Commission 2003; U.S. Commission on Ocean Policy 2004). H.R. 21 proposes the utilization of ecosystem-based management to address the complex and interrelated nature of marine environments. Ecosystem-based management aims to govern based on ecological boundaries rather than political boundaries in consideration of overall ecological integrity and ecosystem health. It is a holistic approach in which the primary objective is the preservation and maintenance of ecosystem services (Robinson, *et al.* 1999; O'Boyle & Jamieson 2006). Ecosystem services are defined here in the broadest terms, referring not only to direct human benefits provided by healthy oceans, such as transport or fisheries, but also indirect and less tangible benefits such as nutrient cycling and climate regulation.

In addition, by examining ocean threats from a wide scientific perspective, cumulative and synergistic impacts are recognized in this system of management (Hardman-Mountford 2005). As such, it requires a creative blend of scientific ingenuity and technical innovation to feasibly develop and sustain necessary information, monitoring, and feedback mechanisms (Pahl-Wostl 2007; Robinson 1999). To respond to this demand for innovation and integration, ecosystem-based management must be dynamic and incorporate adaptive management techniques that allow for the understanding of natural relationships to evolve over time (Guerry 2005). In areas that lack sufficient scientific data and where projected threats for the future are substantial, H.R. 21 mandates proactive conservation consistent with the precautionary principle.

## Interconnection of Problems in Marine Ecosystems

Most environmental processes are interrelated; therefore, marine environmental problems rarely occur in isolation (Semiletov 2007). The complex relationships between local marine ecosystems, basin-wide circulation patterns and global nutrient cycling, for instance, represent the breadth of oceanic linkages (Evans & Fasham 1993; Collins 2007; Walter 2007). While scientific research has indicated that certain species play key roles in ecosystem structure, there has been little exploration of the consequences bought about by their removal (Hoffman & Powell 1998). For example, in coral reef ecosystems the water is often nutrient-poor, and the system depends on benthic organisms to turn over sediment and re-suspend nutrients in the water column. Alternatively, kelp forests receive the majority of their nutrients via currents and rely less on re-suspension due to benthic organisms. It is clear that the removal of benthic organisms in each system would produce cascades of different effects.

Removal is only one way humans interfere with ecosystem structure and function; additions to the system, including surplus nutrients, can also cause multiplicative effects (Munks, *et al.* 2007). For instance, seagrasses have complex root systems that circulate oxygen back into the sediment and maintain healthy soil chemistry (Delgado, *et al.* 1999). Increased nutrient loading can change soil chemistry to such an extent that seagrass roots can no longer perform this important ecosystem service (Duarte 2002). Nutrient increases also result in algal blooms that cloud the water, blocking out the sunlight seagrasses need to flourish (Delgado, *et al.* 1999). Eventually, the seagrasses die from prolonged exposure to low oxygen concentrations in sediment and diminished sunlight. Loss of seagrasses reduces sediment accumulation rates, resulting in increased coastal erosion and instability (Duarte 2002).

Other examples of the interconnection of ecosystem threats include global climate change causing habitat damage, such as mangrove submersion via sea level rise, or booming coastal development causing increased pollution and overfishing (Ernst 2003; Crowder 2006). A recent and dramatic demonstration of ocean threat convergence was seen in the tragedy of Hurricane Katrina. In New Orleans, coastal development below sea level and wetland loss combined with increased hurricane severity, due to global warming, to produce catastrophic results.

## Integrating Scientific Disciplines

Ocean resource management must be global in scale and interdisciplinary in nature. For this reason, a systems approach to understanding our oceans has been proposed (Robinson, 2004). This involves using advanced modeling techniques to synthesize many distinct disciplines for a more complete understanding of ecosystem processes (Nihoul 1998). In application, the models allow for understanding and predictions of interrelated yet distinct ecosystem components. A nexus of interdisciplinary scientific research, technological innovation and information synthesis will support the science and implementation of ecosystem-based management (Pahl-Wostl 2007; Lautenbacher 2007).

The great complexity of ecosystem interactions transcends traditional scientific specialization and warrants interdisciplinary efforts of unprecedented magnitude. Table 1 (below) shows a representative sampling of disciplines required to effectively integrate scientific understanding in applying ecosystem-based approaches to management.

| Physical Science | Biological Science | Chemistry | Applied Science | "Non-Science" |
|---|---|---|---|---|
| Oceanography | General Biology | Physical | Meteorology | Economics |
| Climatology | Botany | Organic | Marine Engineering | Social Science |
| Limnology | Molecular Biology | Analytical | Electrical Engineering | Political Science |
| Physics | Marine Biology | Marine | Environ. Engineering | Law |
| Earth Science | Fisheries Biology | Environmental | Structural Engineering | Mathematics |
| Marine Geology | Wildlife Biology | Biochemistry | Aerospace Engineering | Statistics |
| Hydrology | Genetics | | Water Quality | Historians |
| Geology | Microbiology | | Engineering | |
| Cosmology | Ecology | | Forestry | |
| Astronomy | | | Environ. Science | |
| | | | Environmental Toxicology | |
| | | | Computer Science | |

**Table 1: A representative sample of disciplines required to support effective marine ecosystem-based management.**

For instance, a marine biologist investigating fish ecology might need computer-based, statistical models to interpret data, understand population dynamics or make predictions based on environmental variables. This same marine biologist might desire the assistance of social scientists, historians or economists to understand human relationships to the ecosystem being studied. Although the integration of disciplines is allowing scientists to acquire more data concerning the complexity of marine ecosystems, it is important to note that our understanding remains incomplete (Robinson, *et al*. 1999).

