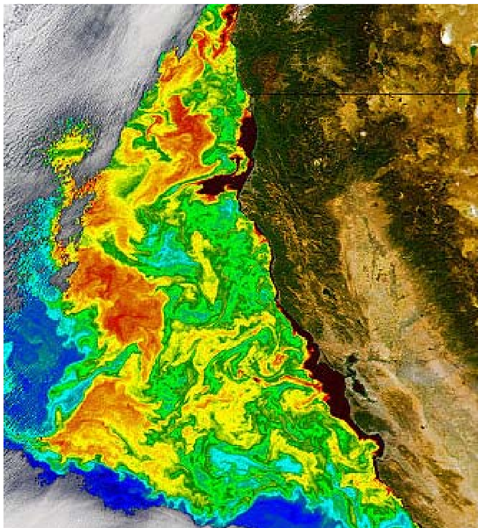
Ecosystem Science Capabilities Required to Support NOAA's Mission in the Year 2020

S. A. Murawski and G. C. Matlock (editors)





U.S. Department of Commerce
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Overview: Ecosystem Science Capabilities Required to Support NOAA's Mission in the Year 2020

The mission of the National Oceanic and Atmospheric Administration (NOAA) is to understand and predict changes in the Earth's environment and conserve and manage coastal and marine resources to meet our nation's economic, social and environmental needs (NOAA, 2004). In meeting its marine stewardship responsibilities, NOAA seeks to ensure the sustainable use of resources and balance competing uses of coastal and marine ecosystems, recognizing both their human and natural components (NOAA, 2004). Authorities for executing these responsibilities come from over 90 separate pieces of Federal legislation, each with unique requirements and responsibilities. Few of these laws explicitly mandate an ecosystem approach to management (EAM) or supporting science. However, resource managers, the science community, and increasingly, the public, are recognizing that significantly greater connectedness among the scientific disciplines is needed to support management and stewardship responsibilities (Browman and Stergiou, 2004; 2005). Neither NOAA nor any other science agency can meet the increasing demand for ecosystem science products addressing each of its mandates individually. Even if it was possible, doing so would not provide the integration necessary to solve the increasingly complex array of management issues. This focus on the integration of science and management responsibilities into an ecosystem view is one of the centerpieces of the U.S. Commission on Ocean Policy's report (USCOP, 2004), and the Administration's response to that report in the U.S. Ocean Action Plan (CEQ, 2004).

Acting through its Ecosystem Goal Team (http://.ecosystems.noaa.gov), NOAA has begun to better integrate the ecological research, observing, and forecasting components undertaken by its "line offices" (i.e., NOAA Fisheries, NOAA National Ocean Service, NOAA Research, NOAA Satellites and Information Service, and NOAA National Weather Service). NOAA's five-year research plan (NOAA, 2005b) emphasizes how the agency will better integrate its current activities, using the Goal Team structure as a framework. In contrast, its 20-year *vision* for science and research encompasses broad themes for the agency in meeting its ecosystem stewardship responsibilities, as "NOAA will provide the scientific underpinnings for an ecosystem approach to management of coastal and ocean resources, so that complex societal choices are informed by comprehensive and reliable scientific information" (NOAA, 2005c, p. 6).

The agency needs to know what types of science, skills, and products will be necessary to inform emerging ecosystem management challenges if it is to move from simply better integrating its current activities to meeting its strategic 20-year research vision. This document was developed to identify a strategic portfolio of research, monitoring, data integration, and decision support capabilities underpinning more holistic approaches to NOAA's stewardship and management of coastal and ocean resources.

For purposes of this discussion concerning the scientific support necessary for an EAM, NOAA defines an EAM as:

An ecosystem[1] approach to management (EAM) is one that provides a comprehensive framework for living resource decision making. In contrast to individual species or single issue management, EAM considers a wider range of relevant ecological, environmental, and human factors bearing on societal choices regarding resource use.

EAM is differentiated from more narrowly focused management by a number of defining characteristics. EAM is: (1) geographically specified, (2) adaptive in its development over time as new information becomes available or as circumstances change, (3) takes into account ecosystem knowledge and uncertainties, (4) considers the fact that multiple simultaneous factors may influence the outcomes of management (particularly those external to the ecosystem), and (5) strives to balance diverse societal objectives that result from resource decision making and allocation. Additionally, because of its complexity and emphasis on stakeholder involvement, the process of implementing EAM needs to be (6) incremental and (7) collaborative (Murawski, 2006, pp. 1-2).

Ecosystem science supporting these characteristics must therefore be integrated on appropriate geographic scales relevant to the particular problem or issue being addressed. Some of these management foci will be local (e.g., a bay or estuary), while many others will scale upwards, including a global scale. All will require greater integration of ecosystem knowledge across traditional disciplines that can be easily reassembled at problem-relevant time and space scales. Given the wider diversity of stakeholder groups that will participate in ecosystem-level problem solving, new information products - including those that integrate and simultaneously interpret biological, social, and physical trends - must emerge. Finally, new management (governance) institutions will also likely evolve from those currently in existence or yet to be formed, and will require the use of natural and social science information to inform difficult, but necessary, coastal and ocean ecosystem management decisions. One of the vexing issues these institutions will face is the divergent value systems held by stakeholder groups (e.g., utilitarian versus preservation views of marine ecosystems). U.S. institutions and science support systems must be prepared to evaluate management from these diverse perspectives.

This set of "white papers" is not intended to be comprehensive with respect to all of the existing and emerging issues, but rather, focuses on a few priority topics that researchers and coastal managers have identified as multidisciplinary themes of EAM requiring NOAA's attention. These themes were assigned to NOAA senior scientists and research managers who are

[1] An ecosystem is a geographically specified system of organisms (including humans), the environment[2], and the processes that control its dynamics.

[2] The environment is the biological, chemical, physical, and social conditions that surround organisms. When appropriate, the term environment should be qualified as biological, chemical, and/or social.

at the forefront of these issues, and who represent a cross-section of the various line offices within the agency collaborating on them. This examination of pivotal issues will help NOAA, its partners, and its stakeholders more fully implement an EAM. It will contribute to how NOAA organizes itself and manages its activities, and how it will interact with other Federal, state, and local management organizations. Most importantly, these papers will inform long-term research planning activities of the agency.

The six white papers consider the following ecosystem-related themes:

Of course, better science capabilities alone will not be sufficient to meet the increasing challenges in managing the Nation's coastal and ocean ecosystems. However, ocean governance systems have not been static. Even within traditional use sectors (e.g., fisheries, energy exploration and recovery), there is an evolution towards broadening mandates to consider their interactions with other sectors and issues. In fact, there is a growing demand from these current institutions for ecosystem-level information and advice for which science is not yet fully equipped to provide (Rice, 2005). Thus, there is an urgent need to address these issues and priorities.

Finally, this exercise in futurism is not the first, and will not be the last, to consider emerging marine science and policy "mega-trends." In 1984, the Intergovernmental Oceanographic Commission posited a vision of emerging themes by the year 2000 (IOC, 1984). Chief among their predictions were the increased importance of interdisciplinary approaches to climate research and ecosystem studies (Field et al., 2005). More recently, in visioning ocean science for 2020, Field et al. (2005) provide a number of tantalizing predictions for science and management challenges for which science must prepare, including: (1) the increased reliance on more capable remote sensing, (2) the importance of the information revolution to ocean science, (3) the "globalization" of modeling capacity, (4) discovering functional biodiversity (molecular ecology), (5) increased emphasis on global climate change, (6) waste disposal in the oceans, (6) understanding of the deep sea floor biosphere, (8) the emerging importance of the land-sea interface and the coasts, (9) the growth of interdisciplinary sciences, (10) greater involvement of society in managing the ocean's limited resources, (11) transitioning to sustainable fisheries, and (12) capacity building in marine science in both the developing and developed world. This volume provides a NOAA-centric view of important challenges for ecosystem management and the role that its science can play in informing and helping to create a sustainable future for our Nation’s ocean and coastal ecosystems.

The authors acknowledge and appreciate the efforts of the numerous individuals who reviewed these white papers, and particularly those of Ms. Lynn Dancy.

Acronyms

ABC acceptable biological catch
AIS aquatic invasive species
ARO NOAA Fisheries' Alaska Regional Office
Bmsy stock biomass necessary to support MSY
CCSP U.S. Climate Change Science Program
CFM coastal flooding model
CHPS Community Hydrologic Prediction System
CZM coastal zone management
EAM ecosystem approach to management
ECOHAB NOAA's Ecology and Oceanography of Harmful Algal Blooms Program
EEZ Exclusive Economic Zone
EFH essential fish habitat
ENSO El Niño-Southern Oscillation
EPA U.S. Environmental Protection Agency
ESA Endangered Species Act
ESU evolutionary significant unit
FAO Food and Agriculture Organization of the United Nations
Flim threshold maximum fishing mortality limit
Fmsy fishing mortality rate associated with MSY
FMP fishery management plan
FY fiscal year
GEOSS Global Earth Observing System of Systems
GIS geographical information system
GLOBEC U.S. Global Ocean Ecosystems Dynamics
HAB harmful algal bloom
IOOS Integrated Ocean Observing System
LMR living marine resource
MERHAB NOAA's Monitoring and Event Response for Harmful Algal Blooms Program
MPA marine protected area
MSE management strategy evaluation
MSFCMA Magnuson-Stevens Fishery Conservation and Management Act
MSY maximum sustainable yield
NASA National Aeronautics and Space Administration
NEXRAD Next Generation Radar
NOAA National Oceanic and Atmospheric Administration
NGO non-governmental organization
NMSP NOAA's National Marine Sanctuary Program
NPCREP North Pacific Climate Regimes and Ecosystem Productivity
NPFMC North Pacific Fishery Management Council
OFL overfishing level
PBA NOAA program baseline assessment
PPBES NOAA's Program Planning Budgeting and Execution System
SAFE Stock Assessment and Fishery Evaluation
SIMOR Subcommittee on Integrated Management of Ocean Resources
TAC total allowable catch

White Paper #1

Ecosystem Responses to Climate Variability

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I. Description of the Issue

Background

Variations in the world's climate have significant implications for the productivity and structure of marine and coastal (including Great Lakes) ecosystems ranging from the tropics to the poles. Climate-driven variability of environmental conditions is manifest on many time and space scales, including year-to-year variation, multi-year (e.g., El Niño-Southern Oscillation [ENSO]), and decadal scales (e.g., Pacific Decadal Oscillation, North Atlantic Oscillation, and Arctic Oscillation). In addition to this shorter-term variability, the Earth's climate system has demonstrably warmed on both global and regional scales since the pre-industrial era, impacting ice extent (IPCC, 2001). As a consequence of global warming and subsidence, sea levels continue to rise and the rate of rise is projected to accelerate. Precipitation and resulting rates of runoff are predicted to change significantly over the next century. These variations and changes in environmental conditions have profound implications for ecosystems and the human activities that are dependent on them by changing the distributions and productivity of living resources.

Climate changes potentially have large impacts on living marine resource (LMR) populations including the Great Lakes (McGinn, 2002). Along the U.S. west coast, El Niño events cause shifts in population distributions of many marine species and greatly impact ocean productivity (Pearcy and Schoener, 1987), while decadal scale climate shifts impact the structure and productivity of North Pacific and Bering Sea ecosystems (Hollowed and Wooster, 1992; Hare and Mantua, 2000; Peterson and Schwing, 2003). Shifts such as the change from shrimp to groundfish dominance in the Gulf of Alaska in the late 1970s reflect decadal changes in ocean climate (Anderson and Piatt, 1999), as do large shifts in Pacific salmon production (Mantua et al., 1997). The Bering Sea is undergoing a northward biogeographical shift in response to changing temperature and atmospheric forcing (Overland and Stabeno, 2004; Grebmeier et al., 2006), and in the North Atlantic many marine fish species have been observed to shift their distributions poleward in response to increases in water temperature (Murawski, 1993; Parker and Dixon, 1998; Perry et al., 2005). Long-term declines in krill stocks have been observed in the Southern Ocean and links between annual krill density and sea-ice cover have been established (Atkinson et al., 2004). Similarly, in the Bering Sea and Arctic Ocean, reductions in sea ice coverage have negative implications for ice dependent species, but positive implications for other species that may be able to take advantage of the changing conditions, thus having consequences that cascade through the food webs (ACIA, 2004). Changed climate forcing affects important physical features in the ocean, thereby impacting marine species that take advantage of these features. For example, the Transition Zone Chlorophyll Front is a sharp boundary in the waters north of the Hawaiian Islands between the stratified, low surface chlorophyll water and the cooler, vertically mixed, high surface chlorophyll water. This productive feature is used as a migration pathway by sea turtles and tunas (Polovina et al., 2001), and its winter location appears important to the survival of monk seal pups. Climate change will also influence the thermal regime in the Great Lakes, impacting the growth rate potential of important fish species (Brandt et al., 2002).

Rising sea level directly impacts coastal ecosystems (Boesch et al., 2000), inundating wetlands and shallow water habitats and increasing, salinity, wave action, and storm surges. In regions where coastal development interferes with the landward migration of coastal ecosystems as sea level rises, the ecosystems may disappear. Shifts in precipitation change the amount, timing, and contents of freshwater runoff, thereby impacting coastal and estuarine areas (Boesch et al., 2000). For example, the large hypoxic zone that occurs each summer over the northern Gulf of Mexico shelf may increase in size and intensity if runoff from the central U.S. increases (Justic et al., 2003). Rising temperatures have implications for the productivity and viability of coral reef ecosystems as mass coral bleaching has occurred in association with episodes of elevated sea temperatures (Hoegh-Guldberg, 1999). Coral reefs, and other calcifying marine organisms including important plankton components, are also susceptible to anthropogenic ocean acidification due to increasing carbon dioxide (CO_2), decreasing their ability to build their calcium carbonate ($CaCO_3$) structures (Feely et al., 2004; Orr et al., 2005; Kleypas et al., 2006).

There exists the need for science to identify how climate variability impacts ecosystems and how different ecosystems respond to climate forcing, to differentiate the impacts of short-term variability (year-to-year, multi-year) from longer term variability (decadal and longer), and to identify the most cost-effective ways to adapt to the changes or reduce the risk of negative impacts. Without this information, society cannot rationally assess the costs and benefits of policy options to mitigate the impacts of climate variability or adapt human uses to account for the magnitude and timing of climate-induced changes.

NOAA's Role in Framing Climate-Ecosystem Issues

The National Oceanic and Atmospheric Administration (NOAA) has responsibilities to monitor, understand, and predict the impacts of global climate change on marine and coastal ecosystems. Specifically, NOAA has responsibilities to:

- monitor and model changes in coastal production as a consequence of predicted climate changes in the rate and amount of runoff and in the timing of spring phytoplankton blooms;
- evaluate and predict climate impacts, including increases in CO_2, on coral ecosystems;
- adapt how it manages marine fisheries, marine mammals, and protected marine species by accounting for the impacts of climate variability and change on marine ecosystems; and
- utilize predictions of climate status to forecast the impact of such change on coastal ecosystems.

As an agency, NOAA has the capabilities and legislative mandates to exert leadership in conducting this work. Without NOAA investment, society's ability to adapt to changes in coastal and marine ecosystems will be severely limited.

To address these needs, NOAA has identified the following high-priority topic areas:

Climate regimes and ecosystem productivity:
Profound shifts in biological productivity, species distributions, and ecosystem structure are often ecological responses to climate variability, and are of great consequence to fishery-dependent communities and the commercial fishing industry. Projects within this topic aim to predict the probable consequences of climate change on coastal and marine systems and the living resources contained therein, and to provide the knowledge and tools needed to incorporate climate variability into the management of living marine and coastal resources. This topic area entails a wide variety of projects to investigate and provide a predictive capability of the impacts of changing climate on coastal and marine ecosystems. In addition to projects focused on what have become known as climate regime shifts (e.g., ecosystems alternating between anomalous warm and cool states (Hollowed and Wooster, 1992)), this topic also includes studies to investigate: coastal and marine ecosystem impacts from any change in the physical environment due to changing climate; the impact of diminishing ice cover (e.g., impacts diminishing sea ice on marine mammals and fisheries within the Bering Sea ecosystem); and how climate variability and change impact the productivity of Pacific salmon within their oceanic and freshwater habitats.

Coastal response to sea-level rise:
To plan development that will protect coastal property and ecosystems, state and local governments need accurate and precise elevation maps showing the extent of coastal inundation due to projected sea level rise. Projects within this topic will collect topographic and bathymetric data to create detailed elevation maps which, along with hydrographic modeling, comprise precise coastal flooding models (CFMs). While CFMs are required to protect human-made infrastructure, projects under this topic also provide for protecting ecosystems by modeling the responses of the various types of wetlands and shallow water habitats to

increases in water depth, salinity, waves, and storm surges.

Nutrient-climate interactions:
Climate change models predict major shifts in the amount of precipitation experienced by various regions of the United States. In addition, the coastal glaciers of Alaska are melting. Such changes may lead to increased runoff of freshwater and its nutrients into coastal and estuarine areas, making them more susceptible to eutrophication. For marine systems, this will also enhance stratification, further increasing the susceptibility to eutrophication. These projects will monitor and model changes in coastal eutrophication as a consequence of predicted climate changes in the rate and amount of runoff.

Coral bleaching:
Bleaching occurs when corals are stressed by a synergistic combination of stressors, including increases in sea surface temperature. These projects will improve the current network of observational sensors and provide an integrated approach capable of forecasting the time, place, and potential severity of coral bleaching events. Successful forecasting of coral bleaching events will allow managers and stakeholders to prepare for, forestall, and/or minimize the devastating effects of bleaching on coastal ecosystems and resource loss resulting from bleaching events.

Decalcification:
The carbonate equilibrium of the oceans is shifting in response to increasing atmospheric CO_2 concentrations. There is also mounting evidence that calcification rates of several major groups of marine calcifiers, including shallow and deep water corals and calcifying plankton, will decrease as CO_2 concentrations continue to rise. Many of these organisms are of direct economic importance to human populations, while the others are important in the marine food web. Projects within this topic will gain a better understanding of how ocean biology and chemistry will respond to higher CO_2 and concomitant lower pH conditions so that predictive models of these processes and their impacts on marine ecosystems can be developed.

Influences External to NOAA that will Drive Future Needs

It is increasingly apparent that coastal and marine ecosystems are not in a steady state and that resource managers must be prepared to adapt to changing conditions. In addition to the importance of annual to decadal scale climate variability to ecosystems, global climate change is predicted to have increasingly significant effects over the next fifteen years. Such change will impact both the mean state of the environment and its variability. By not accounting for climate variability and change in its information exchange with resource managers, NOAA risks providing management advice that does not match evolving environmental conditions and thereby risks mismanagement of coastal and marine ecosystems. As any large-scale climatic change will result in both winners (i.e., species who do better in a new climate regime) and losers (i.e., species who do not thrive under such change), failure to consider climate in management decisions can and will result in over- or under-harvesting of living resources and poor management of non-harvested species. This will clearly impact not only the ecosystems, but also the individuals and communities that are dependent upon coastal and marine resources. Long-range planning will be improved if a predictive capability for climate impacts on ecosystems is developed. Accounting for climate variability and change is an important component of implementing an ecosystem approach to marine resource management as called for in the U.S. Ocean Action Plan (CEQ, 2004). In the coming decades, as anthropogenic stressors continue to impact coastal and marine ecosystems through coastal development and resource exploitation, climate impacts are likely to become increasingly important. Through studies to monitor, understand, and predict the impacts of global climate change on marine and coastal ecosystems, NOAA will address needs identified in the U.S. Climate Change Science Program (CCSP) Strategic Plan (U.S. Climate Change Science Program, 2003).

II. Science Capabilities Necessary to Support Future Decision-Making

Present capabilities

NOAA has made large investments towards understanding the physical climate system and describing the mechanisms that govern climate variability and change. However, very little work has been done to understand the impacts of climate variability or the implications of future climate change on coastal and marine ecosystems. For this reason, NOAA initiated a Climate and Ecosystems Program with the objective of understanding and predicting the consequences of climate variability and change on marine ecosystems. Its strategy is to develop the ability to predict the consequences of climate change on ecosystems by monitoring changes in coastal and marine ecosystems, conducting research on climate-ecosystem linkages, and incorporating climate information into predictive physical-biological indicators and models.

NOAA’s Climate and Ecosystems Program was initiated in fiscal year (FY) 2004 with one project. The North Pacific Climate Regimes and Ecosystem Productivity (NPCREP) project is developing an understanding of how climate fluctuations and change affect the eastern Bering Sea and Gulf of Alaska ecosystems. NPCREP is utilizing a combination of retrospective, monitoring, process, and modeling studies to advance the understanding of climate impacts on the fisheries in the region, thereby generating the necessary foundation for understanding climate-ecosystem relationships. Through the increased understanding being obtained, NPCREP is developing indicators of climate impacts and models to predict the probable consequences of climate change on the eastern Bering Sea and Gulf of Alaska ecosystems. These products are given to fisheries managers at the North Pacific Fishery Management Council (NPFMC) so that climate variability and change can be incorporated into management decisions affecting the LMRs in these regions.

In addition to its Climate and Ecosystems Program, NOAA is involved in a number of projects related to the impacts of climate on marine ecosystems:

- NOAA has helped support projects in the Georges Bank/Northwest Atlantic Region and the Northeast Pacific (with components in the California Current and the Coastal Gulf of Alaska) that are coordinated by the U.S. Global Ocean Ecosystems Dynamics (GLOBEC), a research program addressing how global climate change may affect the abundance and production of marine animals.
- Since 2004, NOAA has been creating CFMs with a precision of 20 cm in order to map coastal inundation under the existing and projected rate of sea level rise. Included is an ecological component to model changes in coastal habitats as a function of rates of sea level rise and landscape characteristics. These models are designed for local managers to accommodate sea level rise and its ecological consequences into coastal development plans.
- NOAA's Coral Reef Watch Program has developed a variety of satellite- and *in situ*-based products that monitor the environmental conditions of coral reef ecosystems, and is linking ecosystem models with current and past climate data to enable understanding of the relationship between climate parameters and coral ecosystem response.
- NOAA scientists are incorporating indices of environmental variation into assessments of the status of living resource populations. Some of these investigations are providing useful information to managers; however, these efforts should be better connected and coordinated to ensure information exchange and use of the most appropriate products and models.
- There is no ongoing NOAA project addressing the effect of climate change on coastal eutrophication or modeling activity directly predicting the locations and intensity of climate-driven coastal eutrophication. However, existing monitoring programs making *in situ*- or satellite-based measurements of water quality and chlorophyll concentrations are beginning to create the long-term database required to document such responses to climate change.

New or Enhanced Capabilities that will be Required

Enabling the incorporation of climate impacts into management plans, by predicting the probable consequences of climate variability and change on coastal and marine ecosystems and delivering the knowledge and predictive tools to managers, is essential. To support this goal, NOAA needs to: 1) expand its capability to develop biophysical indicators and models so coastal and marine resource management can adapt to predicted climate-induced changes in fishery, coastal, and coral reef resources; 2) expand its capability to monitor changes in coastal and marine ecosystems through a network of *in situ* and remote observing systems; and 3) gain an understanding of the mechanisms and rates that control ecosystem response to climate variability and change. Predictive biophysical indicators and models will allow for the proactive management of living resources, the most efficient manner in which to manage resources. Monitoring changes in ecosystems will allow for reactive management and provide data essential for the development of indicators and models. Understanding the mechanisms and rates that control ecosystem productivity and energy flux is critical for the development of predictive indicators and models.

NOAA requires an integrated climate-ecosystem observing system to provide climate variability data as well as synoptic ecosystem structure and productivity information. Such input parameters would be used to document ecosystem responses to climate changes, to develop a better understanding of climate effects on ecosystems, and to develop more timely biophysical indicators and models that support management and policy actions. Additional days-at-sea aboard next-generation oceanographic and fisheries survey vessels are required to make the critically needed observations (via deployment of moorings and satellite-tracked drifters, as well as surveys of hydrography, fish stocks, protected resources, and plankton) and to conduct at-sea research to understand the processes and mechanisms of climate impacts on ecosystems.

Ocean models will be important tools to investigate and describe physical and biological responses resulting from climate variability. Currently both watershed-scale and regional ocean models are being used as research tools to describe ocean responses resulting from recent climate variability. Some of these ocean-atmosphere coupled models also include a lower trophic level component to describe spatial and temporal aspects of plankton dynamics. A priority of future research will be to ground truth the output from these models and develop approaches to directly or indirectly extend them to address higher trophic level dynamics. The development of spatially resolved models to predict and assess the implications of climate variability and change on ecosystems is crucial for planning adaptation strategies. These predictive models will provide a framework within which mitigation or adaptation strategies and policy options can be explored.

Science and Research needed to Support these Capabilities

There is sufficient technology to achieve a better understanding and more accurate and precise predictive capability of ecosystem responses to climate variability and change. While new observation technologies and advances in modeling techniques would accelerate the rate of achievement, the fundamental need for a predictive ability to be achieved is advancement in the conceptual understanding of the mechanisms through which climate impacts ecosystems. This requires process-based research focused on improving the understanding of the linkages between climate forcing and ecosystem responses at various time and space scales. This understanding is essential to enable the development and testing of indicators of climate impacts on ecosystems as well as models to predict the probable consequences of climate variability and change on particular regions. Without the knowledge of the mechanisms linking ecosystem responses to climate, scientists and managers will be forced to rely on correlations between climate forcing and ecosystem responses. Often, these correlations break down over time because there is no mechanistic link among the parameters. They will almost certainly break down under changed climate forcing, since the linkages between the critical mechanisms that impact productivity will likely change.

III. Partnerships Necessary to Effectively Address the Emerging Issues

To effectively address the impacts of climate on marine ecosystems, NOAA must partner with other Federal agencies, as well as state and local agencies, to leverage their expertise and resources. Coordination of programs at the Federal level is conducted through the Ecosystem Interagency Working Group of the U.S. CCSP. NOAA utilizes knowledge gained on ecosystem responses to climate variability within the U.S. and from around the world by academia, government agencies and programs, and other entities. NOAA scientists, along with their partners from academia and private industry who are supported by research grants, are conducting the single existing project within NOAA's Climate and Ecosystems Program. A significant portion of the funding for all proposed Climate and Ecosystems projects would support academic researchers through grants in order to enhance collaborations and provide necessary scientific expertise. In addition, due to the scope of the information needed to address the questions of the program, a wide range of linkages and partnerships with other programs are necessary. For example, NPCREP, the Climate and Ecosystems Program project, is linked with other NOAA projects, the Integrated Ocean Observing System (IOOS) through the Alaska Ocean Observing System and the Northwest Association of Networked Ocean Observing Systems, and programs supported by other agencies and non-governmental organizations (NGOs) (e.g., programs supported by the National Science Foundation, the North Pacific Research Board, and the *Exxon Valdez* Oil Spill Trustee Council). NOAA's work on developing CFMs for a portion of the North Carolina coast - work that could evolve into a national effort - requires the active participation of scientists with local knowledge and state support in obtaining precise topography. NOAA's monitoring of coastal eutrophication within the National Estuarine Research Reserves is done in partnership with states.

IV. Benefits to NOAA, Constituents, and Society from this Effort

There are significant benefits to be derived from better understanding and forecasting of ecosystem responses to climate variability. Projects within this topic have a high potential to positively impact management of these ecosystems and have a wide range of additional benefits. For instance, they would enable NOAA to address the urgent and continuing needs of living resource managers and move NOAA toward its stated goal of ecosystem-based management. NOAA would be able to observe, understand, and predict ecological effects of climate variability and change on major coastal and marine ecosystems of the United States. Users would be provided the information needed for decisions about responses of LMRs and coastal zones to climate-induced perturbations. Consideration of the potential impacts of climate variability on ecosystems and coastal zones would become an explicit component of LMR and coastal zone management (CZM) plans.

Fisheries managers would be able to more accurately predict the optimum yield for fishery stocks, thereby minimizing the amount of unrealized harvest or overharvesting of species. They could use the predictive information to modify fishing effort, timing, or location for particular species; change the gear type used; or change which species are targeted for a region. The knowledge and predictive tools generated by these investigations would be of great value to the management of marine mammals and other protected species, ensuring that potential direct and indirect climate impacts on their populations are considered. This information would also help fishers with their fishing strategies and their equipment investment planning, thus benefiting fishery-dependent human communities.

Coastal managers would benefit from the development of precise maps of predicted coastal inundation due to climate-induced sea level rise, models of ecosystem responses to increased water depth and salinity, and models of changes in coastal eutrophication as a consequence of climate variability. With these models, coastal managers can plan development that will have minimal impact on coastal ecosystems, taking into account climate impacts.

Managers of coral reef resources would benefit from predictions of climate impacts on coral reefs by allowing them to quantify the risk of different reefs to climate impacts, identify regions to maximize conservation, and reduce other stressors on reefs during predicted times of increased climate induced stress. These predictions will also help scientists better understand the cold water corals that are found within U.S. waters.

Climate variability and change have significant implications for the distribution and abundance of species and for the productivity and functioning of ecosystems as climate sets the boundaries within which species are adapted. As species are excluded from presently inhabited geographic regions due to changed climate, some may disappear completely while others may shift their geographic distributions if there is sufficient time and habitat. In regions where major species shifts occur, the newly structured ecosystems may be more or less productive than the present ones, but management policies adapted for the present ecosystem will not apply in the changed ecosystem. Changes in these ecosystems and their management will have a great impact on human communities and sectors dependent upon susceptible LMRs.

White Paper #2

Management of Living Marine Resources in an Ecosystem Context

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I. Description of the Issue

One of the four goals articulated in NOAA's Strategic Plan is to "protect, restore and manage coastal and ocean resources through an ecosystem approach" (NOAA, 2004). This goal flows from the mandates and direction of such Federal laws, executive orders, courts, and international treaties as the Magnuson-Stevens Fishery and Conservation Management Act (MSFCMA), Endangered Species Act (ESA), National Environmental Policy Act (NEPA), Marine Mammal Protection Act, Coral Reef Conservation Act, Coastal Zone Management Act, National Marine Sanctuaries Act, International Commission for the Conservation of Atlantic Tunas, and Inter-American Tropical Tuna Commission. These directives reflect society's desire for policies and institutions to manage the environment. When combined, they reflect the recognition that fishing is but one competing use of ecosystems that produces a broad set of ecological and societal benefits. But the benefits are not achieved without costs; thus, there is a need to manage LMRs in an ecosystem context. The critical need for a more holistic approach to managing the use of LMRs has been well articulated in a number of recent publications, including the U.S. Commission on Ocean Policy report (USCOP, 2004), U.S. Ocean Action Plan (CEQ, 2004), Pew Oceans Commission report (2003), Rappoport (1998), report to Congress by the Ecosystem Principles Advisory Panel (1999), report by the United Nations' Food and Agriculture Organization (FAO, 2003), a series of essays published by the Marine Ecology Progress Series (Browman and Stergiou, 2004), and a series of National Research Council (NRC) publications (1994, 1999b, 1999c, 2001, 2002), as well as numerous references contained therein.

The NOAA Perspective on Management of LMRs

There are more than 90 Congressional laws, treaty obligations, executive orders, regional agreements, NOAA-specific policies, memoranda of understanding with other Federal agencies, and court orders that drive the requirements of NOAA's Ecosystem Mission Goal (NOAA, 2005c). Over the last 20 years, NOAA has worked to establish the scientific underpinning for an ecosystem approach to management (EAM) of coastal and ocean LMRs, so that complex societal choices are informed by comprehensive and reliable scientific information (DeMaster and Sandifer, 2004; NOAA, 2005b). The types of products and services NOAA intends to provide to constituents and agency managers include: (1) forecasts and mitigation strategies related to harmful algal blooms (HABs), invasive species, and air and water quality; (2) ecological assessments and predictions of impacts from climate change on ocean productivity (e.g., coral bleaching and loss of sea ice in the Bering Sea; see White Paper #1); (3) decision support tools for adaptive, ecosystem-based management of fisheries, other marine resources, and coastal development; (4) improved assessments of sea level change on coastal resources and ecosystems; (5) better integration of observing system data for use by managers responsible for the health of coastal ecosystems; and (6) fishery productivity forecasts incorporating the effects of climate change.

For each of these products (e.g., forecasts, assessments, decision support tools), it will be necessary to take account or otherwise incorporate uncertainty associated with parameter estimation and process error (e.g., uncertainty of how a change in one component of an ecosystem influences the others). This is typically done by evaluating the performance of competing approaches using output from computer simulations that are run under a wide range of scenarios (FAO, 2003). Field data collected in support of these models are often not collected from a wide variety of system states, so there must be inference regarding underlying processes dictating changes (e.g., prey switching by predators). The evaluation of performance must be closely coordinated with resource managers and policy makers. Such an approach has become one of the basic tenets of an EAM by many national and international organizations. By necessity, it requires discourse between researchers and managers, and in the future, NOAA will need to increasingly incorporate constituent input into this discourse. The key assumption under this approach is that management tools that do not perform well in computer simulations are very likely to fail in the real world. That doesn't mean that management tools that perform well will necessarily produce satisfactory results in the real world, but they are certainly more likely to be successful than non-tested management approaches. One form of decision support tools used to evaluate the impacts of harvest policy is a management strategy evaluation (MSE). NEPA requires that agencies conduct this type of review to provide public disclosure of potential impacts of management actions. The MSE is an attempt to provide quantitative, rather than qualitative, information for decision-makers. Thus, NOAA scientists play a crucial role in the process by providing the analysis tools and forecasts that will facilitate collaborations among managers, researchers, and constituents to encourage the development of policies with full knowledge of the necessary tradeoffs between the likelihood of sustainable use of a LMR, its community, or its ecosystem and the likelihood of acceptable social or economic performance.

A Common Lexicon for Ecosystem Concepts

As discussed in the overview, NOAA has adopted a common lexicon to promote a shared understanding and usage of ecosystem concepts (NOAA, 2004; FAO, 2003):

> An *ecosystem* is a geographically specified system of organisms (including humans), the environment, and the processes that control its dynamics.
>
> The *environment* is the biological, chemical, physical, and social conditions that surround organisms. When appropriate, the term environment should be qualified as biological, chemical, physical, and/or social.
>
> An EAM is management that is adaptive, geographically specified, takes account of ecosystem knowledge and uncertainties, considers multiple external influences, and strives to balance diverse social objectives.
>
> A *fishery* can refer to the sum of all fishing activities on a given resource. It may also refer to the activities of a single type or style of fishing on a particular resource. The term is used in both senses.

The phrase "ecosystem approach to management" (instead of "ecosystem management") is used throughout the document in deference to the preferred international convention. An EAM is incremental, as neither the scientific nor fiscal underpinnings are usually available to quickly and fully implement ecosystem approaches in every location. LMR management changes ecosystems and their components. Specifying goals for the condition of LMRs, the ecosystem of which they are a part, and the human enterprise of fishing is a prerequisite to the success of this management approach. An *a priori* assessment of possible ecosystem states must become the foundation for the selection of preferred management actions.

Progress towards implementing an EAM for LMRs can occur in stages along a continuum. For example, management under an ecosystem approach can be categorized into at least three levels. The first level is single species management of targeted resources, with issues of protected species, non-target species, habitat, and species interactions incorporated as important considerations. The second level is a multi-species aggregate and system level approach. This management level incorporates important ecological and environmental factors, such as trophic structure, carrying capacity, climate anomalies or regime shift influences, on the condition of the ecosystem. The third level is a comprehensive, multiple sector approach that captures activities and values associated with all external influences (i.e., fishing and non-fishing sectors) impacting the condition and sustainability of ecosystems. The focus is not only on LMR conservation or extraction, but also on uses of and impacts on marine ecosystems by transportation, military, oil and gas sectors, etc.

Background

A number of recent publications provide perspectives and approaches on how LMRs will be managed in an ecosystem context over the next fifteen years:

1. Report to Congress by the Ecosystem Principles Advisory Panel (1999, p. 3):

"*The benefits of adopting ecosystem-based fishery management and research are more sustainable fisheries and marine ecosystems, as well as more economically-healthy coastal communities. We have identified actions required to realize these benefits. We urge the Secretary and Congress to make those resources available*." (Note: the eight ecosystem principals recommended by the Panel are presented in Appendix A).

2. Murawski (2000, p. 649):
"*Ecosystem considerations may be incorporated into fisheries management by modifying existing overfishing paradigms or by developing new approaches to account for ecosystem structure and function in relation to harvesting. Although existing concepts of overfishing have a strong theoretical basis for evaluating policy choices and much practical use, they do not provide direct guidance on issues such as biodiversity, serial depletion, habitat degradation, and changes in the food web caused by fishing.*" and "*Ecosystem considerations do not need to substitute for existing overfishing concepts. Instead, they should be used to evaluate and modify primary management guidance for important fisheries and species*."

3. Clark et al. (2001, p. 657):
"*Planning and decision-making can be improved by access to reliable forecasts of ecosystem state, ecosystem services, and natural capital. Availability of new data sets, together with progress in computation and statistics, will increase our ability to forecast ecosystem change. An agenda that would lead toward a capacity to produce, evaluate, and communicate forecasts of critical ecosystem services requires a process that engages scientists and decision-makers. Interdisciplinary linkages are necessary because of the climate and societal controls on ecosystems, the feedbacks involving social change, and the decision –making relevance of forecasts.*"

4. Hilborn (in Browman and Stergiou [2004, pp. 275-276]):
"*No one questions that the majority of the world's fisheries are heavily used, many are overfished, some have collapsed, and good biological and economic management suggests substantial reductions in fishing pressure are needed for sustainable management.*"; "I*, and others (Garcia et al. 2003, Sissenwine & Mace 2003), believe that we need a form of ecosystem management that emphasizes the interaction between fish, fishermen and government regulators and concentrates on incentives and participation with user groups. This difference can be considered as a choice between a participatory approach with incentives as a 'carrot', and a centralized government using regulations as a 'stick'.*"; and "*To argue that we need more data intensive management and more regulation by central governments in the fisheries of the world that have little data and little regulation is untenable*."

5. Pew Oceans Commission (2003):
The Pew Oceans Commission identified governance structure as one key issue in developing more robust U.S. fisheries management.

6. Jennings (in Browman and Stergiou [2004, p. 279]):
"*EAF* [Ecosystem Approaches to

Fisheries] *is part of the ecosystem approach. The broad purpose of the EAF is to plan, develop and manage fisheries in a manner that addresses the multiple needs and desires of societies, without jeopardizing the options for future generations to benefit from the full range of goods and services (including, of course, non fisheries benefits) provided by marine ecosystems.*"

7. Mace (in Browman and Stergiou [2004, p. 291]):
"*The lack of adequate monitoring of marine species, habitats and oceanographic factors is perhaps the most difficult problem of all to address, primarily because of the prohibitive costs associated with conducting surveys of marine resources and the high costs of simply monitoring catches in many countries. Realistic cost-benefit analyses may well indicate that the costs of comprehensive scientific research far exceed both short- and long-term potential economic benefits to the fishing industry. As a result, while a few countries may be improving their monitoring capabilities (e.g. the United States), others are losing funds for research and monitoring. Recent progress includes several ambitious programs under the auspices of the Global Ocean Observing System (GOOS), Global Ocean Ecosystem Dynamic Programs (GLOBEC), and the Census of Marine Life (CML).*"

8. Sissenwine and Murawski (in Browman and Stergiou [2004, pp. 292-295]):
"*Incorporation of ecosystem-based approaches into fisheries management involves accounting for a number of important classes of interactions that are not routinely evaluated in current species-by-species or fishery-based management programs.*"; "*Controlling fishing mortality, and manipulating its application on particular size or age classes, are the keys to achieving the typical objectives of sustainability, high yield, and efficiency. Often, this is done by setting a Total Allowable Catch (TAC) based on the relationship between catch and fishing mortality. Another approach is to limit fishing effort (days at sea or some other effort metric) since fishing mortality is proportional to effort. Controlling fishing mortality through either a TAC or limit on fishing effort requires considerable scientific information about the fishery and resource species.*"; and "*Moving from 'intelligent tinkering' to a more direct focus on ecosystem properties and outcomes will necessarily involve closer ties between science and management.*"

9. U.S. Commission on Ocean Policy (2004, p. 411):
"*The many potentially beneficial uses of ocean and coastal resources should be acknowledged and managed in a way that balances competing uses while preserving and protecting the overall integrity of the ocean and coastal environments.*"; and "*Downward trends in marine biodiversity should be reversed where they exist, with a desired end of maintaining or recovering natural levels of biological diversity and ecosystem services.*"

10. Pikitch et al. (2004, p. 347):
"*Protecting essential habitat for fish and other important ecosystem components from destructive fishing practices increases fish diversity and abundance. Thus, ocean zoning, in which type and level of allowable human activity are*

specified spatially and temporally, will be a critical element of EBFM. … We believe EBFM can be implemented in systems that differ in levels of information and uncertainty through the judicious use of a precautionary approach. This means erring on the side of caution in setting management targets and limits when information is sparse or uncertain. Greater uncertainty would be associated with more stringent management measures. Because ecosystem management involves a wide range of objectives, great ecosystem complexity, and a high level of uncertainty in predicting impacts, EBFM inevitably requires that some level of precaution be exercised. Ideally, EBFM would shift the burden of proof so that fishing would not take place unless it could be shown not to harm key components of the ecosystem. Progression from data-poor to data-rich EBFM will be facilitated by adaptive management and greater understanding of how ecosystems respond to alternative fishing strategies."