## Science of the Precautionary Principle

The study of marine ecosystems, like much contemporary ecology, is characterized by high uncertainty due to ecosystem complexity, a lack of complete data and the stochastic processes at work in natural systems (Wostl 2006; NOAA 2007). Accounting for uncertainty is an essential aspect of managing the sustainability of marine environments (Hardman-Mountford, *et al.* 2005; Gosson & Luef 2007). Traditionally, conflicting scientific information from different disciplines or researchers has hindered public decision-making (Ellefson 2000). To enable action in the face of uncertainty, H.R. 21 incorporates the precautionary principle and mandates its application to ensure that a "lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation" when "serious threats of serious or irreversible damages" are imminent (Tallacchini 2005). This explicit acknowledgement of scientific uncertainty can greatly aid ecosystem-based decision-making by providing a rationale for exercising precaution. The implication for policymakers is that they must exercise discrimination and carefully examine the science that informs their decisions to enable the proper use of precautionary action (Tallacchini 2005). It is for this reason that successful ecosystem-based management demands an unprecedented amount of scientific synthesis and analysis informed by cutting-edge science (Crowder 2006; O'Boyle & Jamieson 2006).

### *Case Study: the Northwest Hawaiian Islands National Monument*

Affected regional stakeholders rarely meet implementation of the precautionary principle with enthusiasm. In the Northwest Hawaiian Islands, local fishers were accused of employing fishing practices harmful to many species in this extremely biodiverse region, which is home to over 7,000 species (Hawaiian Island Monument 2007). As a result, new federal legislation protected a considerable portion of 140,000 square miles of the surrounding ocean as a national monument. This legislation limits access to the site for fishing and marine services, even though managers pointed to the fact that fisheries in the area have been functioning at a sustainable level for hundreds of years. This is evidenced by the healthy fish stocks present in the ecosystem (Hawaiian Island Monument 2007). The application of the precautionary principle in establishing the Northwest Hawaiian Islands National Monument begs the question: how much precaution is necessary to protect an ecosystem? We also must determine at what point precautionary intervention has a negative overall impact with respect to human and non-human uses. While this particular intervention may increase the health and vitality of the local ecosystem, there is a clear disconnect between scientific understanding of this potential increase and public understanding of the reasons why sustainable fishing activities have been banned. Fishers in the Northwest Hawaiian Islands have been exposed to economic uncertainty by the establishment of the national monument, and reactions to the conservation initiatives there have been largely hostile. H.R. 21 would implement coordinated local and national governance in the region that would stimulate a more efficient flow of scientific information and promote communication with local stakeholders to increase public understanding of the scientific issues. This example illustrates the importance of unifying science with economic and social considerations when developing and implementing marine policy. Although such far-reaching environmental protection will likely safeguard the ecosystem from future overfishing, a more holistic assessment process, such as that envisioned by an ecosystem-based approach, is desirable in the determination of future courses of policy action in the Northwest Hawaiian Islands.

# H.R. 21: The Ocean Conservation, Education and National Strategy for the 21st Century Act

Consistent with the precautionary principle, H.R. 21 prohibits the Federal government from taking any action that would harm or impede the restoration of marine ecosystem health. The three main goals of the legislation are to establish a comprehensive National Oceans Policy that will secure the full range of benefits (ecological, economic, educational, social, cultural, nutritional, and recreational) provided by healthy marine ecosystems, provide a statutory basis for the National Oceanic and Atmospheric Administration and promote ecosystem-based approaches to ocean resource management.

## Title I: National Oceans Policy

According to both the U.S. Commission on Ocean Policy and the Pew Oceans Commission, the designation of a National Oceans Policy is essential to the future maintenance and strategic use of the United States' living and non-living ocean and coastal resources. Federal ocean management is currently fragmented among a number of cabinet departments and agencies that lack the coordination and communication channels necessary for unified decision-making. The establishment of a National Oceans Policy attempts to solve this problem by erecting a conceptual framework within which all marine resource management decisions can be made. The National Oceans Policy presented by H.R. 21 is shown below.

> It is the continuing policy of the United States to protect, maintain, and restore the health of marine ecosystems in order to fulfill the ecological, economic, educational, social, cultural, nutritional, recreational and other requirements of current and future generations of Americans.

The policy's focus on marine ecosystem health over many human generations is evidence of the growing national aspiration to manage natural resources in a holistic manner that ensures continued ecosystem service delivery. As the provider of such essential ecosystem services as climate regulation and fishery stocks, the ocean represents a high-value asset that must be approached in a coordinated and strategic manner by the Federal government.

*Considerations*

Enacting a National Oceans Policy will explicitly promote ecosystem-based management by organizing all federal ocean activities around the concept of sustainable resource use. To implement this comprehensive solution, ocean agencies like the National Oceanic and Atmospheric Administration (NOAA), U.S. Navy, Minerals Management Service and Environmental Protection Agency will face restructuring challenges likely to require significant administrative costs. Lastly, varying public or judicial interpretations of the National Oceans Policy could create conflict during the initial stages of its implementation.

## Title II: National Oceanic and Atmospheric Administration Organic Act

NOAA is currently authorized under Executive Order 11564, signed by President Nixon on October 5, 1970. As authorized under Title II, NOAA's mission will be to oversee U.S. coastal, ocean and Great Lakes waters; understand and predict changes in the oceans and atmosphere and how those changes affect land; sustainably manage ocean resources; protect, maintain and restore ecosystem health; and educate the public. To accomplish its mission, NOAA will conduct basic and applied research on ocean, coastal and climate-change issues; apply ecosystem-based approaches to management; collect, store and share atmospheric and oceanic data; coordinate the oceanic and meteorological services of other agencies; issue oceanic and atmospheric forecasts; and administer public outreach and education programs to increase scientific and environmental literacy about the ocean, coastal waters and other issues.