11. Hall and Mainprize (2004, pp. 18-19):
"*In a fisheries context, perhaps the most important discussion of all must be about what constitutes a desirable or an undesirable state for an ecosystem and how one weighs the importance of the various attributes… Identifying stakeholders, distinguishing between fishing and environmental impacts, initiating comprehensive consultations, finding alternative incentives and choosing ideal measures for management are all critical considerations. Only once this is achieved will we be on the road to producing healthy fisheries that are ecologically and economically successful for present and future generations.*"

Overview of Managing LMRs in an Ecosystem Context

There is increasing recognition of the need for management of LMRs in an ecosystem context. Globally, declines in fishery resources, alteration of critical habitats, incidental capture of non-target species, and the effects of climate variability all point to the need for a more holistic approach to understanding human impacts on marine ecosystems and the interplay of natural and anthropogenic agents of change. Nonetheless, as noted in the U.S. Ocean Action Plan (2004, p. 18), progress toward restoring and maintaining healthy recreational and commercial fishing has been made in recent years. For example, since 2000, "17 major stocks have been rebuilt and/or removed from the list of overfished stocks (dropping from 56 to 39); almost all (over 93 percent) of the remaining overfished stocks have rebuilding plans in place, the number of species subject to overfishing has decreased by 37 (48 percent); and the number of stocks with an "unknown" status level has decreased by 48 (25 percent)."

The U.S. Ocean Action Plan strongly endorsed the concept of EAM following the report of The U.S. Commission on Ocean Policy. The Commission noted that (2004, p. 411)

"U.S. ocean and coastal resources should be managed to reflect the relationships among all ecosystem components, including human and nonhuman species and the environments in which they live. Applying this

principle will require defining relevant geographic management areas based on ecosystem, rather than political, boundaries."

The Commission highlighted the need to consider the interaction among system components and emphasized that ecosystem approaches to management are inherently place-based. Because the properties of an ecosystem are different from those of its parts (see text box), an EAM of LMRs will necessarily differ from traditional single species approaches while maintaining some elements of these approaches.

Harvesting has both direct and indirect effects on marine ecosystems. Direct effects include removal of biomass and potential impacts on habitat and non-target species. Indirect effects include alteration in trophic structure through species-selective harvesting patterns that change the relative balance of predators and their prey. Multi-species considerations in fishery management account for these interactions for harvested species and the need to consider factors such as the food and energetic requirements of non-harvested species such as marine mammals, seabirds, and turtles. Further consideration of the role of habitat in resource and system productivity and the effect of environmental forcing on system dynamics provides a more inclusive and necessary ecosystem perspective. Collectively, these factors can result in shifts in productivity states that must be accounted for in management. Further, it requires that tradeoffs are explicitly considered in management decisions (e.g., between predators and their prey). The development of a full EAM will require consideration of not only these harvesting impacts, but also the effects of factors on the integrity of marine ecosystems and resource productivity such as coastal development, pollution, shipping, and oil and gas extraction. A summary of objectives for regionally-based EAM developed by NOAA Fisheries staff is provided in Appendix B (NOAA Fisheries, 2004).

Spatial Restrictions on Fishing to Manage LMRs

Spatial restrictions on fishing to manage LMRs have long been recognized and used as tools to reduce or redistribute fishing mortality. However, these restrictions are usually directed at a subset of species, specific fishing gear, and over limited time frames. Seldom has the use of complete and permanent spatial prohibitions on all fishing activity (e.g., marine protected areas or MPAs) been used to manage LMRs (although their use is increasing in recent years). However, in many areas MPAs have been touted as a new way to achieve species conservation. For overfished stocks, reducing fishing mortality will theoretically increase them, but the tradeoffs regarding ecosystem health and social and cultural benefits between reduced fishing mortality over the entire fishing grounds and no fishing mortality within a prescribed area have yet to be fully evaluated, or demonstrated widely in practice. Further, the benefits and costs of imposing the restrictions to implement MPAs and achieve society's other non-fishing objectives have received little attention. For example, if one were to create a MPA in which the taking of fish and entry of vessels were prohibited, what would be the result on ships or non-fishing recreational vessels wanting to transit the area? Would catch and release fishing be allowed? Would the removal of a submerged shipwreck be allowed? These questions should be addressed within the context of accomplishing multiple, possibly simultaneously competing objectives. In short, using spatial restrictions to manage LMRs should be examined within an ecosystem context and with the aforementioned MSE tool. One way to frame the general discussion for each potential spatial restriction could be: How does the spatial restriction on fishing contribute to optimizing (or at least reconciling) the competitive objectives of preserving biodiversity, sustaining fisheries and other uses, and preserving cultural artifacts within a large marine ecosystem?

Performance-Based Management of LMRs

As noted earlier, NOAA's goal to "protect, restore and manage coastal and ocean resources through an ecosystem approach" (NOAA, 2004) will only be achieved through incremental improvements to existing practices. Initially, risk adverse management will be based on appropriately conservative harvest management strategies that are consistent with the above stated NOAA goal for managing living marine resources in an ecosystem context.

Figure 1 (from NOAA's Strategic Plan [NOAA, 2004]) connects performance objectives with outcomes of NOAA's Ecosystems Mission Goal.

ECOSYSTEMS MISSION GOAL

OUTCOMES	PERFORMANCE OBJECTIVES
• Healthy and productive coastal and marine ecosystems that benefit society • A well informed public that acts as a steward of coastal and marine ecosystems	Increase number of fish stocks managed at sustainable levels Increase number of protected species that reach stable or increasing population levels Increase number of regional coastal and marine ecosystems delineated with approved indicators of ecological health and socio-economic benefits that are monitored and understood Increase number of invasive species populations eradicated, contained, or mitigated Increase number of habitat acres conserved or restored Increase portion of population that is knowledgeable of and acting as stewards for coastal and marine ecosystem issues Increase number of coastal communities incorporating ecosystem and sustainable development principles into planning and management

Strategies to accomplish the Ecosystems Mission Goal (from NOAA's Strategic Plan [NOAA, 2004, pp. 4-5]) include:

- Engage and collaborate with our partners to achieve regional objectives by delineating regional ecosystems, forming regional ecosystem councils, and implementing cooperative strategies to improve regional ecosystem health.
- Manage uses of ecosystems by applying scientifically sound observations, assessments, and research findings to ensure the sustainable use of resources and to balance competing uses of coastal and marine ecosystems.
- Improve resource management by advancing our understanding of ecosystems through better simulation and predictive models. Build and advance the capabilities of an ecological component of the NOAA global environmental observing system to monitor, assess, and predict national and regional ecosystem health, as well as to gather information consistent with established social and economic indicators.
- Develop coordinated regional and national outreach and education efforts to improve public understanding and involvement in stewardship of coastal and marine ecosystems.
- Engage in technological and scientific exchange with our domestic and international partners to protect, restore, and manage marine resources within and beyond the Nation's borders.

I. Science Capabilities Necessary to Support Future Decision-Making

NOAA's ecosystem research portfolio addresses specific management issues, including aquaculture, coastal resource management, corals, fisheries management, habitat restoration, invasive species, protected areas, and protected species. In its most recent five-year plan (NOAA, 2005b), NOAA identified thirteen key research actions for the foci of the Ecosystems Mission Goal: (1) study ocean phenomena, (2) study coral ecosystems, (3) promote research on inter-disciplinary and biophysical integration of observation systems, (4) promote technological development, (5) investigate sources, fates, and effects of anthropogenic influences, (6) explore submerged landscapes and the effects of physical changes on coastal and marine ecosystems, (7) map and characterize previously uncharted habitats, (8) develop and demonstrate environmentally compatible culture systems for commercial, overexploited, threatened, and endangered species, (9) forecast and asses temporal scales of ecosystem variability, (10) create biophysical coupled models of water mass movements and their effects on biological productivity (including fisheries recruitment and population distribution), (11) study aquatic biodiversity, (12) understand the dynamics of social and economic systems and their relation to ecosystem management, and (13) conduct interdisciplinary research to better understand marine biological, chemical, and physical processes and their implications for human health.

One way to organize the science capabilities necessary to manage LMRs in an ecosystem context is to consider the framework recommendations of the Food and Agriculture Organization of the United Nations, or FAO (FAO, 2003) regarding research needed to implement an EAM for fisheries. These include research organized around the following five areas: (1) ecosystems and fishery impact assessments, (2) socio-economic considerations, (3) assessment of management measures, (4) assessment and improvements of the management process, and (5) monitoring and assessment. The FAO perspective on an EAM is fully consistent with NOAA's definition of EAM (i.e., "Most importantly, the approach aims to ensure that future generations will benefit from the full range of goods and services that ecosystems can provide by dealing with issues in a much more holistic way" (FAO, 2003, p. v). The primary aim of the agency is to transition from the traditional single species management approach to management in an ecosystem context. Below is a realignment of the thirteen areas of key research identified by NOAA in 2005 categorized by the five areas identified by FAO. In addition and as appropriate, NOAA has added science capabilities identified by the FAO that were considered important in managing LMRs in an ecosystem context:

I. Ecosystems and fishery impact assessments
   a. study ocean phenomena
   b. study coral ecosystems
   c. promote research on inter-disciplinary and biophysical integration of observation systems
   d. promote technological development
   e. investigate sources, fates, and effects of anthropogenic influences
   f. explore submerged landscapes and the effects of physical changes on coastal and marine ecosystems
   g. map and characterize previously uncharted habitats
   h. forecast and asses temporal scales of ecosystem variability
   i. create biophysical coupled models of water mass movements and their effects on biological productivity (including fisheries recruitment and population distribution)
   j. study aquatic biodiversity
   k. expand knowledge of how fishing impacts target and non-target species and their associated ecosystems

II. Socio-economic considerations
   a. understand the dynamics of social and economic systems and their relation to ecosystem management
   b. conduct interdisciplinary research to better understand marine biological, chemical, and physical processes and their implications for human health
   c. develop appropriate multispecies bio-economic models

d. conduct research into the factors that influence the day-to-day behavior of vessel operators
e. Apply an integrated environmental and economic accounting framework to the assessment and analysis of interactions between fisheries and other sectors of the economy

III. Assessment of management measures
a. develop and demonstrate environmentally compatible culture systems for commercial, overexploited, threatened, and endangered species
b. develop technology in the area of fishing gear and practices to improve gear selectivity and reduce the impact of gear on ecosystems
c. develop procedures to integrate traditional ecosystem knowledge into management
d. identify the species and ecosystems that are suitable for stock enhancements programs
e. assess the potential role of MPAs as a management tool and evaluate their effectiveness where already implemented

IV. Assessment and improvement of the management process
a. implement research on how to evaluate management performance, how to include uncertainty and risk assessment in management, etc.
b. develop procedures to improve the participatory processes by stakeholders in the management process
c. develop ways to better communicate the implications of different management strategies

V. Monitoring and assessment
a. promote technological development
b. develop simple and efficient appraisal methods
c. develop adaptive management approaches to assist with data-poor situations
d. develop multiple analytical techniques to underpin the decision-making process
e. develop, as possible, a set of generic indicators that can be widely applied to different ecosystems and different fisheries

In addition, in its strategic plan (NOAA, 2005b), NOAA identified four key technology sectors on which it depends to describe, understand, and predict changes in the status of LMRs. These are: (1) sensors capable of gathering information on biological, chemical, and physical components of the environment, (2) platforms (e.g., research and survey vessel fleets, unmanned aerial vehicles and autonomous undersea vehicles, and aircraft), (3) information technology, and (4) telecommunications. Over the next fifteen years, NOAA scientists will exploit these technologies in developing an integrated Global Earth Observing System of Systems (GEOSS), and to maintain existing capabilities for monitoring the status of LMRs and the quality of the ecosystems they inhabit.

The research needed to provide NOAA managers with the necessary information to achieve the agency's stated goals in managing LMRs is taxon specific. That is, commercial fisheries in Federal waters are currently managed under the primary mandates of the MSFMCA. Managers require specific information to meet these mandates. Similarly, marine mammal management is codified in the Marine Mammal Protection Act, while sea turtles are primarily managed under the ESA. Again, the information needs of managers are dictated by a combination of mandates found in Federal law, regulations, and agency agreements. In addition, other statutes also direct or otherwise influence the way NOAA manages LMRs.

Appendix C provides an overview of how LMRs are managed in an ecosystem context in the Bering Sea, which provides an example of the integration of research and management, as well as many potentially beneficial uses of ocean and coastal resources.

II. Partnerships Necessary to Effectively Address the Emerging Issues

The intersection of jurisdictions and the overlap of expertise will identify necessary points of coordination among resource agencies, councils, commissions, and institutions for effective ecosystem research and management. These include:

- Federal authorities such as NOAA, regional fishery management councils, U.S. Environmental Protection Agency, U.S. Corps of Engineers, U.S. Department of Agriculture, U.S. Fish and Wildlife Service (USFWS), U.S. Geological Survey (USGS), U.S. Department of Defense, National Park Service, U.S. Department of Transportation-Maritime Administration, U.S. Coast Guard, and Minerals Management Service.

- State authorities such as state universities and colleges, interstate commissions, CZM agencies, fisheries management agencies, and other natural resource/wildlife agencies.

- Local authorities and institutions such as independent research institutions, planning commissions, and zoning boards.

- Tribes/tribal jurisdictions.

- International commissions and institutions implementing international science and management agreements governing multiple countries, and resource management departments of other countries and their associated research infrastructure.

- Management areas such as marine managed areas/ MPAs; National Wildlife Refuges; National Marine Sanctuaries; National Estuarine Research Reserves; fishery management areas; habitat restoration and special habitat conservation areas; marine mammal management areas; threatened or endangered species management areas; marine parks or historic wreck areas; military exclusion or operations areas; transportation/navigation routes; oil and gas lease areas; and relevant terrestrial and upland protected areas such as parks and coastal reserves.

Note: Management authorities or areas are considered relevant if they contribute directly or indirectly to the management or control of at least one of the factors having an impact on the ecosystem management area (see Appendix B for details).

IV. Benefits to NOAA, Constituents, and Society from this Effort

Coastal areas are among the most developed in the Nation. More than half of the population lives on less than one-fifth of the land in the contiguous United States. Coastal counties, including those along the Great Lakes, are growing three times faster than counties elsewhere, adding more than 3,600 people a day to their populations. Coastal and marine waters support over 28 million jobs and provide a tourism destination for 89 million Americans each year (see Leeworthy and Wiley, 2001). The annual value of the ocean economy to the U.S. is over $115 billion. The amount added annually to the national economy by the commercial and recreational fishing industry alone is over $48 billion, with an additional $6 billion in direct and indirect economic impacts from aquaculture. With its Exclusive Economic Zone (EEZ) of 3.4 million square miles, the U.S. manages the largest marine territory of any nation in the world.

NOAA has a unique mandate from Congress to be a lead Federal agency in protecting, managing, and restoring marine resources. To meet this mandate, NOAA scientists and their external partners contribute world-class expertise in oceanography, marine ecology, marine archeology, fisheries management, conservation biology, natural resource management, and risk assessment. To achieve balance among ecological, environmental, and social influences, NOAA has adopted an EAM as previously described.

NOAA's mission to conserve, protect, manage, and restore LMRs and coastal and ocean resources is critical to the health of the U.S. economy. Research producing the best available scientific information is critical to the success of this mission. In addition, NOAA has made a commitment to improve its ability over the next 20 years in predicting the impact of climate change and variability on the productivity and survivability of species important to commercial fisheries and subsistence fishers. Absent this ability, calamitous changes in the abundance or distribution of LMRs would only be identifiable after the fact, if at all, and most likely not able to be mitigated. It is critical that NOAA develop and implement the research programs necessary to provide reliable predictions regarding LMR availability to provide adequate lead times to regional managers and constituents.

Finally, developed countries such as the U.S. have a responsibility for stewardship of marine ecosystems and for setting standards to protect and manage the shared resources and harvests of the oceans. Believing that it is possible to balance sustainable economic development and healthy, functioning marine ecosystems, NOAA seeks to provide an example for the rest of the world in comprehensively managing resources of the world's oceans and coasts.

White Paper #3

Freshwater Issues

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I. Description of the Issue

Freshwater is our most precious and finite natural resource -- the total amount of freshwater in lakes, streams, rivers, and groundwater accounts for less than one percent of water on the Earth. As human populations increase, so does competition for water to meet societal needs versus to maintain the needs of the earth's biological systems. Additionally, there are increasing demands for recreational use of water in streams, river, and lakes, and increasing awareness of interacting hydrological, ecological, and social systems required for a healthy environment, dynamic economy, and equitable allocation and use of freshwater.

By the year 2020, the human population in the United States will exceed 335 million, with the majority living in coastal counties that account for only 17 percent of the U.S. land area (excluding Alaska). Increasing population density, coupled with faster-growing economies in coastal areas, will require resource management policies that are built upon a holistic approach to managing ecological goods and services, while at the same time accounting for human demands on water resources (Palmer et al., 2004). This will, for example, increase the effects of drought on economic, social, and ecological systems, including delivery of freshwater to estuaries and the coastal ocean (WGA, 2004). A consequence will be the need for an improved drought forecasting capability developed at the appropriate spatial scale. Increasing populations also bring increased biological threats and the need to better forecast and mitigate their effects. For example, aquatic invasive species (AIS) are a global problem threatening sectors of the U.S. economy by changing and reducing the beneficial societal uses of its coastal ecosystems. The pathways by which invasive species reach U.S. coastal ecosystems all involve human activities, especially those related to commerce and trade. Aquatic invasive species can have dramatic effects on ecosystems, including altered trophic structures, reduced productivity, and an increased risk of extinction of native species. Annual costs to the U.S. economy have reached hundreds of millions of dollars per year and are increasing. While the impact of invasive species is not unique to freshwater ecosystems and affects all coastal ecosystems, the Great Lakes is a "hot spot" for invasive species introductions to major interior sections of the U.S. and Canada, having 162 documented introductions representing fishes, invertebrates, aquatic plants, algae, and pathogens.

According to the Council of State Government's report entitled "Water Wars" (CSG, 2003, p. 1):

"Water, which used to be considered a ubiquitous resource, is now scarce in some parts of the country and not just in the West as one might assume. The water wars have spread to the Midwest, East and South as well. . . .   Recent water shortages are putting water rights conflicts in the spotlight. These conflicts are occurring within states, among states, between states and the federal government and among environmentalists and state and federal agencies."

The report of the National Science and Technology Council's Subcommittee on Water Availability and Quality (NSTC, 2004, p. 17) explains that:

"Without quantifiable and scientifically defensible estimates of environmental water requirements, water gridlock–intense competition among irrigation, navigation, municipal supply, energy, and the environment–is unlikely to be resolved."

In 2000, the total amount of withdrawals (not necessarily consumption), including saline water, in the United States approached 400 billion gallons per day (Hutson et al., 2004). Nearly 40% of this amount was used in thermo-electric power generation and about one-third for irrigation and agriculture use (Figure 1). Domestic use accounted for only one percent; the remaining amount was to meet industrial and public water supply needs. It is anticipated that future increases in consumptive use, energy production, and irrigation will accentuate the challenge of achieving an equitable balance between ecosystem conservation and the economic vitality of watersheds and estuaries.

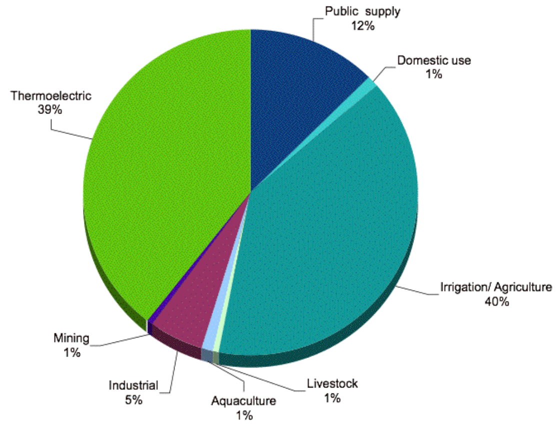

Figure 1. Freshwater use in the U.S. in 2000 as a percentage of total freshwater (surface and groundwater) withdrawl (345.6 billion gallons per day; Hutson et al., 2004).

These environmental and societal drivers shape the fundamental challenges for NOAA in the next fifteen years. The primary challenges for NOAA are:

1. Framing the tradeoffs that decision-makers will face in balancing the conservation of freshwater and coastal ecosystems with demands for safe drinking water, crop irrigation, recreation, and flood control;
2. Forecasting climate change and climate variability effects upon the freshwater-coastal ecosystem and availability of water for human uses;

3. Breaking down the persistent view that there are two separate ecosystems (freshwater and coastal), and advancing a new understanding of the critical coupling of resource pathways and food webs between the two environments;
4. Understanding the linkage between water quality and quantity and public health and developing models and forecasts to aid in reducing human health risks in freshwater and coastal ecosystems; and
5. Delivering relevant science and information for effective decision-making.

NOAA and its partners must rise to these challenges on both national and international scales if the nation is to maintain functioning freshwater, estuarine, and coastal ecosystems that support biodiversity and sustainable resource use, promote prosperous coastal communities, and pose minimal human health risks.

II. Science Capabilities Necessary to Support Future Decision-Making

The recommendations of the National Council for Science and the Environment (Schiffries and Brewster, 2004) on water sustainability and security underlined fundamentally new approaches for balancing societal water needs with those of the Earth's ecosystems while assuring sustainability. Specific recommendations that NOAA's mission supports through its science include:

- Managing water resources based on hydrological and ecological linkages (rather than political boundaries) and equitable allocation for people and ecosystems;
- Developing a robust set of indicators for sustainable water management;
- Advancing inter-disciplinary scientific research;
- Closing the gaps between water science and water policy;
- Developing a broad spectrum of capabilities to assure water quality, sanitation, and security; and
- Improving education and outreach.

In addition, the General Accounting Office has noted that the U.S. lacks a national system to assemble key information on economic, environmental, social, and cultural issues (GAO, 2004). Support for effective decision-making on freshwater issues will require an integration of economic, environmental, and social/cultural issues around each of the recommendations made by the National Council for Science and the Environment (Schiffries and Brewster, 2004). The need for integration highlights the critical need to meld physical and biological sciences with social and economic sciences if NOAA's data and information products are to effectively support regional decision-making.

Future water resource conflicts will be intense in freshwater systems. It is therefore critical that NOAA's scientific products help decision-makers understand fundamental tradeoffs between human needs for water and environmental services provided by freshwater in rivers and estuaries. Resolving these fundamental tensions will require that NOAA develop a sound scientific understanding of watersheds and coastal regions as a single ecosystem, and deliver science products that inform decisions regarding allocations of a diminishing resource. Developing valuation systems (e.g., the cost effectiveness of water recovery systems versus the ecological consequences of extracting larger amounts of freshwater for agriculture, power generation, and industrial purposes) to assist in evaluating tradeoffs is equally important. NOAA must also deliver timely scientific information in support of major decisions regarding climate variability and change, and protection of freshwater-dependent ecosystems from the harmful effects of pollution and habitat alteration arising from coastal development. Prototypes of such approaches already exist (Kimmerer, 2002; Powell et al., 2002). The development of multi-scale socio-ecological models will be essential for informing policy and management decisions by providing a wider range of alternatives for achieving resource sustainability and accounting for variability at different temporal scales (Costanza et al., 2002).

Understanding and reducing human health risks from degradation of freshwater and marine ecosystems is a major challenge facing our Nation. NOAA's Oceans and Human Health Initiative has recently begun to investigate how ecosystem conditions in the oceans and Great Lakes affect human health and well being, and strengthening these capabilities will improve our ability to respond to this challenge. Research, monitoring, modeling, forecasting, and education are all key elements used by NOAA in such integrated science programs. NOAA's strong capabilities in ecosystem modeling and integrated sustained observation programs for coastal ecosystems will enable stronger support of a wide range of activities and improve ecological forecasts. These integrated scientific capabilities allow NOAA to help guide a wide range of ecosystem restoration and species recovery efforts that explicitly include humans as part of the ecosystem (e.g., South Florida, Pacific salmon), and also to develop the NOAA National Center for Research on Aquatic Invasive Species. This new center provides communication and coordination for the agency's research investments in support of understanding, preventing, responding to, and managing AIS invasions in the U.S. coastal ecosystems.

Meeting the Challenge: NOAA Science Priorities

To help meet the Nation's future freshwater ecosystem challenges, NOAA will need to collect and deliver accurate ecosystem-level information to managers. This will require a shift from traditional small-scale research and piecemeal management schemes to large-scale, holistic frameworks for both science and policy. The task must be to predict the consequences to ecosystems and society of alternative management strategies, and provide these predictions to decision-makers in a timely and transparent fashion. Thus, NOAA must be prepared to play a key scientific role in evaluating ecosystem responses to alternative ecosystem management plans, many of which will be locally-developed "bottom up" initiatives encompassing diverse economic and environmental interests.

NOAA's research priority in meeting one of the Nation's biggest challenges – the looming conflict between ecosystem conservation and increasing human use of water resources – will be to develop advanced models that accurately forecast water supplies, as well as a new suite of hydrologic models that describe how freshwater environmental attributes will shift with climate change and land uses. The use of high-resolution (i.e., 1 km spatial resolution) distributed hydrologic models has not been practical in operational forecasting until fairly recently. It is now feasible to develop and implement high-resolution rainfall-runoff models due to the advent of high-quality spatial data, the ability to process that data using geographical information systems (GIS), and the improvement in the spatial estimation of precipitation as a result of the Next Generation Radar (NEXRAD) network. As part of the calculations necessary to produce streamflow forecasts, these models have the capability to obtain estimates of information, such as soil moisture, snow water equivalent, soil temperature, and other ecosystem habitat parameters, at the same high resolution. These new forecasts will inform the decision-making process for agriculture, water, and ecosystem managers alike.

NOAA is leading the way in implementation of these greatly enhanced services by placing the proposed Community Hydrologic Prediction System (CHPS) at the core of its Water Resources Initiative. CHPS will allow scientists to couple different models, improve forecasts, and expedite the research-to-operations timeline. These goals will be achieved by developing models directly in the same environment used in NOAA's National Weather Service river forecast operations. CHPS will include the ability to couple models operating at disparate temporal and spatial resolutions, such as groundwater models and surface hydrology models. CHPS will also build on standard sets of tools and protocols, and utilize open data modeling standards. It will support data assimilation, high-resolution distributed forecasts, including uncertainty estimates, data assimilation, and the operational implementation of advanced water quantity and quality forecast models not currently available. This open architecture of CHPS will encourage partnerships with other Federal and non-Federal organizations.

Understanding and predicting how shifting climate regimes will affect water supplies and freshwater-coastal ecosystems are NOAA's second major science priority. Climate cycles have strong influences on annual streamflows, freshwater ecosystem structure and function, and abundance of important aquatic species (Kiffney et al., 2002; Greene et al., 2005). Long-term climate change is likely to alter flow regimes in ways that will adversely affect water availability for both human consumption and the recovery of important species (Mote et al., 2003; Beechie et al., 2006). NOAA will need increased capabilities to be able to forecast how such climate changes will affect flood and drought intensities, productivity of freshwater and coastal ecosystems, drinking water, and recreational and shellfish beaches.

NOAA must also be able to predict where the ecological effects of decadal scale wet or dry regimes will be most dramatic, and provide scientific information on the ecological consequences of different freshwater management approaches to meet the human demands for freshwater.

Just as important as the development of new models is the procurement of data required to drive those models, and identification of new uses for those observations. In collaboration with the National Aeronautics and Space Administration (NASA), NOAA will be exploring the use of space-based observations to improve potential evapotranspiration estimates, and to assimilate snow water equivalent and soil moisture observations into the new high-resolution hydrologic models. It is estimated that the use of new observations, in coordination with better estimates from dual-polarization radars and enhanced automated surface observation stations, will greatly improve the skill in short- and long-term forecasts of streamflows, in ranges from droughts to floods. NOAA is gaining the resources that will also increase the amount, type, and accuracy of water resource information available to NOAA and its external customers. The integration efforts of NOAA's Water Resources Initiative will make use of the efforts of the National Integrated Drought Information System, NOAA's Environmental Real-time Observation Network, the National Water Quality Monitoring Network, and the emerging IOOS.

NOAA's third science priority is the development of new ecosystem response models to help predict how resource decisions will impact the delivery of ecosystem goods and services, including the abundance of commercial and recreational aquatic species. Breaking down the persistent view that freshwater and coastal ecosystems are separate and developing a new understanding of integrated ecosystems will be needed to better characterize the consequences of water management decisions. Freshwater and marine environments are tightly coupled by the delivery of sediments, contaminants, and nutrients from watersheds to estuaries and coastlines, as well as migrations of anadromous and catadromous species between marine and freshwater habitats. NOAA will require a greater capacity to predict the ecosystem consequences of human actions such as reduced sediment supply by reservoir construction/operation and its effect on coastal erosion, increased delivery of pollutants to the freshwater-coastal ecosystems, and altered nutrient fluxes between freshwater and coastal environments. In turn, this will require much improved scientific understanding of the complex linkages between freshwater and coastal food webs at different spatial scales and temporal resolutions. Biomass fluxes between freshwater and coastal environments - mainly anadromous fishes such as striped bass, American shad, sturgeon, and Pacific and Atlantic salmon - are critical pathways by which food resources and nutrients are transferred between freshwater and saltwater food webs, and models that help predict how changes in abundance of these species impact freshwater-coastal ecosystems are sorely needed. Likewise, for species that make transitions between freshwater and marine systems, models that accurately represent the drivers of these populations will require integration of freshwater and marine processes (Greene et al., 2005). NOAA must also improve its capabilities in understanding and modeling critical drivers on species and food webs, including water quantity and quality changes, non-native species introductions, fishing, altering physical processes, and other human impacts.

NOAA's fourth science priority is to provide managers with a better understanding of the human health consequences of freshwater and coastal ecosystem degradation. A variety of contaminants can adversely impact drinking water, recreational waters, and fish and shellfish leading to illness (e.g., see Health Canada, 1995). Chemical contaminants come from both point and non-point sources of pollution, with urban/suburban runoff and atmospheric deposition increasingly becoming major sources. Microbial contaminants such as viruses and bacteria can come from sewage treatment plants, septic systems, agricultural livestock operations and wildlife, and combined sewer overflows after storm events (Whitman and Nevers, 2003). Another threat is HABs. For example, bloom-forming, toxic cyanobacteria occur worldwide in nutrient-enriched freshwaters and have caused human and animal illness/mortality. HABs can have disastrous short- and long-term consequences for water quality and resource utilization (e.g., see Paerl and Millie, 1996). While drinking water contamination is a major concern, chemical contaminants, microbial contamination, and HABs also pose public health concerns through contact with contaminated water during recreation (Health Canada, 1998; WHO, 1998) and indigestion of contaminated fish and shellfish.

NOAA has a significant role in identifying and reducing human health risks through its research and application of its research findings at the intersection of meteorology, biological oceanography, hydrology, microbiology, toxicology, and watershed and coastal processes. This will require NOAA to increase its multidisciplinary approach to understand and forecast coastal-related human health impacts to improve public health and natural resource policy and decision-making. Predictive models and monitoring networks will need to be reconfigured to provide data and information products relevant to water quality impacts on human health. The NOAA Center of Excellence for Great Lakes and Human Health (Brandt et al., 2004) is a multidisciplinary research effort to understand the inter-relationships between the Great Lakes ecosystem, water quality, and human health. There are other NOAA Centers of Excellence with a scientific focus on ecosystem forecasting to minimize risks to human health at the watershed–coastal marine intersection, including the proposed Northern Gulf of Mexico Cooperative Institute.

NOAA will also need to expand its science-based ecosystem approach to restoring habitat structure and function in order to ensure that drinking water flowing through watersheds and into the Great Lakes and marine coastal areas do not present a risk to human health. This need is exemplified in the Great Lakes because its coastal waters are potable. There are 121 watersheds feeding into the Great Lakes, with approximately 44 million people living in the Great Lakes basin (20 million reside in the U.S.) and depending on the Great Lakes for drinking water. Once in place, the NOAA Great Lakes Habitat Restoration Program will address habitat loss and degradation, two issues that span the entire Great Lakes basin as well as other coastal areas nationwide. Strong partnerships and sharing of expertise, knowledge, and resources are the key to effective restoration and protection.

Finally, NOAA's science must be translated in transparent ways for use by managers and decision-makers in order to yield its full benefit to society. NOAA will need to develop more efficient mechanisms for the delivery of scientific information to managers and policy makers. Regional ecosystem management plans will likely be large and complex, describing strategies and actions aimed at improving the functioning of an ecosystem. Implementation of these plans, however, will occur through multiple institutions that govern or influence only a particular geographic sub-region of the ecosystem or subset of the ecosystem's functions, or both. To the extent that the ecosystem components are interconnected, so too must the laws and regulations that institutions enact and implement; the stronger the connections among the ecosystem's components, the stronger must be the connections among the institutions. Moreover, socioeconomic factors such as population growth, economic development, and land use can be influenced by laws and regulation, but not fully determined by these formal governance mechanisms. Instead, these factors are the aggregation of many small, individual decisions. NOAA must improve its understanding of the dynamics of these economic and social spheres in order to develop more efficient methods of delivering relevant scientific information. This drives the need to interweave social and economic models with physical, biological, and ecosystem models.

Better monitoring is at the core of an effective EAM, and better synthesis of data will be essential to effective decision-making regarding freshwater management. The stakes are high in meeting the human needs for freshwater while sustaining ecosystem goods and services. The need for regional coastal observing systems has been highlighted recently in a number of studies as well as by the NOAA in its strategic plan, the National Oceanographic Partnership Program, and the IOOS Development Plan. Continual assessment of the status and trends in watershed and coastal environments permits identification of perturbations that may signal changes in the ecosystem, puts current trends into an historical framework, allows scientists to differentiate true environmental change from variance, and provides a context in which to assess the impact of predicted changes. The development of a coastal component of IOOS is a fundamental need in coastal, marine, and Great Lakes regions.

III. Partnerships Necessary to Effectively Address the Emerging Issues

Largely due to jurisdictional boundaries, agency mandates, and nascent scientific strategies to support integrated management, the overall goal to balance the multiple demands of the limited freshwater resources of the Nation (or specific coastal watersheds) has remained elusive.

First and foremost, NOAA must provide leadership for developing a holistic response to freshwater issues for the year 2020 and beyond. Meeting these enormous challenges will require partnerships with academia, the private sector, other Federal agencies, and international institutions to bring to the forefront: 1) technology necessary for more environmentally sound use, allocation and conservation of freshwater; 2) ecological indicators and forecasts at multiple scales; and 3) an improved understanding of the interactions among the atmosphere, biosphere, and hydrosphere as they affect the coupled marine/Great Lakes and watershed ecosystems.

This will also require fostering stronger partnerships with institutions that have inland, coastal, and atmospheric mandates, including the U.S. Departments of Agriculture, Interior, and Defense; U.S. Environmental Protection Agency (EPA); USGS, and NASA. NOAA should also strengthen scientific cooperation and information exchange with the international community in order to cut across political and jurisdictional boundaries. The importance of such linkages is exemplified in the Great Lakes where joint management of water resources with Canada is essential. The International Joint Commission (a commission jointly appointed by the President of the United States and the Governor in Council of Canada) brings together international, Federal, state, local, private, and tribal entities to focus on specific water management issues. In addition, NOAA will need to establish closer and more effective partnerships with the Shared Strategy in Puget Sound, CalFed Bay-Delta Program, county and local emergency managers, and river basin entities such as the Delaware River Basin Commission, the Susquehanna River Basin Commission, and the Florida River Management Districts. This will further facilitate participation by local stakeholders to address specific issues and reach mutually acceptable management options.

IV. Benefits to NOAA, Constituents, and Society from this Effort

There is no resource more precious or finite than freshwater. Science-based ecological frameworks using "next generation" hydrologic and ecosystem models and forecasts are needed to inform local, state, and Federal decision-makers as they set goals and targets for adequate and reliable supplies of freshwater while meeting goals for ecosystem goods and services. The need and urgency for such a course of action have been articulated for many years, most recently by the National Science and Technology Council (NSTC, 2004), the U.S. Government Accountability Office (GAO, 2004), the NRC (NRC, 2004), and the National Council of Science and the Environment (Schiffries and Brewster, 2004). The societal benefits accrued from NOAA's ecosystem science in this area are:

a. Providing scientific data and expert counsel prior to any changes in the water budgets that may pose adverse environmental or social consequences;
b. Forecasting the amounts and timeliness of streamflow for

human activities and sustaining the production of ecosystem goods and services; and

c. Providing scientific information and management support on the supply and quality of water to protect, restore, and enhance aquatic ecosystems and human health.

NOAA’s water resources information should support the full range of stakeholders (e.g., farmers, utilities, water managers, land managers, wildlife managers, business owners, and decision-makers) with the science needed to make informed decisions on their operations, and allow them to plan for, rather than react to, the inevitable changes from shifting climate regimes (e.g., decadal scale changes from “wet” to “dry” periods). The freshwater allocation issue allows NOAA, working with partners, to help illustrate that protecting functioning ecosystems and conserving aquatic species will provide the natural services that benefits, rather then competes with, robust human societies.

The following are priorities for science to support an ecosystem approach to freshwater management:

- Develop next-generation models to forecast ecosystem-scale changes in water budgets in response to human demand and climate and land use change at annual and decadal scales. These models also need to inform the selection of alternative management strategies.

- Establish and facilitate integrated monitoring programs that provide a continuum of observations from the headwaters of watersheds to the coastal ocean to provide a holistic understanding of hydrologic cycles and biological status, trends, and interactions.

- Improve the knowledge base, technologies, and forecasts to minimize public health risks from consumptive use and contact recreation in coastal systems.

- Increase environmental literacy of the relation of climate and land use to freshwater supply and quality, as well as the tight biologic and hydrologic coupling between watersheds, estuarine drainage areas, and adjacent coastal waters.

These priority efforts can only be accomplished through partnerships based on an ecosystem approach to both science and management. A regionally based, nested ecosystem framework with a shared strategy to management will be needed. This shared strategy must acknowledge jurisdictions and management mandates, and provide a forum for collective decision-making. This will require that observations and research are also done with a greater degree of collaboration and are guided by and responsive to shared management needs, while still providing the science to meet the management needs. Ecosystem-based agreements assuring transparent data sharing and management will be essential to facilitate the necessary collaboration, as well as to provide information on the scale needed to inform shared decision-making. This is not just a theoretical construct, but has been initiated and put into action (e.g., with regard to South Florida Ecosystem Restoration under the aegis of Federal-state-tribal task force established in Federal law, and the Shared Strategy in Puget Sound, a voluntary, collaborative effort to recover ESA-listed Chinook salmon).

White Paper #4

Marine Zoning and Coastal Zone Management

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I. Description of the Issue

Background

Coastal areas and nearshore waters are subject to an array of human activities with steadily growing impacts on the natural ecosystems. While coastal watershed counties comprise less than 25 percent of the land area in the United States, they are home to more than 52 percent of the total U.S. population (USCOP, 2004). With increasing population and development pressure, coastal managers are faced with a need to manage competing demands for coastal and marine resources, minimize the impacts of development and other uses on the coastal and marine environment, and conserve coastal and marine ecosystems. In addition, a growing number of activities are taking place or are proposed in Federal waters from three to 200 miles offshore and in international waters beyond the EEZ.

Over the coming decades, the use of coastal and marine ecosystems will increase. Coastal land will continue to be in high demand for development, ports, and recreation. In addition, in marine ecosystems on the continental shelf, activities such as fishing, energy generation, mineral extraction, aquaculture, waste disposal, transportation, tourism, recreation, and other uses will compete for space.

The U.S. Commission on Ocean Policy envisions a desirable future for the oceans and Great Lakes, a worthy goal for NOAA to help achieve (USCOP, 2004, p. 4):

"In this future, the oceans, coasts and Great Lakes are clean, safe, prospering, and sustainably managed. They contribute significantly to the economy, supporting multiple beneficial uses such as food production, development of energy and mineral resources, recreation and tourism, transportation of goods and people, and the discovery of novel medicines, while preserving a high level of biodiversity and a wide range of critical natural habitats.

In this future, the coasts are attractive places to live, work and play, with clean water and beaches, easy public access, sustainable and strong economies, safe bustling harbors and ports, adequate roads and services, and special protection for sensitive habitats and threatened species. Beach closings, toxic algal blooms, proliferation of *invasive species, and vanishing native species are rare. Better land-use planning and improved predictions of severe weather and other natural hazards save lives and money."*

To achieve this vision, the busy seas and coasts will demand governance solutions to manage an intensifying and increasingly conflicting set of activities. With few exceptions, such as Oregon's ocean policy or state interests on offshore impacts on coastal zone resources, the past 30 years of CZM generally have seen the vast majority of states and territories focusing on the "dry side" rather than the "wet side" of the land and water margin. This is no longer the case. Already, states such as Massachusetts and California are exploring the potential of marine zoning as a tool to separate conflicting uses, achieve conservation and economic objectives, and enhance safety. The Pew Oceans Commission also advocates marine zoning to improve marine resource conservation, actively plan ocean use, and reduce user conflicts (Pew Oceans Commission, 2003).

Similar to zoning on land, marine zoning designates geographic areas for specific uses, such as transportation, conservation, non-consumptive uses, energy development, or fishing. Zoning is a way of reducing user conflicts by separating incompatible activities and allocating or distributing uses based on a determination of an area's suitability for those uses in relation to specific planning goals (Courtney and Wiggen, 2003). Ideally, zoning has numerous components including a map that depicts the zones and a set of regulations or standards applicable to each type of zone created (Courtney and Wiggen, 2003), as well as plans for implementation, monitoring, and enforcement. Zoning is also a tool for resource management, conservation, and restoration.

In their discussion on ocean zoning in the Gulf of Maine, Courtney and Wiggen (2003, p. 7) note that:

"ocean zoning is… complex in that it needs to address and manage activities on the ocean surface, in the airspace above, throughout the water column, and on and beneath the seabed. It is conceivable that one area of the ocean could support multiple uses (by different sectors) or several management objectives simultaneously and it is also possible that one use or management objective would preclude all others. Ocean zoning may also have a temporal dimension."

Like other ocean management tools, ocean zoning often involves tradeoffs between competing uses. These conflicts may be more explicit within a zoning scheme as uses and use prohibitions are spatially delineated. However, zoning also offers an opportunity to better assess the tradeoffs associated with different management actions. Assessing the social and economic costs and benefits of different management options within a zoning framework allows managers to look at not only who gains and loses, but also where those gains and losses are likely to occur, and to better predict unintended consequences and their impacts.