In addition to defining NOAA's mission and activities, Title II codifies NOAA's leadership structure by defining the number and nature of agency leadership positions. Specifically, the bill describes the function, pay grade and authorities of NOAA leadership personnel. It provides for an Under Secretary of Commerce for Oceans and Atmosphere as the NOAA Administrator, an Assistant Secretary of Commerce for Oceans and Atmosphere as the NOAA Deputy Administrator and a Deputy Under Secretary of Commerce for Oceans and Atmosphere as NOAA's Chief Operating Officer. Furthermore, the bill authorizes three Deputy Assistant Secretaries of Commerce for Oceans and Atmosphere whose functions must be consistent with one of NOAA's three main mission objectives (assessment, prediction and operations; management; and research and education). Title II also authorizes a General Counsel and five NOAA Assistant Administrators to oversee NOAA's line offices.

*Considerations*
Codifying the mission, organization, duties and responsibilities of NOAA in law will create a sense of agency continuity and stability and prevent the Executive branch from making substantial changes to the agency without Congressional consent. The largest financial outlay required is associated with reorganizing agency management and administrative offices to comply with the new agency organizational structure specified in H.R. 21.

**Title III: National Ocean Leadership and Coordination**

National ocean leadership and coordination structures as set forth in this title include a National Oceans Advisor, a Committee on Ocean Policy, and a Council of Advisors on Oceans Policy. The National Oceans Advisor in the Executive Office of the President will give advice on all federal activities relating to U.S. ocean waters and marine ecosystem health, the implementation of H.R. 21 and the activities of the Committee on Ocean Policy. The National Oceans Advisor shall serve as Chair of the Committee on Ocean Policy to coordinate Federal agency actions related to U.S. ocean waters and marine ecosystem health.

H.R. 21 codifies the existing Committee on Ocean Policy, which is comprised of Secretaries of federal departments and heads of relevant independent agencies, to facilitate interagency coordination and resolve interagency disputes regarding implementation of marine ecosystem-based management. The Committee on Ocean Policy is charged with submitting to Congress a plan for the coordinated management of ocean resources and a schedule for implementation of H.R. 21's initiatives for all U.S. waters under federal jurisdiction.

The Council of Advisors on Oceans Policy will be comprised of non-Federal advisors to the Committee on Ocean Policy. The council will include representatives from states, tribes and local governments; the marine science and education communities; the fisheries, agriculture and timber industries; non-fishing marine industries; and non-governmental and watershed organizations. This council represents the integration of science and policymaking that H.R. 21 aims to establish nationwide.

*Considerations*
The establishment of the National Oceans Advisor, Council of Advisors on Oceans Policy and the codification of the Committee on Ocean Policy will contribute to the increased coordination and integration of policy initiatives between ocean agencies at the national level. This improved communication is essential in order for the U.S. to effectively implement ecosystem-based management

strategies. Furthermore, the new Advisor position will bring ocean issues directly to the ear of the President, elevating the importance of addressing ocean threats to the highest level of government. Finally, the Title III enables further mechanisms for scientific analysis and synthesis to reach the Committee on Ocean Policy through the Council of Advisors on Oceans Policy. The members of this Council and the existing Committee on Ocean Policy are explicitly outlined and will help accelerate the process of moving towards national implementation of ecosystem-based management.

Some potential limitations of this National Governance title include the fact that reorganization, particularly at such a high level of government, will require significant human and financial resources. It is unknown how efficiently the integration of the Advisor and Council will be integrated into current administrative structures. The addition of the Council as an advisory body for the existing Committee on Ocean Policy may create territorial disputes, since the Committee will have been working on oceans issues for some time and may therefore resist advice provided by the newly appointed Council.

## Title IV: Regional Cooperation and Ecosystem Planning

Regional ocean governance under Title IV is to be carried out through Regional Ocean Partnerships, entities formed to integrate management beyond traditional jurisdictions using regional ecosystem based boundaries. The Partnerships are regarded as the chief mechanisms to be used in reforming ocean and marine resource management throughout the nation and will work to solve pressing ocean issues and develop regional-level ocean management strategies. Partnerships will plan strategically by cooperating and collaborating with multiple government agencies and other stakeholders to consistently monitor and assess progress. The ocean regions for which Partnerships will be formed are identified as the North Pacific, Pacific, West Pacific, Gulf of Mexico, Caribbean, Southeast Atlantic, Northeast Atlantic, Mid-Atlantic and Great Lakes. The regions may develop sub-regional strategic plans, if appropriate. Similar to the Council of Advisors on Oceans Policy, the Partnerships are fora for multiple stakeholder involvement including federal, state and local governments; regional fishery management councils; Indian tribes; and foreign governments or international agencies, where appropriate. The Regional Ocean Strategic Plans produced by each Partnership shall include ecosystem assessments, designation of ocean ecosystem health indicators, short- and long-term ecosystem goals and ecosystem-based approaches to solving priority problems. The NOAA Administrator is authorized to dispense $25 million per year from 2009 to 2013 for the implementation of Regional Ocean Strategic Plans.