For example, many commercial and recreational fishers are concerned about potential restrictions to fishing from marine reserves or "no take" MPAs. Fisheries are a historically important and socioeconomic relevant use of the coastal zone with a well established constituent base. Because of the many types and widespread nature of fisheries, establishing marine reserves almost anywhere in U.S. waters is invariably contentious to at least some fishers. The socioeconomic and cultural impacts on historic uses of a specific area should be balanced with the sustainability and biodiversity protection that marine reserves have been shown to provide.

While the Federal government retains the power to regulate commerce, navigation, power generation, national defense, and international affairs throughout state waters, states have the authority to implement zoning based on their right to manage, develop, and lease resources throughout the water column as well as on and under the seafloor (USCOP, 2004). From a Federal perspective, state ocean zoning plans should integrate state CZM programs with offshore activities.

Marine zoning in Federal waters may be modeled after use restrictions on Federal public lands. As Courtney and Wiggen (2003) note (p. 8), "federal lands share with the ocean several important characteristics: public ownership, high natural resource and economic value including recreation; policy debate over resource conservation versus economic utilization, multiplicity of agencies and laws; and a significance to local, regional, and national interests." However, marine ecosystems feature highly mobile resources and there is often great difficulty in controlling access to marine systems; thus, zoning in these areas might require a somewhat different approach to zoning currently in place on land.

Marine zoning can be an effective tool to minimize the risk of damage to habitats and resources. Risk assessments require three types of information: 1) the classification of ecosystem components as delineated by their vulnerability to environmental stressors, such as food supply, mechanical disturbance, or contamination; 2) the distribution and degree of effort of human activities in the areas of concern; and 3) the impact of these activities on specific ecosystem components. The last requires knowledge of the sensitivity and recoverability of damaged habitats and biota. Informed with these assessments, zoning can be established to conserve or minimize loss of ecosystem diversity, including rare or endangered species and fragile habitat structures. Furthermore, establishing zones restricting specific human activities establishes baseline conditions for evaluating the impacts of the same types of activities in similar but unmanaged areas. Notably, although the suite of human-activity stressors can be broad, risk assessments for these rely largely on a common set of data for habitats, biota, and ecosystems processes.

MPAs are a component of a comprehensive marine zoning plan. Applied widely throughout the world, MPAs are a management tool that governments use to protect and restore resources in estuarine, nearshore, and offshore areas. The U.S. currently has an estimated 2,000 marine managed areas established by approximately 200 state and Federal programs (see http://www.mpa.gov). NOAA is now working with Federal and state agencies and other stakeholders to develop a national system of MPAs - including Federal, state, and perhaps tribal and local sites - to protect representative habitats as well as natural and cultural resources of national and regional importance. Beyond the EEZ, increased economic activity and global conservation agreements will require a higher level of cooperation, and have already led to calls for the creation of high seas MPAs.

While MPAs are an integral part of a larger ocean zoning scheme, zoning is also used as a tool within MPAs, most notably domestically within national marine sanctuaries and internationally by the Great Barrier Reef Marine Park in Australia. NOAA's National Marine Sanctuary Program (NMSP) has the authority to establish zones to help protect sanctuary resources and qualities from the impacts of human uses. As national marine sanctuaries have used zoning for over 20 years to protect resources and manage conflicting uses, the NMSP's experiences and techniques will be a valuable component of considering broader ocean use zoning.

In the coastal zone, land use planning, habitat restoration, land conservation, and the development of new technologies to mitigate environmental impacts will continue to be the primary approaches to reduce the impacts of human activities. Current patterns of growth that encourage low density sprawl and consume agricultural and forest land are a major threat to water quality and habitat. A few states are now working to promote "smart growth" which advocates compact, transit-oriented development and conservation of resource lands.

Local governments are responsible for most land use decisions in the coastal zone, and these decision-makers need information, data, tools, and technologies, as well as a directed education program to assist them in minimizing the impacts of new development, protecting sensitive areas, and planning for the potential impacts of climate change, sea level rise, and coastal hazards. States also play an important role through the implementation of the Coastal Zone Management Act. In 2004, the Coastal States Organization sponsored a survey of state coastal resource managers to better understand their science and technology needs. Managers identified land use and habitat change as their top two management concerns at both the national and regional level (CSO, 2004).

Over the past half century, there has been tremendous losses in tidal and nontidal wetlands, seagrass beds, and other vital habitats. The joint EPA/NOAA/USFWS/USGS *National Coastal Condition Report II* (EPA, 2005, p. ES-3), states that the "indicators that show the poorest conditions throughout the United States are coastal habitat condition, sediment quality, and benthic condition." While many inputs of nutrients and chemical contaminants have been reduced through source reduction and point source controls, non-point sources of these pollutants continue to be significant threats to coastal and marine habitats.

These habitats must be protected from further degradation and restored to ensure healthy, functioning ecosystems as well as provide for the sustainable production for the Nation's fisheries among other ecosystem services. Protecting and restoring coastal habitats requires a watershed approach to comprehensively address threats from physical alterations, pollution, and other impacts. These efforts require not only long-term ecosystem monitoring efforts, but directed research as well. Once thought to be the sole responsibility of government, land conservation and restoration have increasingly been undertaken by private conservation organizations at the national, state, and local level.

The development of new technologies based on research and monitoring data to mitigate environmental impacts will become an increasingly important tool to restore and maintain healthy watersheds, coasts, and oceans. These range from new techniques for stormwater management, to oil spill cleanup technologies, to vessel monitoring systems that help enforce fisheries regulations, to accurate and timely forecasts and coastal modeling efforts. As new technologies become available, they will serve as valuable tools to help resource managers protect and restore coastal and marine ecosystems.

NOAA's Role

NOAA's mission – to understand and predict changes in the Earth's environment and conserve and manage coastal and marine resources to meet our Nation's economic, social and environmental needs - outlines a major role for the agency in preparing to meet these challenges (NOAA, 2005a). As the NOAA Strategic Plan notes (p. 4), "NOAA has a specific mandate from Congress to be a lead Federal agency in protecting, managing, and restoring coastal and marine resources."

Specific authorities for NOAA's responsibilities that relate to CZM and marine zoning include:

- Coastal Zone Management Act (1972)
- Coastal Zone Act Reauthorization Amendments of 1990 (CZARA) – Section 6217
- MSFCMA (1976)
- Oil Pollution Act (1990)
- Coral Reef Conservation Act (2000)
- ESA (1973)
- National Marine Sanctuaries Act (1972) and site-specific statutes
- National Offshore Aquaculture Act (2005)
- Executive Order 12906 (Coordinating Geographic Data Acquisition and Access)
- Executive Order 13158 (Marine Protected Areas)
- Executive Orders 13178 and 13196 (Northwestern Hawaiian Islands Coral Reef Ecosystem Reserve)

A key challenge to integrated management of the coastal and marine environment is the fragmented nature of existing authorities, plans, and programs. Current ocean plans and zones are typically based on the requirements of a particular sector and/or geographic location, with little recognition of its relationship to other uses, or to the complexity of the underlying ecological system. This was noted by the U.S. Commission on Ocean Policy and the Pew Oceans Commission, both of which recommended significant organizational changes to address the problem. In the absence of these major changes, NOAA will need to take a leadership role in working with other Federal, state, and tribal authorities responsible for coastal and marine decision-making. New structures and processes will need to be established to provide a framework for integrated decision-making, and additional scientific understanding will be needed to inform these processes. Some efforts already have begun through the U.S. Ocean Action Plan and Executive Order 13158 (Marine Protected Areas).

II. Science Capabilities Necessary to Support Future Decision-Making

To address the complexity of coastal and marine management issues, research and the synthesis of existing research for use by managers and decision-makers is needed in a wide range of areas as noted below. A unified concept of habitat types and communities, and thus an ecological classification, is of fundamental importance to a suite of marine issues such as the assessments of CZM areas, MPAs, environmental quality reports, and fisheries management. It will be increasingly important to be cognizant of the structural, compositional, and functional properties of ecosystems and habitats as they relate to specific issues in the coastal zone, and to integrate these attributes together to form a more coherent, ecosystem-based approach to coastal management efforts.

Natural Science (NOAA National Marine Protected Areas Center, 2003)*:*

- <u>Resource characterization</u> – to improve the understanding of the extent, location, life stages, and quality of natural and cultural resources in the coastal and marine environment.

- <u>Seafloor Mapping</u> – to improve bathymetric data collection and information about the composition of the seafloor.

- <u>Effectiveness of Best Management Practices (BMPs)</u> – to provide data on the effectiveness of recommended practices to mitigate the impacts of human activities in the coastal zone and marine environment (e.g., pollution control, aggregate extraction, coastal engineering).

- <u>Monitoring</u> – to continue to collect baseline biological, physical, and chemical data in order to assess changes over time. Monitoring is an essential component of adaptive management, and is needed to understand resource status and trends, oceanic and anthropogenic factors influencing resource health, and responses to management actions, and to predict recovery trajectories.

- <u>Species</u> – to continue to collect life history and habitat requirements in order to determine the appropriate types of management tools to employ, including spatial and temporal closures, spawning closures, habitat protection and restoration, and take restrictions.

- <u>Habitat</u> – to improve mapping and trends analysis, and to enhance the understanding of the functional linkages between habitat types (including watershed impacts) and habitat sensitivity and recoverability.

- Connectivity – to understand the linkages between species, their life stages, and priority habitat areas for conservation.

- Restoration science – to establish the scientific foundation for restoring coastal and marine habitats and their functionality, including efforts to restore "dead zones."

- Chemical contaminants – to continue to identify chemical impacts and true effects levels, including sub-lethal effects which lead to reduced viability in combination with other environmental stressors (Peterson et al., 2003), effects on egg and larval stages, links to HABs, and identification of sources and sinks in coastal and ocean systems.

- Mariculture – to improve the understanding of the impacts of coastal and shelf aquaculture on ecosystems.

- Nonindigenous species – to improve the early detection, treatment, and prevention techniques associated with invasive species.

- Cumulative effects – to understand the cumulative and secondary impacts of multiple stressors on coastal and marine ecosystems.

Social Science (NOAA National Marine Protected Areas Center, 2003)*:*

- Patterns and types of human uses of coastal and marine environments – to identify how and where coastal and marine areas and their resources are being used, both for extractive and non-consumptive purposes.

- User conflicts – to understand how different uses conflict, how these conflicts can be minimized and how uses can be prioritized in ways that provide maximum protection.

- Attitudes, perceptions, and beliefs – to identify the underlying motivations that may influence human preferences, choices and actions (see White Paper #6).

- Economics – to describe economic conditions and trends associated with the allocation and use of coastal and marine resources, including market and non-market values, costs and benefits, and positive and negative impacts associated with activities, including impacts on coastal communities and industry.

- Cultural heritage and resources – to characterize historical and traditional artifacts in and from coastal and marine areas.

- Governance, institutions, and processes – to understand the formal and informal institutions responsible for managing coastal and marine resources, and elements of successful processes to integrate coastal decision-making.

Technology and Tools (CSO, 2004; Pew Oceans Commission, 2003; USCOP, 2004):

- Predictive models – to enable researchers and decision-makers to understand the potential consequences of sea level rise, other coastal hazards, watershed management BMPs, fisheries management options, HABs, designation of EFH, etc.

- Technology – to provide new tools needed for a wide range of coastal science and management activities, including pollution control, navigation, monitoring equipment, and lower cost remote sensing.

- Decision support tools – to enhance planning and public engagement (e.g., web-based GIS applications), improve emergency response (e.g., spills, collisions), and engage coastal decision-makers with the information needed for sound management.

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Research and technology development in these areas could significantly improve managers' ability to address the challenges they face in conserving coastal and marine resources. In addition, approaches are needed to meaningfully integrate natural and social science information in a spatial framework. This integration is a critical component of an EAM. As NOAA moves toward this integration, a common approach is the use of map overlays to illustrate different data sets for a geographic area, allowing managers to identify linkages between uses, conditions, and resources. However, not all data can or should be presented spatially, and methods must be adopted to integrate this critical contextual information. Another challenge is the effort required to identity, obtain, and format data for a common geographic boundary.

Such mapping tools have been used by MPAs in the U.S. and other countries to identify various zoning options for public review. These experiences highlight the risks and rewards of such a spatially integrated approach, as zoning maps can be problematic if introduced too early in the process, fail to include key data, or are based on data distrusted by stakeholders. However, they can be powerful consensus-building tools when stakeholders are involved in the data collection and when data analysis and decision rules are transparent.

To facilitate decision-making, scientists and managers will need to engage in a continuous dialogue that guides research priorities and delivers scientific results in a form managers can use. This type of dialogue will likely need to be mediated through targeted education and outreach programs that provide the link between the separate research science and coastal management audiences.

III. Partnerships Necessary to Effectively Address the Emerging Issues

The complex suite of resource-dependent commerce, land- and water-based resource users, and conservation interests and goals requires an equally complex, participatory mix of public and private sector partners to support science to management action. Participants should include Federal, state, and tribal agencies; universities and institutes; industry; and NGOs. Lessons also can be learned from other countries and international organizations. Key partners include:

- Researchers, data/information collectors, and analysts are needed to research, collect, store, and analyze the data; test the technology; and develop the information necessary to support sustainable management.

- Trainers and educators are needed to develop the applications, tools, coursework, and information documents necessary to train, educate, and transfer information to on-site staff and managers who then apply what is learned.

- Resource managers are the front line people making the daily decisions affecting the health of the nation's resources. They apply the information and techniques to management problems; develop and adapt resource management plans in cooperation with the public; evaluate the effectiveness of management actions; and identify research necessary to conserve and restore resources. In addition to traditional resource managers (e.g., state, territorial, Federal, tribal, regional, local, and international) and the already robust management of coastal lands by the private sector (e.g., private forests and land with conservation easements), the nearshore marine environment is likely to see increased management by NGOs in partnership with government (e.g., The Nature Conservancy and other local and regional land trusts).

- Opinion makers, opinion influencers, and information sources (e.g., the media) play a significant role in enhancing public and decision-maker understanding of coastal and marine ecosystem issues, problems, and solutions; encouraging participation in decision-making; and influencing behaviors that affect coastal and marine resources. The ability to synthesize and transfer information to the public is critical to management success in this increasing complex management environment. Resource management initiatives cannot be optimized, and indeed are likely doomed to failure, without public "buy-in" and active support.

- Resource users and other stakeholders are critical partners in developing coastal management initiatives, including marine zoning efforts. Resource users often have significant impacts on natural and cultural marine resources, and resource management decisions may have substantial economic and social impacts on users. Activities of concern can be extractive (e.g., fisheries, oil and gas, sand and gravel, seabed mining, biopharmaceuticals, desalinization), non-extractive (e.g., tourism, recreation), constructive (e.g., development), agricultural, silvacultural, aquacultural, or conservation-focused. To be successful, coastal management efforts must provide opportunities for stakeholders to participate throughout the process. Stakeholders can also bring a wealth of knowledge about marine resources, uses, and impacts to inform decision-making.

- Government decision-makers, both elected and non-elected government officials, must be involved since they ultimately make the policy decisions; determine program direction; approve program cooperation and coordination, both domestic and foreign; and provide the funding and staff resources necessary for ecosystem-based management. Competition for limited fiscal resources will likely continue and even increase, as will the competition for use of coastal and marine resources, including those at the trans-boundary and deep-ocean levels.

NOAA can address the vast majority of ecosystem management questions and issues, and partner with the broad spectrum of agencies, organizations, industry, and the public identified above. Successful implementation will require not only unified action by the program components of the Ecosystem Goal Team, but also linkage with NOAA's Commerce and Transportation, Weather and Water, and Climate Goal Teams to address overlapping issues such as conflicts between marine transportation and other resource uses, and land use planning to mitigate coastal hazards and climate change.

IV. Benefits to NOAA, Constituents, and Society from this Effort

While the challenges of comprehensively addressing an integrated approach toward coastal management and ocean zoning are considerable, the consequences of failing to act are even more dramatic. The Ocean Conservancy, in partnership with many other NGOs, already has documented the phenomenon of "shifting baselines," or failing to see the cumulative changes in our environment because these changes occur over several generations (see http://www.shiftingbaselines.org). Coastal ecosystems around the Nation are bearing the impacts of excess nutrients, habitat loss, invasive species, and depletion of keystone species, all of which have led to significant degradation. This degradation is already leading to economic as well as environmental losses and must be reversed. NOAA clearly has the capability to conduct research, deliver information, and help society identify and set appropriate targets for long-term conservation and sustainability.

In addition, rationalizing the use of space within the coastal zone and the marine environment will provide a stable environment for economic growth in relatively new sectors, such as aquaculture and bio-prospecting. With sound zoning to minimize conflicts, as well as environmental safeguards, these activities could become part of a thriving, sustainably managed coastal and marine economy.

NOAA is well positioned to play a leadership role in helping local, state, and Federal decision-makers work with stakeholders to develop a comprehensive approach to coastal and ocean management. NOAA can provide this leadership, expertise, and tools by:

- Improving and expanding its ability to produce ecological forecasts and warnings in coastal and offshore regions, such as those associated with recent HABs and with telemetry efforts associated with the IOOS to improve near real-time coastal data delivery to managers;

- Providing the scientific support to build a truly integrated CZM capability for the U.S. that focuses on the land-water interface, as well as the EEZ and beyond;

- Providing the scientific knowledge and management support technology (including data management and visualization) necessary to objectively address the increasing impacts of land-based stressors and increasing use of the ocean and its resources;

- Developing strategies based on the best available natural science, social science, and economic data to manage fisheries and other competing uses of the Nation's marine resources in concert with the development of a national system of MPAs; and

- Transferring NOAA science, technology, and tools to Federal, state, and tribal partners responsible for managing the Nation's diverse coastal and marine resources.

NOAA's mission includes a responsibility to "conserve and manage coastal and marine resources to meet our Nation's economic, social and environmental needs." The laws that drive NOAA's programs and requirements also make clear that this mission must be undertaken not just for the current generation, but for the sake of future generations. NOAA's science programs and partnerships are the foundation of this effort, and must be more firmly linked to the management outcomes so critically needed in the coastal and ocean environment.

To this end, there are a number of specific management actions that NOAA can take:

- Complete and release the zoning policy paper for the NMSP, which outlines how the NMSP considers and creates zones within sanctuaries. This policy paper can serve as an example for other organizations on how to develop and implement zones within MPAs;

- Support the development of a national system of MPAs as a key element of a future marine zoning plan. The national system of MPAs is now being developed by NOAA and the U.S. Department of Interior in cooperation with other Federal, state, and tribal agencies as well as stakeholder groups. It will enhance the management of and linkages among existing MPA sites and programs, as well as facilitate regional planning processes to identify conservation priorities in need of additional protection;

- Work through the Subcommittee on Integrated Management of Ocean Resources (SIMOR), formed as part of the U.S. Ocean Action Plan to guide Federal agency coordination of ocean management. Through SIMOR, NOAA can help develop coordinated approaches to ocean zoning. Federal agencies can take a leadership role in moving toward zoning in Federal waters to accommodate the increasing number and types of uses; and

- Along with other Federal agencies, continue to work in partnership with coastal states and tribes as they begin to develop regional governance structures and management strategies. NOAA should bring together technical, scientific, and management staff responsible for key resources and uses within the same regions to form cross-disciplinary, cross-NOAA working groups. Through these regionally-focused groups, NOAA can enhance its capacity to integrate data within a spatial framework that will be fundamental to future zoning efforts.

White Paper #5

Ecological Forecasting

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I. Description of the Issue

The health of the U.S. economy is inextricably linked to the health of our Nation's ecosystems and the goods and services they deliver to our economy. Each year, U.S. ecosystems provide over $227 billion in added value to the U.S. economy (CENR, 2001) as well as other harder-to-quantify services and benefits such as waste detoxification and decomposition, air and water purification, maintenance of biological diversity, and recreational and spiritual renewal (Daily et al., 1997). Coastal ecosystems, in particular, provide a wealth of fisheries resources and recreational benefits, and are a potential source of life saving pharmaceuticals. These important ecosystems can also directly impact human health from exposure to contaminated water (e.g., from urban and agricultural runoff, pollutants, coliform, and other pathogens, and toxic algae) or contaminated food (e.g., fish and shellfish).

Sustaining productive ecosystems, and restoring damaged ones, depends on the ability to understand and predict the impacts of human activities and natural processes on those systems and to forecast ecological change. Policy makers, natural resource managers, regulators, and the public often call on scientists to estimate the potential ecological changes caused by these natural and human-induced stressors and to determine how those changes will impact people and the environment. During the last decade, using technological and scientific innovations, scientists have developed and tested forecasts in ways that were previously not feasible (Clark et al., 2001), signaling the emergence of a new and challenging science called "ecological forecasting."

What is Ecological Forecasting?