Pursuant to Title IV, the National Research Council of the National Academy of Sciences will carry out a study of existing regional- and ecosystem-based approaches to ocean and coastal management, and Ocean Ecosystem Resource Information Systems will be created to integrate new data management tools with information gathered by existing ocean monitoring systems. Each Partnership will maintain an Ocean Ecosystem Resource Information System, and additional databases will be created for the Long Island Sound, Gulf of Maine, San Francisco Bay and Delta, Chesapeake Bay, Mississippi River Delta and Puget Sound.

### *Considerations*

The regional governance solutions in H.R. 21 work towards achieving the successful implementation of ecosystem-based management in many ways. The Partnerships are facilitators for cooperation and collaboration at multiple levels of government, and mandatory involvement in them, as compared to the voluntary efforts authorized under the existing Coastal Zone Management Act, should lead to more concrete policy action. This management across agency boundaries puts a focus on ecosystems instead of the agencies' individual areas of jurisdiction. The scientific background provided by the National Research Council will guide creation of the Regional Ocean Strategic Plans and offer a framework that can be used to implement adaptive management. There will be equal representation of federal and non-federal entities in the Regional Ocean Partnerships, and additional non-governmental stakeholders will be involved through Citizen Advisory Committees. This cooperative arrangement should lead to a broad constituency supporting the development and implementation of the Regional Ocean Strategic Plans. Lastly, funding for Partnerships and Regional Ocean Strategic Plans will be made available under Title V (below).

Regional Ocean Partnerships are innovative management tools but will need to be sensitive to possible overlap with existing regional ocean resource management efforts. The National Research Council study will not address this difficulty despite its focus on existing regional ecosystem-based management plans. There is a long time horizon for some final products; for example, the Ocean Ecosystem Resource Information System for the Great Lakes is not due to be completed until 10 years after the passage of H.R. 21. Finally, the human and financial resource requirements of implementing this title's provisions are substantial, and it is unknown how much time it will take to fully integrate the complex solutions proposed.

## Title V: Ocean and Great Lakes Conservation Trust Fund

A trust fund is established under H.R. 21 to provide monies for the Regional Ocean Partnerships and other purposes consistent with the National Oceans Policy. The Ocean and Great Lakes Conservation Trust Fund shall draw resources from general revenue, sales of a healthy ocean stamp, amounts distributed but not disbursed in the previous year and interest. The NOAA Administrator shall allocate the Fund disbursements to coastal states based on their length of coastline and population.

### *Considerations*

The Fund is an essential component of implementing ecosystem-based management since it provides a long-term funding source for Regional Ocean Partnerships and implementation of Regional Ocean Strategic Plans. A significant amount of money is authorized to this Fund from the U.S. Treasury; and additional revenue will be generated by interest and sales of a Healthy Oceans Stamp. This stamp will provide a valuable means of increasing public awareness about ocean issues and facilitating public involvement. The funding allocation mechanism set forth in Title V creates another way for national and regional governments to be further coordinated, because the NOAA Administrator is in charge of fund disbursements to coastal states. This advanced communication and integration will help bring the U.S. closer to successfully implementing ecosystem-based management.

There are some limitations on disbursements from the Fund, however. First, the allocation ratios are based on proportions of shoreline miles and coastal populations. The fact that states with larger coastal populations will receive greater funding creates a perverse incentive for even greater coastal development and less preservation. Second, the funding is somewhat inflexible, since it can only be directed towards Regional Ocean Partnership implementation of Regional Ocean Strategic Plans. Finally, any money appropriated to the Fund will be taken from another piece of the zero-sum federal budget, i.e. establishing this Fund will likely reduce funding for other federal ocean programs.

The legislative solutions proposed by H.R. 21 are based on the scientifically supported foundation of ecosystem-based management. Although uncertainty remains as to the best implementation methods for ecosystem-based approaches, H.R. 21 provides a flexible basis from which adaptive management techniques can operate. The bill also coordinates federal activities concerning the oceans and focuses marine resource management on the increasingly important, and scientifically valid, concept of sustainable resource use.

# Is the Ocean Environment Healthy? Measuring Success in H.R. 21

The Ocean Conservation, Education and National Strategy for the 21st Century Act specifically requires the use of ecosystem-based management in governing U.S. ocean and Great Lakes resources. In order to gauge the success of H.R. 21, we must evaluate how well EBM implementation enhances, restores or otherwise improves the health of marine ecosystems; enhanced or restored ocean ecosystem health is the primary indicator of success for H.R. 21.

## Indicators of Success

Environmental indicators "relate the condition or health of a natural resource" (BTNEP 2002). H.R. 21 does not contain specific indicators for success because these indicators are best determined on local scales. The Regional Ocean Partnerships authorized in Title IV of H.R. 21 are responsible for outlining specific regional success indicators. Below are some examples of questions that regional managers might ask when determining appropriate indicators for specific ecosystems.

- How is the ecosystem's boundary defined?
- What marine species are native to the ecosystem? What keystone or endangered species are present? How is biodiversity measured in the ecosystem?
- What are the critical indicators of water quality? (e.g. dissolved oxygen, salinity, temperature, nutrients, pathogens, toxics)
- What is the human impact on the ecosystem? (e.g. tourism, fishing, coastal communities)
- What ecosystem services does the ecosystem provide? (e.g. provisioning, supporting, regulating, cultural)
- What is public perception of the ecosystem?

## Measurement Difficulties

It is difficult to determine at what point an ocean ecosystem is considered healthy (Murawski 2007). This is complicated by the fact that our perception of ecosystem health changes over time, making it difficult to assess a baseline value to which we can compare current values (Shifting Baselines 2007). This shifting baselines phenomenon is defined by the gradual lowering of our standards. Acknowledging the difficulties of establishing a baseline before measurement lends credibility and flexibility when creating regional ecosystem plans (Peat 2007).