Ecological forecasts predict the impacts of physical, chemical, biological, and human-induced change on ecosystems and their components (CENR, 2001). Extreme natural events, climate change, land and resource use, pollution, and invasive species are five key drivers of ecosystem change (CENR, 2001) that interact across wide time and space scales (i.e., hours to decades and local to global; Figure 1). Ecological forecasts aim to understand, predict, and provide information to mitigate the impacts of these stressors on ecosystems. In much the same way that a weather or economic forecast can help society plan for future contingencies, an ecological

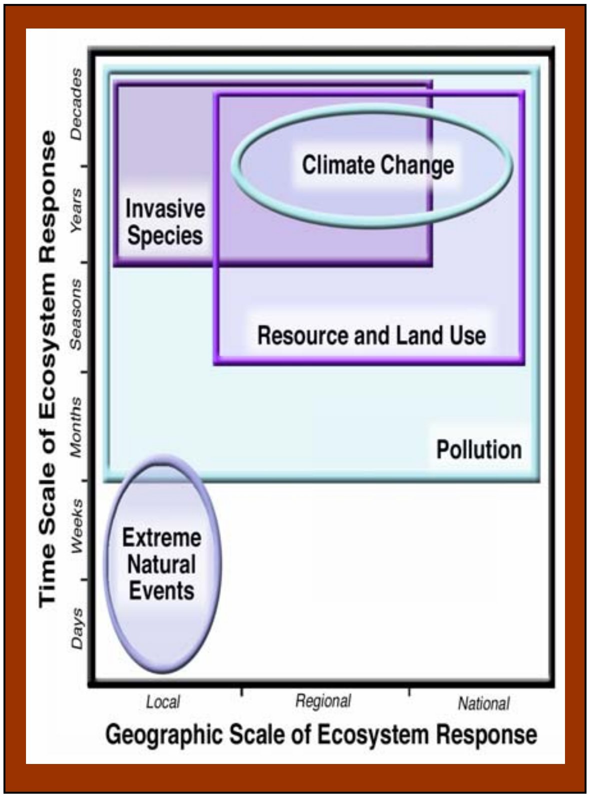

Figure 1. Time/Space Scale of Ecosystem Response. The five key ecosystem stressors – pollution, land and resource use, invasive species, extreme natural events, and climate change – can challenge the integrity of ecosystems and impede the delivery of their goods and services. These stressors can act alone or together, and their cumulative effects are poorly understood. Ecosystem responses are as varied as the inputs that strain them, playing out in scales from hours to decades and from local to global. Figure is reproduced from NOAA Technical Memorandum NOS NCCOS 1, p. 2.

forecast helps managers make informed decisions regarding alternative management scenarios and take appropriate actions to affect those conditions and better manage the Nation's coastal resources. Ecological forecasts give managers the tools to answer "what if" questions about the ocean and coastal environments and provide a bridge between science and policy. Ecological forecasts also have the potential to provide widespread societal and economic value to the country. These values include improved decision-making for coastal stewardship; mitigation of natural events and human activities (e.g., land-use practices, fishing); reduced risks to human health; reduced impacts of natural hazards; enhanced communication among scientists, managers, and the public; and overall, more effective prioritization of science.

Types of Ecological Forecasts

There are many types of potential ecological forecasts. Some will be predictions of what is likely to happen in a particular location in the short-term like weather forecasts (e.g., sea nettle swarms in the Chesapeake Bay, the landfall of harmful algal blooms (HABs), beach closings, drinking water quality, the movement of oil spills, and coral reef bleaching events). Others will focus on much longer-term and larger-scale phenomena (e.g., year-to-year variation in fish stocks, extinction risk of endangered species, new invasive species encroachments, rates of habitat restoration, effects of climate change on biota, and water quality and quantity).

Specific issues within each of these categories of stressors are listed below:

Extreme natural events – Such events may include extreme changes in water resources, severe spring storms and hurricanes, extreme climate variation (e.g., an exceptionally cold or warm year compared to the average), shifts in marine populations, hypoxic/anoxic events, and toxic algal blooms. The ability to predict the occurrence of these events and their ecosystem effects, as well as their interactions with other causes of change, is important for planning management and response activities.

Climate change – Climate change may include changes in sea level, large-scale ecosystem drivers (e.g., current patterns, storm tracks and frequency), nutrient flow regimes and the extent of "dead zones", the amount of precipitation, and river flow. Climate change may be reflected as a change in the mean or trend of a parameter, shifts in seasonal cycles, or extreme natural events (e.g., coral bleaching, ENSO). To plan for and minimize impacts of these events, resource managers need forecasts of the interaction of climate change and variability (e.g., in sea surface temperatures, freshwater input, coastal nutrients) with other stressors on ecological integrity; goods and services (e.g., fisheries, water quality and quantity), particularly the distribution and abundance of species; production of ecologically/economically important species; and the availability of clean water.

Land and resource use – Human use of land and resources can dramatically change the structure and function of an ecosystem. Fishing, for instance, can remove predators or prey in the food web, which may then cause changes in the abundance of less desirable species, some of which can cause a degradation of the overall quality of the system. The ability to predict the ecosystem consequences of various levels of fishing effort is critical for the management of ecosystem resources. Additionally, changes in coastal ecosystems may be linked to changes in land and resource use which are often associated with agriculture or local urbanization as well as the resultant nutrient loadings and deterioration of coastal habitat. Current needs include forecasts of changes in the health and productivity of ecosystems that are critical in providing food and recreation.

Pollution - Concerns about the presence of potentially harmful chemicals and excess nutrients in the environment remain a top concern. Current needs include forecasts of the effects of air pollution and land-based activities (e.g., agricultural production, forest harvest, urban growth and residential development, waste disposal, toxins) on aquatic ecosystems. The damage to the ecosystem may be direct (e.g., hypoxia/anoxia, HABs), or may impact its goods and services (e.g., contaminated fish and shellfish).

Invasive species - Invasive species are species that are introduced intentionally or accidentally from other geographic areas, and are capable of spreading rapidly and replacing native species. These invaders exist in nearly all U.S. ecosystems, pose potential threats to the integrity of biodiversity and ecosystems, and cost billions of dollars annually to mitigate. Current needs include forecasts of the conditions favorable to the introduction, spread, and ecological impacts of potential and already-introduced species.

Interactive and cumulative effects – Large aquatic ecosystems are subject to multiple causes of ecological change. For example, an extreme natural event may provide opportunities for new species invasions, and the success of that invader may be enhanced by altered climate (new precipitation and temperature patterns), use of land and related resources, and the level of pollution in the environment being invaded. The cumulative impact of threats may be greater than the sum of individual impacts. Building the ability to forecast the cumulative effects of these multiple stressors is one of the most significant challenges for applied ecology.

Thus, ecological forecasts can span a wide range of issues and space/time scales, reflect a diverse user community, and involve a multitude of biological factors (e.g., life history traits, behavior, species, population and ecosystem interactions) as well as physical and chemical factors. Ecological forecasts can also involve predictions that are independent of time and involve "scenario testing" or examination of alternative management scenarios (e.g., impacts of nutrient reductions, the setting of harvest levels, and ecological effects of sea level rise). Models are often used to conduct forecasts, but these are just one of many tools (e.g., satellites, sensors, test kits) that can be used and integrated to provide valuable ecological forecasts for management applications.

NOAA's Role in Ecological Forecasting

Ecosystem forecasts have been gaining momentum for the past few years, particularly among academics (Clark et al., 2001) and Federal agencies (NOAA, 2001). The National Science and Technology Council's Committee on Environment and Natural Resources report on ecological forecasting (CENR, 2001) stressed the Nation's need for developing forecasts of ecological change. Since 2001, NOAA has formalized the development of an ecological forecasting capability for resource managers through a partnership across all NOAA line offices and with universities and other Federal agencies across the country. The report of the U.S. Commission on Ocean Policy (USCOP, 2004) also highlights the importance of ecosystem-based management and its reliance on the development of predictive capabilities for ocean ecosystems, providing further justification for NOAA to undertake ecological forecasting to support its ecosystem-based management responsibilities.

NOAA has recognized the importance of ecological forecasting by including the development of prediction and forecasting tools as high priority areas it in its recently published five-year and 20-year research plans. In the NOAA five-year plan, the development of routine forecasting products for issues such as fish stock assessments, HAB forecasts, beach closings and water quality are listed as part of an "end-to-end" ecological observing system capable of providing these forecasts for resource managers and the public (NOAA, 2005b). In the NOAA 20-year plan, ecological forecasting related products are highlighted prominently in the list of example NOAA products and services for 2025 (NOAA, 2005c). These include: forecasts and mitigation strategies related to: anoxia/hypoxia, harmful algal blooms, beach closings, invasive species, waves, air/water quality and quantity; ecological assessments and predictions of impacts from climate change (e.g., coral bleaching); decision support tools for adaptive, ecosystem-based management of fisheries, coastal development, and marine resources; improved assessments of sea level change on coastal resources and ecosystems; fishery productivity forecasts that incorporate the effects of climate change.

A dedicated ecological forecasting capability is critical for the agency to achieve the mission and goals set out in the NOAA Strategic Plan (NOAA, 2004) to "understand and predict changes in the Earth's environment and conserve and manage coastal and marine resource" (Mission Statement); "protect, restore, and manage the use of coastal and ocean resources through ecosystem–based management" (Goal 1); and "increase its investments in short-and long-term research in development of advanced technology to understand, describe, and predict changes in the natural environment" (cross-cutting priority). In the NOAA FY 2007 Annual Guidance Memorandum (NOAA Program Planning and Integration, 2005), language supportive of ecological forecasting is included in the sections on integrating global observations; advancing NOAA's modeling capability; providing leadership for the oceans; increase climate information, services, and products; and providing critical information for water resources.

II. Science Capabilities Necessary to Support Future Decision-Making

NOAA is well poised and has the legislative mandates to take a leadership role in developing ecological forecasts for coastal and marine environments that will yield significant economic and societal benefits to the Nation. Ecosystem-based management, a critical mission for NOAA, will not be possible without ecological forecasts. Through its comprehensive research investments, NOAA is developing the knowledge about ecosystem structure and function (i.e., physical, chemical, biological, and human interactions) necessary to develop ecological forecasts. These knowledge-based products include everything from applied research efforts to long-term observations. NOAA is also developing the infrastructure necessary to support ecological forecasts through the development of regional observing systems, coupled physical-biological models, sensors, and computational and data visualization/presentation capabilities. Together, these research and infrastructure capabilities have led to a suite of successful ecological forecasts with many more currently in development (see Appendix E).

The complexity of an ecosystem approach to management (EAM) demands a suite of complex, often linked, models, tools, and technology to provide a scientific basis for decision-making (e.g., linkage of airshed, watershed, water quality, and fisheries models). To achieve this full capability for ecosystem-based management, NOAA will need to develop integrated ecological forecasting systems over the next decade. As one approach, NOAA has proposed to establish or enhance existing regional centers for ecological forecasting that will be responsible for developing and transferring to the management community a suite of regionally-specific, integrated ecosystem modeling and ecological forecast tools to provide a scientific basis for the proactive and complex decisions that must be made at all levels of government. Having the regional centers and other NOAA ecological forecasting research programs associated or collaborating with the integrated ocean observing system (IOOS) will allow for regionally-coordinated planning for observations and models, and bring in regional user groups. Real-time integrated observing systems can also provide critically needed information to assess natural scales of variability, provide drivers for forecasting models, and provide data to test the accuracy and precision of forecasts.

The establishment of regional ecological forecasting centers will allow NOAA, in conjunction with other Federal, state, and local partners, to: 1) bring together research, monitoring, and modeling efforts to understand ecosystem composition, structure, and function, and to monitor ecosystem status and trends; 2) identify the requirements of the regional management community through workshops, focused studies, and continuous engagement; 3) track, coordinate, and integrate, where possible, ecosystem and socioeconomic modeling efforts within and external to NOAA; 4) identify critical gaps in knowledge for each region; 5) ensure those gaps are filled through the use of internal and external funding; 6) transition models, tools, and forecasts to operational status; and 7) provide predictions for management decisions at all ecosystem scales.

To build and reinforce NOAA's capability in ecosystem forecasting, a number of research, procedural, and tool needs have been identified along with a diverse set of challenges:

Research Needs

Research into anthropogenic stressors to ocean, coastal, and Great Lakes ecosystems has centered primarily on the effects from overfishing, habitat degradation, and declining water quality as well as natural physical hazards. Less is known about the linkages among climate change, food webs, physical-biological coupling, and ecosystem production dynamics. Understanding the fundamental knowledge base of ecosystem structure and function will allow NOAA to develop a suite of robust ecosystem forecasts addressing such issues as HABs, anoxia, fish distribution and abundance, beach closings, coral bleaching, and water quality and quantity. This research, by its very nature, is long-term. Specific types of research needs include:

- Definition of the time and space scales needed to capture the fundamental physical and biological drivers required for ecosystem forecasts.
- Measurements of the natural scales of variability regarding physical-biological coupling, food web dynamics, and ecosystem production.
- Definition of the observational needs to drive ecological forecasting models, assess the accuracy of model forecasts, and assess the impact of management decisions on resources and habitat quality.
- Development and testing of new sensors for physical and biological observing systems.
- Increased understanding of ecosystem composition, structure, functioning, and variability, and the connection between the abiotic and biotic components of coastal ecosystems. This includes an

understanding of large-scale ecosystem drivers and an understanding of ecological communities, including interactions among species (including poorly-understood "hidden players" such as viruses, microbes, and invertebrates), the physical environment, evolutionary history, and the "assembly rules," if any, by which ecosystems are formed.

- Increased understanding of ecosystem indicators and establishment of thresholds and breakpoints within ecosystems beyond which there are concerns or needs.
- Comprehensive process studies to understand the ecological mechanisms producing ecosystem patterns, and definition of ranges for key physical and biological parameters within ecosystem models.
- Integrated ecosystem studies involving observations, research, model development, and process studies. This will allow for increased understanding of connections among ecosystem drivers and functions as well as the ability to quantify key biological parameters and species dynamics necessary for biological models.

Procedural and Decision Support Tool Needs:

- True interdisciplinary integration among scientists and agencies involved with the physical, geochemical, and biological aspects of ecosystem process and function.
- Strong connections, to integrate multiple technologies (e.g., satellites, observation platforms, ship surveys, biological sensors) associated with the development of IOOS and regional associations.
- Fully integrated, spatially explicit, coupled hydrodynamic and biological models with appropriate links to watershed and higher tropic level models on key ecological scales to support place-based ecosystem management.
- Robust physical modeling platforms to provide the foundation on which to embed biological models. As most of NOAA's ecological forecasts involve the movement of water (e.g., larval transport, HABs), an accurate physical hydrodynamic model (i.e., four-dimensional) is a necessity. Within this framework, various biological components could be added depending on the issue and forecast.
- Robust biological models capable of predicting distributions, behaviors, and interactions among biota (e.g., movement, predator/prey dynamics, growth, death, reproduction processes).
- Responses to data issues such as the integration of disparate data sources, establishing and enforcing data integrity, formatting output for appropriate decision support software, satellite data calibration and validation, archiving forecasts, as

well as the data upon which they are based.

Challenges to Fulfilling these Needs:

- Ecosystem science is highly complex.
- A series of predictions tailored to the local or regional needs are necessary due to a diversity of issues and users, as a single, one-size-fits-all forecast is not possible.
- Physical and biological components of ecosystems are grossly under sampled with current technologies and effort levels.
- Decisions regarding the types of forecasts for specific regions; locations where these forecasts will be operated; and who will run, maintain, issue, and fund the forecasts must be made.
- Disseminating the forecasts and informing the public must be balanced against scientific uncertainties.
- Science-based assessments and information must be developed and disseminated to decision-makers in understandable and utilizable formats.

NOAA, as the primary Federal agency for ocean science supporting a variety of societal needs, is both an initiator and user of ecological forecasts. As an enabler, NOAA provides resources and personnel to collect the data, develop the forecasting products, summarize scientific results for decision-makers, produce assessments, and disseminate the synthesized results and information. The agency expects to use many of the forecasts to support its stewardship role. NOAA's ecological forecasting capability will be improved by the ability to simulate ecosystem complexity with coupled physical/biological models and data assimilation, and develop new models to predict ecological outcomes from alternative scenarios and facilitate the evaluation of management plans. These integrated forecasting systems will also foster the transition/operationalization of forecasts by assessing forecast accuracy, sensitivity, and error; defining acceptable levels of accuracy for proposed forecasts; enhancing risk assessment tools for management scenarios; linking socioeconomic cost-benefit analysis to ecological forecasts; developing testing and comparison metrics for forecasts; and developing methods to share, visualize, and communicate forecasts and uncertainty to user groups.

III. Partnerships Necessary to Effectively Address the Emerging Issues

The success of ecological forecasting depends on partnerships at all levels, from universities and local/state governments to other Federal agencies. The scale and complexity of ecological forecasts will require that NOAA improve its partnerships with external users and stakeholders and increase interactions among the NOAA programs and goal teams. NOAA must take advantage of its existing partnerships with other Federal agencies (e.g., IOOS, U.S. CCSP), international organizations (e.g., GEOSS, International Geosphere-Biosphere Programme), coastal states, and users of coastal ecosystems and their resources (e.g., commercial and recreational fishers). Strong partnerships will help decision-makers within and outside the government to identify the most critically needed forecasts and support efforts to build, test, and issue them. Some key elements of those partnerships are emerging but must be made stronger:

University partnerships (extramural research community): NOAA partnerships with the extramural research community are necessary to provide the research understanding and prototype ecological forecasts which will become the foundation for the development of "operational forecasts" within or outside of NOAA. There are several successful examples with NOAA's joint institutes and other major extramural research programs (e.g., GLOBEC, Ecology and Oceanography of Harmful Algal Blooms Program (ECOHAB), Monitoring and Event Response for Harmful Algal Blooms Program (MERHAB), Oceans and Human Health Initiative) where integration has occurred. NOAA also has an ongoing program dedicated to the development of ecological forecasts which encourages collaboration among university and NOAA scientists as well as coastal managers.

Local/state government partnerships and user community: The scale and complexity of ecological forecasts will also require that NOAA continue and improve partnerships with resource users and stakeholders. NOAA partnerships with decision-makers within local and state governments (e.g., managers of beaches, fisheries, shellfish, and water resources) are necessary for many reasons. State and local governments are one of the principal coastal management decision-makers and therefore the true users of the ecological forecasts. Information needs identified by managers will help define the types of forecasts produced, the level of accuracy required, and the most appropriate vehicles to disseminate the information. Other users include boaters, coastal landowners, recreational fishers, divers, surfers, the beach-using public, and commercial enterprises. Once forecasts are developed, these users can provide feedback to help identify needed improvements in forecast capabilities and to provide direction for future research. Local and state governments may also be involved in the actual transition, operation, and maintenance of developed forecasts. Establishing connections with the user community is critical during the development and transition of forecasts, and NOAA engages this community through a variety of mechanisms including workshops, surveys, networks, and participation in research (e.g., NOAA, 2002; Sturdevant, 2004; Hendee et al., 2006).

Federal partnerships (e.g., NASA, EPA, USGS, U.S. Corps of Engineers, National Science Foundation, USFWS): NOAA fosters partnerships with other Federal agencies to leverage expertise and funding and to collaborate on activities related to development of an ecological forecasting capability to support ecosystem management at a scale that is often larger than the purview of individual agencies. Some of these regional issues, including climate change, watershed-estuary-ocean interactions, coral reef health, habitat restoration, hypoxia, and HABs, can only be addressed through large-scale ecosystem based programs, the integration of multiple technologies, and large-scale coordination efforts such as IOOS and regional taskforce, alliance, and other collaborative endeavors (e.g., the Great Lakes Regional Collaboration, Gulf of Mexico Alliance, Mississippi River Watershed Nutrient Taskforce). NOAA is currently working with other agencies on the development of climate change forecasting centers and integrated earth systems frameworks for ecosystem management. The recently released U.S. Ocean Action Plan (CEQ, 2004) has also established a new ocean governance structure (i.e., the National Science and Technology Council's Joint Subcommittee on Ocean Science and Technology) aimed at integrating the activities of Executive Branch agencies regarding ocean-related matters and provides another avenue of coordination toward the development of ecological forecasts.

<u>NOAA partnerships</u>: NOAA is applying its extensive intramural and extramural research capacities and modeling expertise to assure successful development, validation, and demonstration of a wide variety of ecological forecasts. Ecological forecasts result from the integration of data, information, and models produced by multiple scientific disciplines, and thus reflect a multidisciplinary "Corporate NOAA." For example, a typical forecast may require collaboration among many NOAA programs, including NOAA Satellites and Information Service (for satellite information), NOAA National Weather Service (for hydrology, wind fields, and rainfall data), and NOAA Research, NOAA National Ocean Service, and NOAA Fisheries (for interdisciplinary research, hydrodynamics, and food web information). In turn, one part of a forecast may be best operationalized within the NOAA National Weather Service, whereas another part may be best operationalized within NOAA National Ocean Service (e.g., Great Lakes forecasting system). This cross-line office and cross-goal aspect of research applications is central to the success of NOAA's ability to conduct ecological forecasts.