Costs are likely to be high when monitoring large ecosystems (O'Boyle & Jamieson 2006). Collecting long-term data can pose further difficulties for establishing reliable measures. Furthermore, because ocean systems do not generally respond immediately to changes, measures of success will have to take into account a fairly broad timeline (Robinson, *et al.* 1999; Crowder 2006; Beckage 2007). The final difficulty to address here is economic valuation of ecosystem services. In order to maintain a balance between human and ecosystem needs, quantifying ecosystem services will need to be practiced.

Working to address these challenges, various regions will need to consider indicators that are specific to their regions. Indicators appropriate for use in one region may not necessarily be of use in other regions. The Ocean Ecosystem Resource Information Systems outlined in H.R. 21 will provide convenient mechanisms for reviewing current and past data to choose appropriate indicators and monitor ecosystem health over long timescales. Even considering the use of advanced data aggregation systems, scientists will still argue over the best way to characterize the health of marine ecosystems.

### *Biodiversity*

Biodiversity is understood at the genetic, species, phylogenetic and ecosystem levels (Vecchione & Collette 1996). Although scientists agree that all these types of biodiversity exist, there is debate over their relative significance as indicators of overall ecosystem health. For example, some researchers prefer to use keystone species as indicators of ecological integrity and therefore only monitor abundance of one or two animals in order to characterize ecosystem health. Others desire a more rigorous evaluation of ecosystem dynamics and analyze overall species richness or species abundance at multiple trophic levels. This can lead to situations where the same ecosystem is characterized in very different ways depending on the way that biodiversity is defined and then measured. Because of the close association between different levels of biodiversity, it is critical that more resources are devoted to understanding these relationships in the marine environment (Robinson *et al*. 1999). Previous work on defining biodiversity at an ecosystem level has focused on tropical rainforests, but definitions of biodiversity taken from terrestrial systems fail to acknowledge the unique structure and function of ocean ecosystems (Pew Ocean Commission 2003; U.S. Commission on Ocean Policy 2004). The controversy over oceanic biodiversity definition and measurement is largely due to a lack of data and the high uncertainty associated with marine ecosystem complexity. Pelagic and deep-sea habitats are particularly difficult to characterize, and there is debate over whether a complete taxonomic survey of the marine environment is even feasible given current research funding (Grassle 1991; Vecchione & Collette 1996; Cotterill 1995).

### *Endangered Species*

A controversy similar to that of measuring and defining biodiversity studies involves the classification of endangered species. Due to the unique life history characteristics of marine species and the complex environment in which they live, it is difficult to assess levels of endangerment with scientific certainty (Poweles, *et al*. 2000). As a result, scientists employed by governments and conservation organizations use diverse methods to determine the status of endangered and threatened species. According to NOAA's National Marine Fisheries Service, there are approximately 1,300 species in U.S. waters classified as endangered, but the agency's accounting method is relatively controversial because it counts spatially discrete populations (distinct population segments) as individual species (NFMS Inventory 2007). In addition, the scientific evidence used by the IUCN (World Conservation Union) to classify endangered species is quite different from that used by NOAA. This has led to divergent classification of both the beluga whale and Atlantic sturgeon, which stymies protection measures. Without the coordinated determination of endangered species' status, protection measures in one region may be completely ineffective due to a lack of regulation somewhere else.

## Conclusion

Although the United States' ocean territory covers an area larger than its continental landmass, marine resources once considered inexhaustible are now clearly experiencing marked declines. A strong body of scientific research has indicated that direct and indirect threats are acting synergistically to exacerbate these declines. In the absence of new strategies for understanding and managing marine ecosystems, current marine environmental problems are expected to broaden and continue affecting the delivery of essential ecosystem services.

H.R. 21 outlines ecosystem-based management as the primary strategy to address declining marine ecosystem health. This innovative approach uses interdisciplinary science to inform policy through adaptive management processes at multiple levels of government. Not only will marine ecosystem-based management re-focus ocean policy to address ecosystem-scale threats as opposed to narrowly defined sectoral challenges, but it will also provide a way to implement proactive management solutions through application of the precautionary principle. In addition to promoting ecosystem-based management by stating a National Oceans Policy, H.R. 21 propones the integration of science and management institutions by authorizing a stronger National Oceanic and Atmospheric Administration and the creation of novel regionally-based ocean management institutions.

In order to ensure the current and future benefits of stable fisheries, clean beaches, healthy seafood, abundant wildlife and vibrant coastal communities, a significant reorganization of marine science and management institutions is necessary. H.R. 21 is a vehicle for ecosystem-based management by which this sea change can take place.

# Appendix: Ecosystem-Based Management in Action at Elkhorn Slough

## Introduction

After exploring the general scientific foundations of ecosystem-based management (EBM), technology involved in its successful implementation and potential environmental impacts, it is useful to examine an actual example of how this might look in the real world. Though the national, comprehensive and integrated approach to managing marine resources envisioned by the authors of H.R. 21 is not yet in place, smaller scale examples of EBM in action are beginning to emerge in the United States. One such example exists at Elkhorn Slough.