Within the agency, there are, however, several organizational and procedural challenges:

Organizational challenges include:

- Management of ecological forecast development through NOAA's Program Planning Budgeting and Execution System (PPBES) structure, which contains at least five programs working on components of ecological forecasting.
- Development of an 'end-to-end' approach for ecological forecasts that includes user identification, needs prioritization, funding of research and development, forecast product testing, planning for and funding of the transfer to application, and, when necessary, routine operation of the forecasts.
- Capacity-building to handle the accelerating increase in forecast products, if NOAA is the ultimate operational entity, or development of a robust procedure to assure the most appropriate transfer to all parties involved, if the operational entity is outside of NOAA.

Procedural challenges include:

- Prioritization of research, given the need for high risk, but potentially high payoff, research.
- Establishment of effective connections with the user community during the development and transition of forecasts.
- Definition of roles and responsibilities for ecological forecasting from a corporate level (e.g., who develops the forecasts, who receives and routinely runs the forecasts, what the users do with the forecasts, how resources are allocated, what is not done if there are no additional funds, the role of government versus the role of the private sector).

One of most challenging near-term issues for the agency is how to prioritize the development and transition to operations of the wide range and diversity of ecological forecasts currently in development. As evidenced in Appendix F, the ecological forecasting capability of NOAA is rapidly advancing on all fronts and the transition to operations of these forecasts will probably not be possible or warranted given funding constraints and other agency priorities. Prioritization among potential ecological forecasts will allow NOAA to invest resources and personnel in the most promising products. Potential prioritization criteria and questions include:

- Is the forecast a mandate for NOAA's coastal responsibilities?
- Is the forecast within NOAA's mission and goals?
- Should NOAA be the lead?
- What benefits will the forecast have after investment?
- Does investment in the forecast offer collaboration/leverage with other offices/agencies?
- Does investment in the forecast benefit multiple user groups?

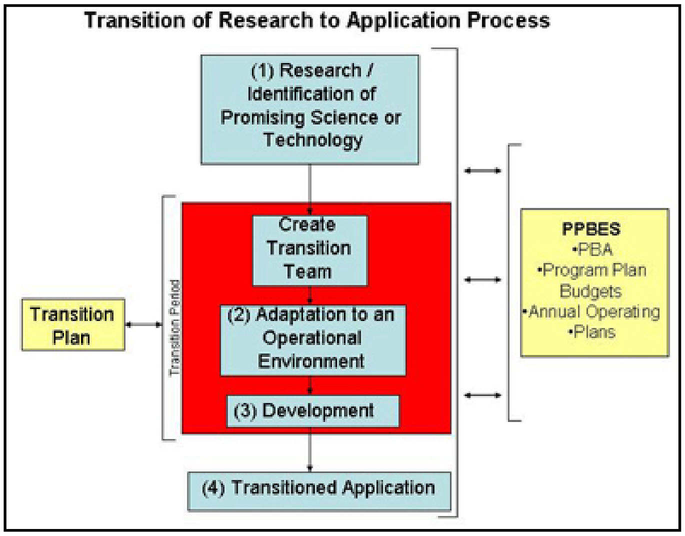

Figure 2. Proposed NOAA Transition Process outlining the steps involved with transitioning any research result, information, or tool into application.

- What is the time frame for development of the forecast?
- What is the overall level of investment needed?

NOAA has begun a path toward addressing some of these issues with the recent development of a research to application transition policy. The policy describes the process by which any research result, information, or tool should be transitioned into application. The policy calls for the creation of a Transition Board and of Transition Teams. Figure 2 outlines the proposed formalized process linking together program offices with various NOAA planning processes, which would help to prioritize the development and transition of new and ongoing ecological forecasts.

IV. Benefits to NOAA, Constituents, and Society from this Effort

Maintaining ecosystem function and health will benefit U.S. society which demands coastal resources, such as uncontaminated fish and shellfish, and access to clean coastal waters. NOAA is charged by Congress and the Administration with specific mandates prescribed by law. Ecological forecasting will aid the agency in its stewardship responsibilities by providing information on future ecosystem-related problems, including feedbacks that affect human health, for which NOAA can respond and plan. NOAA has numerous ecosystem-related mandates, policies, treaties, and international agreement and at least 24 of these can be addressed or facilitated through ecological forecasts (see Appendix D).

A key mission for NOAA is to develop scientifically sound ecological forecasts relevant to NOAA's mission, practical to its customers, and providing a necessary underpinning of ecosystem-based management. NOAA is developing ecological forecasts for coastal managers in an effort to help merge wide-ranging research and observation programs around this new and challenging science, which ultimately enriches the science-policy interface. Focusing on developing, testing, and applying ecological forecasts provides the coastal research and management communities with three benefits. First, ecological forecasts will help decision-makers better manage the Nation's coastal resources because they provide valuable information for better assessments that predict future conditions of proposed actions and the potential impacts of their decisions. Second, focusing on defining ecological forecasts needs will strengthen the link between research and management by tying management needs to a scientifically challenging agenda. Finally, the desire to build and improve ecological forecasts will help focus NOAA's coastal science agenda by assuring that NOAA's monitoring, research, and model development efforts are geared towards the needs of coastal managers who benefit from ecological forecasts.

This chapter has been an initial look at NOAA's current capability for ecological forecasts from near-real time to periodic forecasts and the needs, issues, and challenges that the agency will face in the next twenty years. Ecological forecasting is a very young and interdisciplinary field that capitalizes on NOAA's existing physical and biological expertise. NOAA must strive to integrate its research and provide the best forecasts as efficiently and effectively as possible. The authors hope this chapter will serve as a framework for facilitating the development of a robust ecological forecasting capability within NOAA and among its external partners as this field of science matures.

White Paper #6

Science Requirements to Identify and Balance Societal Objectives

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"*Once we accept the concept of multispecies management, we are faced with the question, what (and how) do we optimize? We cannot answer this entirely in ecological terms but must introduce social and economic values …*" (National Research Council, 1980)

I. Description of the Issue

The question addressed by this paper navigates the murky waters where science intermingles with governance and all of its sociocultural, psychological, economic, ethical, institutional, and other human dimensions. The question is: What are we managing ecosystems for? In other words, what should be the end(s) of coastal and ocean management? NOAA provides an answer in the context of its strategic Ecosystem Mission Goal. This goal prescribes the protection, restoration, and management of coastal and ocean resources following an EAM that, among other criteria, balances diverse societal objectives (NOAA, 2005a). In the context of an EAM, the proper aim of coastal and ocean management is not any particular set of societal objectives, but "balance" among them.

Societal objectives encompass the plurality of conditions, experiences, and opportunities valued by stakeholders. The natural capital and functions integral to environmental systems provide services – referred to as ecosystem services – that contribute to human well-being. Such services can be categorized as supporting (e.g., nutrient cycling and soil formation), provisioning (e.g., timber and food), regulating (e.g., water purification and flood control), and cultural (e.g., recreation and social relations). These services contribute to human well-being by directly and indirectly providing for values essential to personal and social security, basic material needs, physical and psychological health, good social relations, and freedom of choice and action to achieve personal values and foster personal identity (Millennium Ecosystem Assessment, 2005).

In the United States, at least four types of institutions affect the spatio-temporal pattern of and relationships among ocean and coastal resource uses. Following a definition provided by Ostrom (2005, p. 1), institutions are "the prescriptions that humans use to organize all forms of repetitive and structured interactions, including those within families, neighborhoods, markets, firms, sports leagues, churches, private associations, and governments at all scales." A democratic political institution is comprised of governmental agencies and management bodies (such as regional fishery management councils). A legal institution, with rules defining resource use entitlements and responsibilities, is comprised of the body of laws and distribution of property rights among the government and citizenry. An economic institution, which is closely tied to the legal institution (e.g., enforcement and security of title), regulates the economic value of coastal and ocean assets *in situ* or their commodity and service flows in market and, increasingly, non-market situations. Finally, other social institutions such as cultural practices shape patterns of resource use such as subsistence harvesting and recreational activity.

Whether political, legal, economic, cultural, or (most likely) an interaction of institutions balances societal objectives, NOAA's vision of an EAM leaves the following questions unanswered: (1) Which societal objectives? (Lackey, 2001) (2) What is meant by "balance" among societal objectives? (3) How will balance be achieved? In particular, how must decision making processes and institutions change to accommodate the concept of EAM and fulfill NOAA's mission "to understand and predict changes in the Earth's environment and conserve and manage coastal and marine resources to meet our Nation's economic, social, and environmental needs"? These questions are considered below, focusing on their implications for the ecosystem science conducted and sponsored by NOAA to achieve its Ecosystem Mission Goal, with particular emphasis on economic and democratic mechanisms.

II. Science Capabilities Necessary to Support Decision-Making

The identification, articulation, and prioritization of values as drivers of coastal and ocean science, policy, and resource management has profound social, cultural, and economic implications for NOAA's constituents. If policy makers, coastal and ocean resource managers, stakeholders, and other key decision makers are to balance societal objectives, as NOAA's vision of an EAM requires, then resource management systems must critically engage stakeholders, and the plurality of values they advocate, to identify resource use conflicts, establish priorities, and evaluate alternative scenarios.

An emphasis on the role of decision processes in balancing diverse societal objectives is enhanced by a focus on the development of decision institutions with the proper incentives and restrictions influencing human behavior. In particular, Hanna (1998) recommends that EAM institutions promote multiple objectives, cost-effectiveness, legitimacy, flexibility, and long time horizons. These criteria require a suitable set of well-defined property rights evolving from an open, deliberative process that people believe to be legitimate. The property rights need to be indefinite, transferable, and enforceable in order for the other elements to be voluntarily internalized. For example, secure, indefinite title promotes stewardship, as opposed to aquaculturalists and fishers making a living in an open access or regulated open access property rights regime in which the rule-of-capture prevails. Exchange promotes multiple uses and flexibility as well as value. Ownership results in cost-effective behavior because one is accountable for his or her own costs.

Incorporating Societal Objectives into Decision-Making

A purpose of the political-policy process in a democratic society is to adjudicate personal preferences to elucidate and express collective ends – a debate that is, ideally, informed by scientific information (including local and traditional knowledge) and reason-based discussion about values and value priorities. The output of this debate is a set of Federal laws, executive orders, and judicial decisions that, to some extent, represent the vast plurality of societal objectives that stand to be influenced (in terms of their achievability and sustainability) by resource management. The objectives specified in such authorities (herein referred to as "policy ends") are directed by Congress, the President, and the courts to be implemented by the U.S. Department of Commerce, NOAA, NOAA's component organizations, and other governmental agencies with resource management responsibilities. Accordingly, policy ends expressed by NOAA's authorities are an important source of societal objectives to serve as the ends of coastal and ocean resource management.

However, it would be democratically and practically disadvantageous to derive resource management goals solely from policy ends. From a democratic standpoint, policy ends may not represent the full ensemble of values that influence, and are influenced by, resource management decisions. Social groups and, consequently, their values can be marginalized from political-policy processes, risking the undemocratic outcome of failing to consider a subset of societal values in coastal and ocean management decisions. From a practical perspective, engaging participatory decision processes as a way of recognizing the values of a diverse constituency can improve the substance, perceived legitimacy, and effectiveness of decisions (Mascia, 2003; Sutinen and Kuperan, 1999). In addition, statutory authorities often leave societal objectives undefined or articulate them at a high level of generality that requires quantitative and/or qualitative specification to be operational for decision-making.

For these reasons, a participatory approach to elucidating societal objectives is widely advocated as essential to democratic and effective coastal and ocean management (e.g., Mascia, 2003). There is "widespread consensus that forging partnerships with people and creating more meaningful opportunities for public participation should be part of the ecosystem management paradigm" (Endter-Wada et al., 1998, p. 894). Such a consensus is demonstrated by the many environmental regulations that require some form of public participation in environmental decision-making, including the Administrative Procedures Act, NEPA, National Marine Sanctuaries Act, MSFCMA, and Coastal Zone Management Act at the Federal level.

In addition, social science research is essential to design critical, democratic and effective decision approaches such as collaborative learning and co-management. An NRC publication, *Decision Making for the Environment*, lays out research priorities for the social and behavioral sciences to improve decision processes affecting environmental quality (NRC, 2005). Endter-Wada et al. (1998) provide a valuable discussion of social research contributions to public involvement in planning and policy making, summarized as follows (p. 894):

"Some social scientists focus their research and analysis on broader processes of group and societal decision-making; i.e., the objects of their science are these processes. Their work generally analyzes the structure and dynamics of various public involvement processes, the conditions under which these processes work best, their suitability for addressing different types of problems, their effectiveness in facilitating public involvement, and their success in improving situations or attaining different outcomes. … Other social scientists have borrowed heavily from conflict negotiation and mediation experiences outside natural resources (e.g., labor disputes, divorce settlements) and applied these techniques to understanding and managing those conflicts …"

In addition to social science research focusing on decision processes, sociocultural assessment and monitoring are crucial to characterize stakeholders and their objectives. Multidimensional characterization of stakeholders – e.g., values, priorities, perceptions (e.g., of user conflict), and attitudes and knowledge – is required to inform decision making and governance in the context of an EAM. Social scientific methods provide breadth and specificity in characterizing stakeholders and stakeholder objectives, enabling representation of a diverse constituency in ecosystem science, policy, and decision processes. Among many useful guidance documents, the *Socioeconomic Manual for Coral Reef Management* (Bunce et al., 2000) is widely used as a tool for managers to establish socioeconomic monitoring programs. In addition, the U.S. Environmental Protection Agency (EPA, 2002) provides a guide to community assessment that focuses on identifying community attitudes and values.

Economics Perspectives on Decision-Making and Resource Use

In the *MIT Dictionary of Modern Economics* (Pearce, 1992, p. 121), economists define economics as "the study of the way in which mankind organizes itself to tackle the basic problem of scarcity. … All societies have more wants than resources …, so a system must be devised to allocate these resources between competing ends." This definition reflects the importance of economics to EAM for more than measuring the economic notion of value and impacts of regulations. The ways that "mankind organizes itself" are also germane to questions about resource use, including in an EAM.

The political-policy process described earlier is an important mechanism for identifying and adjudicating societal objectives. However, in some cases, the scientific uncertainty characteristic of an EAM could hamstring a deliberative process due to the transaction costs of information and other requirements of negotiation (Libecap, 1989). This seems to be most likely to occur when EAM is being used to manage increasingly more resource attributes. Attributes such as predator-prey relationships, habitat requirements, sex ratios, and genetic diversity are significantly more expensive and difficult to research, manage, and enforce than only biomass and, perhaps, the age-structure of a stock. Furthermore, this greater attention to heterogeneous attributes will most often be complicated by spatial distributions, all of which are characteristic of EAM.

NOAA should consider the option of partnering with stakeholders to design institutions with entitlements, rules, and attenuations necessary to create the expectation that people will behave consistent with an EAM as new scientific (and other) information becomes known, technologies change, and preferences of the American public change (see Hanna, 1998). Rather than expand regulations or renegotiate co-management agreements to accommodate new information, shifts in state variables, or changes in external factors (e.g., water movements and trade), the government could transfer (through sale, lease, or auction) part of its legal "bundle of sticks" – i.e., property rights – to interested parties and grant them responsibility for decisions. The objective here is to design decision institutions run by stakeholders whose behavioral incentives match NOAA's ideals for EAM but can respond to information and uncertainty more effectively than a political institution or process.

Concepts of Economic Value and Measurement for EAM

It is helpful, where possible, to measure gains and losses when speaking of balances, even where the natural environment is concerned, partly because losses almost always accompany a choice. In these cases, the components of the ecosystem are considered assets (e.g., fish stocks, heat capacity of ocean waters, potential energy of currents) and flows (e.g., primary preproduction and oxygen production). In addition, human use can alter the levels, or rates, of assets and flows while at the same time generating human values. Finally, non-extractive uses of the ocean (e.g., whale watching, snorkeling on reefs) and even "non-uses" are valued.

A variety of economic methods has been developed since the 1960s to measure economic benefits or values as well as costs (i.e., opportunity costs or lost economic values) of environmental and natural resources (including quality dimensions, not discussed here; see Freeman, 1993). In addition to market values such as commercial fishing, shipping, and oil and gas production which are analyzed by traditional methods, the so-called non-market values are classified and handled somewhat differently. Use values involve an *in situ* experience with extraction (e.g., sport fishing) or without (e.g., sunbathing and swimming) extraction. Non-use values, which do not involve personal use, are divided into preservation or existence values and bequest values for future generations. Other value categories relate to uncertainty, including option value (e.g., an insurance coverage) and quasi-option value for specific circumstances when irreversible development would most likely preclude learning about the suspected high value of a resource.

The NRC (1999a) recently reviewed a variety of methods used by economists to estimate the market and non-market values of environmental and natural resource assets and the flows of products and services derived from their use and existence. NOAA staff have estimated, for example, random utility models (RUM) of the value of recreational fishing, the public's valuation of protected species and marine reserves using stated-preference research, and asset accounts of the value of fishery resources in situ and the resource rent component of harvests. Current practices of measuring only the value of market activity associated with commercial (e.g., harvests) or recreational (e.g., economic impacts and multiplier effects) fishing give a biased picture of the total economic value of the resources and uses of the ocean under NOAA's authority. This will be a fertile and rewarding area of EAM research and policy for NOAA in the future.

Recommendation #1

To support the Ecosystem Mission Goal, NOAA requires greater investment and intra- and interagency coordination in human dimensions research to comprehensively identify and describe the plurality of objectives advocated by constituents. Such research should focus on social scientific and humanistic approaches to: (1) improving and facilitating participatory decision processes, (2) assessing and monitoring sociocultural and economic causes and consequences of ecosystem stress and management responses**,** (3) designing and influencing governance arrangements effective for an EAM, and (4) describing and, where possible, quantifying the values of natural resource assets and flows.

Balancing Societal Objectives

Conflict is fundamental to resource management (Hanna, 1998**;** Larkin, 1996; Link, 2002). Juda (1999, p. 96) captures this point by explaining that

"*All societies are faced with mutually exclusive choices regarding the use of resources. In line with the opportunity of opportunity costs, the use of a limited resource obviates its alternative uses. Accordingly, some values must be given a higher, and others a lower, priority*."

Importantly, "tradeoff" does not mean "trade-in." That is, the de-prioritized value does not necessarily get discarded. In economics, tradeoffs imply comparing differences in small, or marginal, changes of two or more activities to see if they are ever equal at some point. That point identifies where the combination of values is greatest.

NOAA's authorities offer little guidance regarding how to prioritize conflicting objectives across sectors, social groups, or generations. For example, National Standard 8 of the Sustainable Fisheries Act of 1996 redefines the goal of MSY as articulated in the MSFCMA, requiring management plans to include measures minimizing adverse economic impacts to fishing communities. The standard does not state whether the conservation and restoration of stocks are to receive priority over shorter-term community objectives or vice versa. As Cicin-Sain and Knecht (2000, p. 149) recognize, “if a stock is in grave danger of being depleted, fishing effort must be either greatly reduced, which is detrimental to dependent fishing communities, or allowed to continue, which is detrimental to fish stocks.” In such instances, fisheries managers face a tradeoff between the cultural and short-run economic vitality of fishing communities and the preservation of stocks for future generations.

In more general terms, current and emerging management issues involve tradeoffs among the various benefits of agricultural production and water quality in the Gulf of Mexico and other areas; off-shore energy development and resulting habitat damage, emissions, and oil spill risk; ship ballasting benefits and the introduction of invasive species; cultural, recreational, and other uses of coral reefs and their protection for future generations; the protection of marine mammals and human activities such as fishing and ship traffic; and aquaculture and the potential spreading of disease among fish populations and risks of non-native species introductions (USCOP, 2004).

In view of the centrality of such tradeoffs to coastal and ocean management, balancing societal objectives means reducing or eliminating resource conflict to make objectives mutually achievable in so far as possible across social groups, places, and generations. This requires prioritizing societal objectives when conflict is irresolvable. More specifically, an EAM is an enterprise in:

1. Identifying tradeoffs among societal objectives that enter into policy making and implementation, and management decisions;
2. Establishing priorities that are ethically defensible through means that are democratic or revealed by self-governance arrangements designed to create behavior that complies with the EAM principle; and
3. Envisioning, implementing, and evaluating regulatory, participatory, technological, educational, institutional, and other strategies to achieve an acceptable integration of priorities.

To support an EAM, the ecosystem science prioritized, conducted, and supported by NOAA must inform and enable these steps. In the most general terms, an ecosystem-based research approach and institutional structure is vital. This may seem obvious, yet most research supported and conducted by NOAA has an environmental science focus (i.e., on observation and forecasting of biological, physical, and chemical systems in isolation of human dimensions). A truly ecosystem-based focus would integrate human dimensions research themes such as human causes and consequences of ecosystem stress (see Stern et al., 1992), decision approaches (see NRC, 2005), documentation of local and traditional knowledge, risk communication, assessment of community vulnerability to hazards, and governance arrangements (especially for LMEs) (e.g., Juda, 1999).