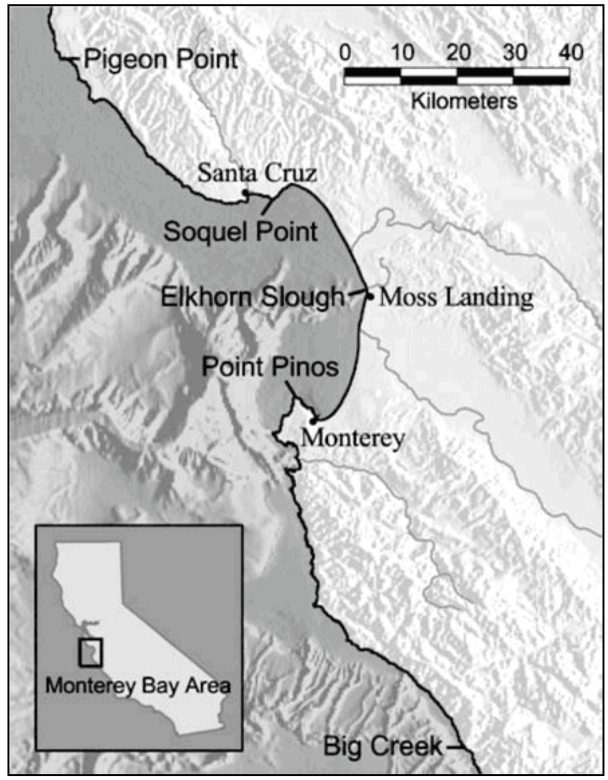



**Figure 1.** Map showing geographic location of Elkhorn Slough, Moss Landing, CA. Wasson et al., 2005.

## Background

Resulting from an amendment to the Coastal Zone Management Act of 1972, there are currently 27 National Estuarine Research Reserves in the country overseen by NOAA. In 1979, the California State Department of Fish and Game and NOAA formed a partnership under this program, and the Elkhorn Slough Reserve was created. In 1983, the managing board also established through the federal-state partnership created the Elkhorn Bay Foundation to help manage Elkhorn Slough. The Elkhorn Slough has been managed with an ecosystem-based approach under mandate of the Elkhorn Slough National Estuarine Research Reserve Draft Management Plan 2007-2011 (ESNRR) and the Elkhorn Slough Foundation Strategic Initiative for 2006-2010, since 1999. There are specific problems that have been prioritized by these plans based on historical research that has been conducted in the area. These include understanding of continued degradation of certain habitats within the reserve, such as salt marsh plant communities, overcoming information gaps which still exist in the understanding of local community interactions and their relationships with migratory species that frequent the area, and understanding of the effects of continued anthropogenic pressures on the relatively small reserve. The decision by the Elkhorn Slough Foundation and cooperating agencies to use an ecosystem-based approach came from a growing scientific consensus that ecosystem such an approach is necessary to truly accomplish their stated goals. They realized that the traditional approach was not getting the answers they desired; that some species and habitats within the Slough were still deteriorating, and they still could not definitively explain why. Further, they have realized from the existing knowledge base that the reserve cannot continue to be treated separately from the surrounding regional influences that affect it, and must be managed in this greater context to accomplish the underlying goal of its ecological preservation.

## Geographic Description

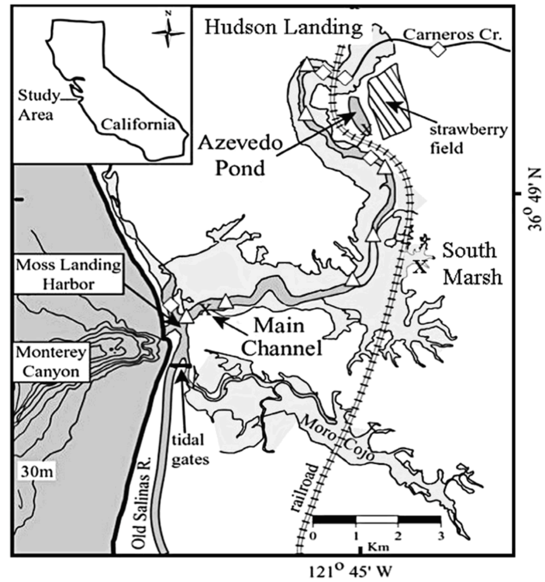



**Figure A:** Elkhorn Slough (Caffrey 2007).

Elkhorn Slough is located in Monterey, California, USA along the Pacific Coast approximately 100 miles south of San Francisco, situated in the center of the Monterey Bay Coastline. The area is surrounded by farms and low lying hills.

## General Description of Habitat Types

Elkhorn Slough is a small estuary (area 3.25 km$^2$) consistent of a variety of habitats. Some of the habitats near the mouth of the slough are impacted by a semi-diurnal tidal influx, however a railbed running through the slough separates sections from tidal flow (Figure A) (Caffrey 2007).

The hydrology and railbed form saltwater and brackish marshes, salt and brackish open water and mudflats within the slough. There are also freshwater wetlands and riparian forests that are surrounded by coastal dune scrub, live oak forests and maritime chaparral. Many of the fauna and flora typical of such habitats are listed as federally threatened, endangered or species of concern (Southern sea otter, California brackishwater snail, Tidewater goby, California brown pelican, California black rail, California clapper rail, Western snowy plover, California least tern, California red-legged frog, California tiger salamander, Santa Cruz long-toed salamander, Southwestern pond turtle, Monterey spineflower, Coast wallflower, sand gilia, Loggerhead shrike, Gairdner's yampah, Pajaro Manzanita, Monterey ceonethus, Eastwood's goldenbush and Yadon's piperia) or listed as threatened endangered or species of concern by the State of California (Northern harrier, Merlin, Black skimmer, Cooper's Hawk and Black legless lizard).

## Main Threats

Research has shown that the most prominent threats to Elkhorn Slough are:

- Tidal Erosion
- Sedimentation
- Pollution
- Invasive Species
- Moss Landing Power Plant

## Science of Ecosystem-based Management in Application

*Tidal Erosion*

The opening of the river mouth in 1947 by the Army Corps of Engineers has increased tidal volume causing more sediment to be washed away from the slough. Long-term studies (involving oceanography, limnology, hydrology, and geology) have shown that continuous alteration of Elkhorn Slough habitats by increases in tidal volume have resulted in tidal erosion of channels and loss of salt marsh (Wasson 2001). The long-term studies (involving limnology, ecology, and hydrology applied in an environmental science context) conducted by Wasson, *et al*. tracked changes due to tidal erosion by conducting a number of individual studies measuring, main channel bathymetry, bank erosion, tidal creek width, and salt marsh deterioration, in order to determine the ecosystem-wide affects that tidal erosion is causing. Other studies (involving a similar blend of disciplines, but also including more marine and biological sciences) have shown how tidal erosion reduces the diversity of invertebrates, fish and shorebirds. Presently, the dominant invertebrate species are smaller and more active at the surface compared to the 1970's. It is suspected (through ecological and biological synthesis) that larger native species cannot live in the highly mobile deposits that shift direction with strong tidal current but more importantly muddy bottom has retreated up the slough since the 1970's, reducing available habitat for native invertebrate species (Wasson 2001). Long-term tidal erosion monitoring studies offer explanations for observed changes in invertebrate abundance. This highlights the importance of conducting studies within the ecosystem in differing spatial and temporal scales, and how diversity in study design can better facilitate the understanding of a problem leading ultimately to its solution.

*Erosion of Upland Areas*
The Elkhorn Slough is situated below steep slopes covered with strawberry fields. For this reason, an understanding of the agricultural and soil sciences helps to lend understanding to interactions in the greater watershed influencing the health of Elkhorn Slough. Drainages between farms carry sediment to the slough during episodic, extreme winter storm events, creating large areas of deposited sediment, or sediment fans. This is understood through the application of geology, soils sciences, hydrology, and engineering in unison. Upland erosion rates have continuously increased since the 1930's from increased agricultural land use (Table A), subsequently increasing the number of sediment fans in the slough (Dickert 1985; Byrd 2006).

| Photointerpretation category[a] | 1931 Acreage | 1931 Percentage of watershed[b] | 1981 Acreage | 1981 Percentage of watershed | Percent change | Change as percentage of watershed |
|---|---|---|---|---|---|---|
| Brush | 5,765 | 12.8 | 3,395 | 7.6 | −41 | −5.3 |
| Pasture | 24,334 | 54.2 | 20,674 | 46.0 | −15 | −8.2 |
| Oak woodland | 4,838 | 10.76 | 6,280 | 13.9 | 30 | 3.2 |
| Row crops | 1,975 | 9.40 | 5,194 | 11.6 | 163 | 7.2 |
| Strawberries | 0 | 0 | 2,358 | 5.2 | — | 5.3 |
| Orchards | 2,556 | 5.69 | 182 | 0.4 | −93 | −5.3 |
| Tree plantations | 794 | 1.77 | 1,609 | 3.6 | 103 | 1.8 |
| Urban | 45 | 0.10 | 572 | 1.3 | 1,171 | 1.1 |
| Industrial | 123 | 0.27 | 300 | 0.7 | 144 | 0.39 |
| Commercial | 10 | 0.02 | 517 | 1.2 | 5,070 | 1.1 |

[a]The photointerpretative categories represent level I and II in the standard classification for land use and land cover data (Anderson 1976). More detailed categories were used for the wetland units and for the range of residential parcels shown in Table 2.
[b]The total area of the Watershed is 70.2 square miles.

**Table A: Land use changes in the Elkhorn Slough watershed from 1931-1981** (Dickert, *et al.* 1985).

Remote sensing and Geographic Information System (GIS) analyses of historical imagery (aerial photos), which also incorporated current and historical field monitory data, have established that increases in strawberry farms during the 1980's caused especially high sediment rates (geology, hydrology) and larger sediment fans. The vegetation assemblages of areas (understood through biology, botany and ecology) where sediment fans were formed have shifted from grassland and salt marsh plant communities to mainly arroyo willow (Byrd, 2006). The decline of important marsh grasses, such as pickleweed, will reduce their ability to trap sediments (understood using ecology, botany, hydrology, environmental science), which counter tidal erosion (Wasson, 2001). The correlation between specific land uses within the watershed and their effects on the slough will enable further studies to examine these relationships further. A library that contains historical aerial photos of Elkhorn Slough enables researchers to analyze environmental variables and how they have changed over time, even when gaps exist in more traditional field data. This practice can be enhanced further by improvements in the GIS and modeling software, and the application of newer aerial and satellite imaging technology over time. Such information then also becomes available for use in future studies to gain better understanding of relationships between other components of the ecosystem and track overall ecosystem health.

*Pollution*

Sources of pollution in Elkhorn Slough from local industries, harbor-related activities, power generation, municipal waste treatment and agricultural runoff have been examined by a number of researchers (biologists, hydrologists, environmental scientists, toxicologists, chemists, engineers) and pesticides, heavy metals, nutrients and hydrocarbon have been shown to be present throughout the estuary (Rice, 1993). The disparate and varied sources of contamination affecting the ecosystem, and the regional to global transport processes (understood through oceanography, environmental science, marine chemistry, climatology, meteorology, physics, and atmospheric chemistry) associated with their deposition highlight the complexity inherent in ecosystem-based management. T  hese complexities have been dealt with by the implementation of a nationwide database (integrating applied computer sciences and engineering) that coordinates and standardizes water quality data collection. The National Estuarine Research Reserve System (NERRS) Centralized Data Management Office has been established to alleviate the variability of measuring and quantifying pollutants among the nation's estuaries so that researchers can easily gather water quality data by simply accessing the NERRS, Central Data Office database. Water quality data are available for 4 stations at 30 minute intervals for the following parameters: water temperature, specific conductivity, salinity, percent saturation, dissolved oxygen, depth, and turbidity. Nutrient data are collected from four locations at monthly intervals for the following parameters: orthophosphate, ammonium, nitrite, nitrate, and chlorophyll a (NERRE, CDO).

*Invasive Species*

In Elkhorn Slough invasive species are more diverse and abundant than on the open coast, and are some of the more conspicuous species in the slough, such as, the mudsnail *Batillaria*, the orange sponge *Hymeniaciadon*, the reef-building tube-worm *Ficopomatus* (Wasson, 2005). Understanding the spatial variability of invasive species is difficult because of high variability of environments and species, and requires biological specialists working in conjunction with applied scientists with technical savvy. Propagation and abundance of invasive species is governed by two mechanisms, one is their introduction rate and second, is their success rate of establishment (Levine, 1999). The early detection and quantification of invasive species enable Elkhorn Slough managers to initiate management efforts that reduce the propagation of invasive species. Integral to the success of this program is the assessment of invasive species by first, identifying, and second, quantifying their abundance. In 2001, managers of Elkhorn Slough and local researchers collaborated on a literature review and field investigation that identified 56 known exotic species of invertebrates at ES (Wasson, 2001). Compilation of all of the invasive species research has been put into the "Aquatic Invaders" booklet. This serves as an information source that can be given to researchers and visitors of ES, so they can identify species that are invasive and report back to managers (ES website, http://www.elkhornslough.org/research/biomonitor_invasion.htm). By thus educating and including volunteers, the efficiency of monitoring and data collection is greatly enhanced. The collection of invasive species data will allow ecosystem-scale comparisons between different estuaries and help researchers determine what habitat components are positively correlated with particular invasive species (Wasson, 2005).

*Moss Landing Power Plant*

The Moss Landing Power Plant (MLPP) is situated next to Elkhorn Slough. It is a large fossil-fuelled power plant and draws cooling water near the harbor entrance. Most of the cooling water is discharged to nearshore Monterey Bay, but a limited amount is discharged into the slough. The plan to expand the plant was passed in October 2000. There were baseline studies (involving the synthesis of chemistry, environmental science, biology, toxicology, and oceanography) of hydrocarbons that provided three years of data on the spatial, seasonal and annual variability of hydrocarbons and total organic carbon present in marine sediments at three sites: ES, Moss Landing Harbor and nearshore Monterey Bay, anticipating that the power plant would switch to fuel oil to run the plant (Rice, 1993). However, the plan to expand the plant did not include switching to fuel oil and it actually proposed the removal of two oil tanks on the site (CEC Order No. 00-1025-24). Baseline studies such as this are great tools for future assessments of pollutant levels. Nonetheless, the expansion of the plant is expected to increase invertebrate larvae, fish larvae, and haloplanktonic larvae mortality due to entrainment in the intake water. Monterey Bay National Marine Sanctuary requested further research be conducted on sea otter behavior relative to the power plant thermal plume, this request triggered by researcher observations during a study (involving a synthesis of various biological disciplines, chemistry, hydrology, and applied physics/engineering) on the ecosystem impacts of thermal discharge into Monterey Bay from the MLPP (Bentall, 2006). Therefore, a study (more focused, traditional marine biology, incorporating wildlife biology design principles) centered on sea otter behavioral changes was conducted to determine the ecosystem impacts of thermal discharge into Monterey Bay from the MLPP (Bentall, 2006). The plume structure provided habitat favorable to hard-bottom prey species within a soft-bottom (sandy) habitat, which caused slight shifts in the distribution of hard and soft-substrate prey foragers (Bentall, 2006).

The pioneering efforts underway at Elkhorn Slough indicate that it is feasible to undertake an ecosystem-based approach to management at the local level. This voluntary, local community and regionally based program is relatively young, and its application of EBM principles is voluntary and experimental. Elkhorn Slough, however, does afford a real-world example of EBM might look at the ground level with local partnerships driving scientific research promoted and sustained by various levels of government intervention. This example also demonstrates the beginnings of an integration of local research into a national framework (through the NERRS database) as would be the case under a nationally mandated EBM approach. Under the OCEANS Act, the National Academy of Sciences shall review this and other fledgling local EBM programs, to report recommendations for national implementation through the designated regions. Even now, it is through NOAA that this local program is overseen and even funded (through national grants).

The science exists at the ground level in Elkhorn Slough, but this serves as relatively isolated example in a special marine science-rich community, one amongst a handful of peer communities with similar programs. It is also worthy of mention that located in Moss Landing, right next to Elkhorn Slough, is the Monterey Bay Aquarium Research Institute (MBARI), a world-renown hub of cutting edge marine scientific research. The nature of Elkhorn Slough's context in a generally progressive, marine science-rich community sets it apart as an exception, not the national norm. Yet its connection to a greater framework of scientific understanding and regional management is understood to be its hope for continued ecological preservation amidst external environmental pressures.

Once linked to a greater, more comprehensive system of regional EBM, mandated by national statute, the science being conducted at Elkhorn Slough will be better served by enhanced integration into regional management addressing more comprehensively the external influences still resulting in habit loss and damage, even within the boundaries of such a formally established ecological reserve.

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