In terms of NOAA "business strategy" or organizational structure, such a commitment requires cross-disciplinary integration in addition to intra- and inter-NOAA Goal Team coordination and social science representation at senior levels. The need for a truly ecosystem-based focus – in terms of research content, institutional organization, and staffing and senior representation – is supported and elaborated by a Social Science Review Panel report to the NOAA Science Advisory Board, *Social Science Research Within NOAA: Review and Recommendations* (NOAA, 2003b).

An EAM will complicate NOAA's missions in scientific research and management for several reasons. First, by its nature, EAM will expand the number and type of resources and resource attributes being researched and managed, from the unit-stock biomass and age-structure of target species to interactions (e.g., predation) and the spatial heterogeneities and topologies (i.e., relationships, such as connectivity) of resources, other species (including humans), and habitat. This places a heavy demand on information which connects environmental variability and resource dynamics, fishing behavior, regulatory actions, and the political and legislative responses to stakeholder demands and competitions. Second, EAM will force NOAA to find legal, ethical, and cost-effective ways to inform and facilitate the identification and evaluation of tradeoffs among resource uses and among resource users. Third, EAM should make it self-evident that management is inherently a normative endeavor (Lackey 2004). That is, humans manipulate the environment in order to satisfy objectives which locate value in the human experience (anthropocentric), ecological systems (ecocentric), and/or living entities such as species (biocentric). Even policies that preserve a species or set up a network of marine reserves are normative (i.e., they aim to restore nature to a desired previous state).

More specifically, identifying tradeoffs requires a picture of the viability of societal objectives, individually and in relation to one another, as they are likely to be influenced by interactions within and between human and environmental systems. The challenge of evaluating tradeoffs can be illustrated by applying the portfolio theory to fisheries. Assume that the overall objective for an LME or sub-region is to balance expected aggregate returns (i.e., aggregate income from all species plus changes in asset values) against the return risks associated with recruitment, various interactions (e.g., predation, multi-species harvest technology, product substitution in markets), and other uncertainties (Edwards et al., 2004). Internalizing interactions into multi-species management requires deliberate tradeoffs among yields of different species. Since yields support a plurality of economic, cultural, spiritual, and recreational values, tradeoffs among yields give rise to tradeoffs among such values. For example, increasing the yields of highly valued piscivorous species might require fisheries for their prey to be substantially cut back. As Gulland (1982) recommended for the North Sea, one could fish down the top piscivores, such as cod, and then fish the herbivores only moderately in order to encourage the growth of flounders and other valuable benthivores.

Although this example is confined to multi-species management, the portfolio framework is a considerable step in the direction of EAM because it deals directly with interactions and uncertainty in a search for what an ecosystem can produce of economic value. Furthermore, it can be applied to more difficult resource scenarios, such as tradeoffs among fisheries and other human endeavors such as marine reserves, aquaculture parks, and oil and natural gas leases. However, like the single-species approach which is described primarily in terms of the natural sciences, the portfolio framework is two-pronged and needs to be implemented with a management approach that involves people and behavior, both in government and at sea. Thus, once again, the type of institution that will properly define the objectives of a technical framework, such as the portfolio framework, must be identified: (1) one that increases the number of regulations to a large extent; (2) one that negotiates solutions to the many interactions democratically; or (3) one that entrusts the design of EAM institutions to have the correct incentive structures to influence socially-appropriate behavior. This is a question of governance and resource allocation under uncertainty.

The power of the EAM concept as an instrument to envision and sustain a better world derives from its broad applicability to decision-making across sectors, incorporating non-market values, and utilizing alternatives to command-and-control regulation, such as democratic and economic alternatives, to elucidate values and adjudicate conflict among them. The social sciences (economic and non-economic) and humanities offer diverse approaches to establishing priorities in this broader context, including cost-benefit analysis; tradeoff analysis, which can be utilized in a participatory decision process (e.g., Brown et al., 2001), conflict mediation (e.g., McCreary et al., 2001); discursive ethics (e.g., O'Hara, 1995); and contracting (Townsend and Pooley, 1995).

More broadly, Sutinen et al. (2000, p. 3) identify the following socioeconomic research needs in a "Framework for Monitoring and Assessing Socioeconomics and Governance of Large Marine Ecosystems":

1. Identify principle uses of LME resources;
2. Identify LME resource users and their activities;
3. Identify governance mechanisms influencing LME use;
4. Assess the level of LME-related activities;
5. Assess interactions between LME-related activities and LME resources;
6. Assess impacts of LME activities on other users;
7. Assess the interactions between governance mechanisms and resource use;
8. Assess the socioeconomic importance of LME-related activities and economic and sociocultural value of key uses and LME resources;
9. Identify the public's priorities and willingness to make tradeoffs to protect and restore key natural resources;

10. Assess the cost of options to protect or restore key resources;
11. Compare the benefits with the costs of protection and restoration options; and
12. Identify financing alternatives for the preferred options for protecting/restoring key LME resources.

One research need omitted by this framework is an analysis of social factors driving human activities that significantly contribute to ecosystem stress (e.g., demographic change; attitudes, values, and beliefs; technological innovation; political forces; and regulatory instruments). Knowledge of social drivers is essential to focus environmental protection, restoration, and management strategies on underlying causes of ecosystem stress.

Finally, research is necessary to identify and facilitate governance patterns conducive to priority setting and strategy development in the context of LME policy and management. Governance refers to the "formal and informal arrangements, institutions, and mores which determine how resources or an environment are utilized; how problems and opportunities are evaluated and analyzed; what behavior is deemed acceptable or forbidden; and what rules and sanctions are applied to affect the pattern of resource and environmental use" (Juda, 1999, pp. 90-91). Juda (1999) lays out considerations for developing and implementing a governance approach. Townsend and Pooley (1995) provide a broad taxonomy of "distributed governance" (i.e., how rights and responsibilities are distributed across government, the fishing industry, and fishing communities) and contrast the current regulatory approach with external institutional relationships (co-management, harvest rights, and contracting) and internal relationships (self-organizing groups, cooperative management, communal management, corporate management). Notice that the Federal government is party to each form of external governance. Further, different combinations of external and internal governance arrangements will result in a different balance of societal objectives and set of outcomes for the environment and interested parties. For example, objectives from a regulatory arrangement will differ from those associated with the combination of co-management/corporate management and from contracting/self-organizing groups.

Recommendation #2

NOAA requires greater investment and intra- and interagency coordination in human dimensions research on topics that support NOAA's aim of striving to balance diverse societal objectives such as those discussed earlier. Balancing societal objectives is an enterprise in identifying tradeoffs; establishing priorities that are ethically defensible to stakeholders and fair to the American public through means such as democratic decision making and/or other combinations of distributed governance that match EAM principles and provide self-governance incentives; and developing and implementing strategies informed by ecosystem science incorporating human dimensions.

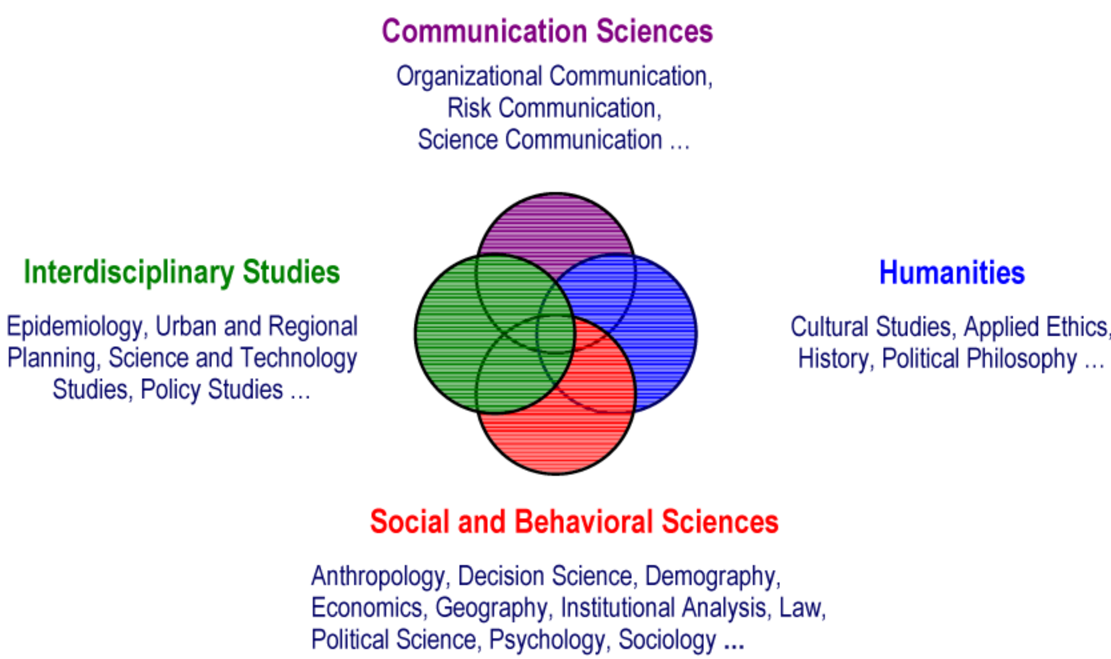
III. Partnerships Necessary to Effectively Address the Emerging Issues

Partnerships among biophysical and human dimensions scientists - across NOAA's line offices and with external partners – are critical to meeting scientific, organizational, and individual challenges presented by NOAA's commitment to a comprehensive ecosystem science enterprise supporting an EAM. From a scientific standpoint, ecosystem science requires innovative approaches to linking the concepts, methods and results of biophysical and human dimensions research to inform decision making. From an organizational standpoint, critical needs include greater internal capacity in human dimensions disciplines; leadership with interdisciplinary understanding and team-building skills across disciplines; management practices that encourage, require and reward interdisciplinary research; integrated research prioritization and planning; adequate funding for human dimensions and interdisciplinary research; and leadership and workforce training to facilitate awareness and appreciation of the value of human dimensions research for NOAA's Ecosystem Mission. Fundamentally, envisioning and implementing such scientific and organizational transformations requires fostering a workforce with the knowledge, skills, and dispositions to engage in and be transformed by learning, communication, and collaboration across disciplinary cultures and approaches.

IV. Benefits to NOAA, Constituents, and Society from this Effort

This section is intentionally left blank since this paper is devoted to the topic of science requirements critical to achieve NOAA's Ecosystem Mission Goal (i.e., benefits to NOAA) by identifying and balancing societal objectives (i.e., benefits to society).

Figure 1. Diverse disciplines are integral to understanding the human dimensions of ecosystems.



Appendix A: Ecosystem Principles
(Ecosystem Principles Advisory Panel, 1999)

- The ability to predict ecosystem behavior is limited.
- Ecosystems have real thresholds and limits which, when exceeded, can effect major ecosystem restructuring.
- Once thresholds and limits have been exceeded, changes can be irreversible.
- Diversity is important to ecosystem functioning.
- Multiple scales interact within and among ecosystems.
- Components of ecosystems are linked.
- Ecosystem boundaries are open.
- Ecosystems change over time.

Appendix B: Summary of Recommendations for a Regional Ecosystem Approach to Management (NOAA Fisheries, 2004)

(1) *Derive the maximum value to society (on a sustainable basis) available from the living marine resources under our stewardship,* subject to sub-goals 2-9 *described below. In implementing this overall goal, NOAA Fisheries must:*

- Account for other ecosystem goods and services as they affect, are affected by, and are in addition to fisheries.
- Promote participation, fairness, and equity in policy and management development.
- Allocate resource use and non-use among sectors in a transparent, safe and feasible manner.

(2) *Prevent Overfishing*

- Develop and implement conservation and management measures that prevent overfishing of species or species complexes in each region. The objective is to prevent overfishing while achieving, on a continuing basis, the optimum yield from each U.S. fishery.
- Monitor the status of species or species complexes relative to overfishing and overfished limit reference points.
- Develop rebuilding plans for those species deemed to be overfished.

(3) *Protect Sensitive Species*

- Reduce mortality of marine mammals, sea turtles, sea birds and similar protected apex species to a level that is sustainable.
- Develop and implement conservation measures to maintain marine mammals at optimum sustainable population levels. This includes ensuring that incidental takes do not exceed a stock's potential biological removal level.
- Develop conservation and recovery plans that contain site-specific management measures with objective, measurable criteria to recover ESA-listed species and depleted marine mammal stocks.
- Monitor population status.
- Create measures to recover threatened or endangered species.

(4) *Conserve Biodiversity*

- Develop and implement measures to conserve non-target species.
- Ensure that no native species shall go extinct due to anthropogenic factors.

- Monitor and evaluate impacts of invasive species on native species.
- Establish conservation and management measures to reduce fishing mortality of non-target species (e.g., minimize bycatch and discarding), and establish bycatch thresholds that will sustain non-target species.
- Monitor the status of non-target species that are significantly impacted by anthropogenic activities.
- Establish measures to conserve species diversity where an observed and sustained decline in species diversity (e.g., mean species richness from fisheries independent surveys) is below the range of observed natural variability.

(5) *Conserve Genetic Diversity and Structure*

- Define evolutionary significant units (ESUs) for threatened, endangered or overfished species.
- Develop and implement harvest policies that protect genetic diversity of species or stocks by protecting ESUs from excessive mortality.
- Monitor ESU status for local spawning aggregations.
- Establish measures for those species or stocks at risk of losing genetic diversity to protect the ESU.

(6) *Conserve Living Marine Resource Habitat*

- Develop and implement measures to conserve essential fish habitat (EFH) and critical habitat for all targeted and protected species with respect to their ability to spawn, breed, feed and/or grow to maturity.
- Evaluate habitat designations.
- Evaluate potential adverse effects of fishing on habitat and minimize adverse effects of fishing on habitat.
- Minimize adverse perturbations (from both fishing and other user sectors) to be less than the range of natural disturbances for the appropriate physical and geological processes that operate in ecosystems.
- Establish measures to conserve those habitats that are negatively impacted.

(7) *Maintain Trophic Structure*

- Develop and implement measures to minimize anthropogenic impacts on trophic structure and functioning. Ecological relationships between harvested, dependent and related species shall be maintained within the range of observed natural variability.

- Develop and implement measures to take the trophic role of species into account when establishing harvest levels, including the effects of the combined removal of all targeted species on the ecosystem.
- Monitor trophic relationships among targeted species, their predators, and their prey.
- Establish measures to restore the fundamental ecological relationships in those food webs that have human-induced deterioration of trophic structure.
- Develop and implement harvest policies that sustain adequate forage base, in situations where fisheries potentially compete with top trophic level consumers (e.g., marine mammals, turtles, sea birds, or similar protected species) for shared resources (e.g., forage fish such as small pelagics), to ensure that sufficient quantities of the shared resource are available to sustain the top trophic level consumers at their population thresholds.

(8) *Prevent Systemic Overexploitation*

- Prevent systemic over-exploitation of an ecosystem at relevant spatial and temporal scales, cognizant of items 1-7 above as appropriate. This may require development and implementation of a limit for the total combined removal of all targeted species or some equivalent means. It provides a buffer for uncertainty such that the total removal cap is established as less than the combined total of all targeted and non-target removals.
- Allocate tradeoffs in harvestable biomass among all targeted species subject to the constraint of the total removal cap, up to but not exceeding the total cap.
- Establish measures and policies to avoid exceeding the systemic cap and to reduce total system-wide exploitation if it is exceeded.

(9) *Improve knowledge of natural and anthropogenic processes controlling ecosystem structure and function to enable more accurate forecasts of living marine resources*

- Monitor the status of non-target species that are significantly impacted by anthropogenic activities.

- Monitor trophic relationships among targeted species, their predators, and their prey.
- Monitor population status of protected species and marine mammals at specific levels of assessment quality every X years.
- Monitor the status of species or species complexes relative to overfishing and overfished reference point at specific levels of assessment quality every X years.
- Improve our understanding of the importance of bottom-up forcing in determining episodic recruitment events in target species and the prey of target species.

Appendix C: Basic Approach to Fisheries Management in Federal Waters

(with an emphasis on groundfish management in the Bering Sea and Gulf of Alaska)

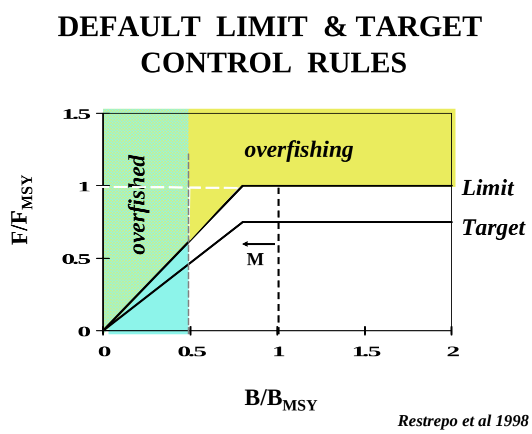
Several elements of the fisheries management system adopted by NOAA conform to the goals of EAM. Several regional councils and their associated regional offices have adopted harvest strategies designed to prevent overfishing, rebuild protected species, preserve biodiversity, protect habitat, and encourage public participation in decision-making. This system evolved over time in an effort to comply with the requirements of the various laws governing fisheries management, including NEPA, MSFCMA, and ESA. The groundfish management system recommended by the North Pacific Fisheries Management Council (NPFMC) and implemented by NOAA Fisheries is a good example of a fishery management plan (FMP) that has successfully integrated the goals of EAM into its management strategy.

Overview of National Guidelines for Fisheries Management

NOAA Fisheries established guidelines for FMPs to ensure that the catch of Federally managed species is consistent with the goals of building sustainable fisheries. Overfishing is defined as any amount of fishing in excess of the limit fishing mortality level (Flim). The fishing mortality rate (Fmsy) that would produce the maximum long-term average catch (maximum sustainable yield, or MSY) is the upper bound for Flim. The long-term expected level of biomass (i.e., stock abundance) that would result from fishing at Fmsy is defined as the MSY stock size (Bmsy), recognizing that natural fluctuations above and below the MSY stock size are normal.

NOAA Fisheries guidelines pertaining to the first of the ten national standards (herein "National Standard 1") required of FMPs pursuant to the MSFCMA instruct managers to implement harvest strategies that maintain stock sizes at or above their MSY stock size on average. When stock sizes decline to a level where there is significantly increased concern regarding potential impairment of stock productivity, delayed rebuilding to Bmsy, or potential ecosystem harm, the stock is considered to be depleted (Figure 1). When a stock reaches this level, rebuilding plans must be developed and implemented to improve stock condition.

Figure 1. Summary of thresholds used in managing commercial fisheries in Federal waters.



Each council and associated regional office of NOAA Fisheries is responsible for defining MSY control rules. These rules generally guide managers to set target fishing mortality levels below the limits to avoid exceeding the Flim and, to the extent possible, to account for social, economic, and ecological factors.

NOAA Fisheries is also responsible for enforcing its harvest policies. Ideally, catch and bycatch should be directly monitored with an in-season catch reporting system that provides accurate estimates of catch of both target and non-target species. In many regions, NOAA Fisheries supports fishery monitoring programs that consist of at-sea and/or shoreside observers. These monitoring programs allow managers to assess the amount of catch of target species and incidental species in real time. Fisheries can be closed to protect a species from reaching the overfishing level (OFL). In regions where time-area or gear restrictions are utilized to control catch, scientists conduct research to verify that these management tools provide sufficient control to keep fishing mortality at or below Flim.

NOAA Fisheries is also responsible for conducting stock assessment surveys, which provide relative biomass estimates of many target species, non-target species, and indicator species. LMRs are typically monitored through periodic surveys. These surveys represent a major contribution to the goal of conserving biodiversity because they provide a historical record of distribution and abundance.

Overview of Alaskan Groundfish Management

The management system used in the Alaska groundfish fisheries serves as an illustration of how the MSFCMA, ESA, and NEPA guide managers toward an EAM. In an effort to prevent overfishing and to comply with the provisions of the MSFCMA, the NPFMC working in association with NOAA Fisheries' Alaska Regional Office (ARO), has developed a system of in-season constraints on target groundfish species, non-target groundfish species (primarily groundfish incidentally captured), forage species, and prohibited species (important non-groundfish species incidentally captured). The catch constraints are built around a tier system for estimating acceptable biological catch (ABC) and OFL for stocks or stock complexes. The tier system provides guidance on the maximum permissible levels of catch given the quality of information available (see Goodman et al., 2002 for a review of harvest strategy employed in the North Pacific groundfish fishery). In addition to the constraints on catch at the species or species group level, the NPFMC also imposes an overall cap on the total amount of groundfish that can be removed (Witherell, 2005). In the Bering Sea Aleutian Islands region, this overall constraint results in considerable reductions in catch for several target species.

The establishment of total allowable catches (TACs) is fundamental to the management of Alaskan groundfish fisheries in Federal waters. It involves annual evaluation of the best available scientific information at public meetings and through the review of applicable documents. The first step begins with the preparation of Stock Assessment and Fishery Evaluation (SAFE) reports. These reports contain analyses summarizing the information about the individual stocks and groups, and include ABC and OFL recommendations for future years. The authors of these reports (generally NOAA Fisheries scientists) present their findings to NPFMC and its Groundfish Plan Teams and Scientific and Statistical Committee for further review. After scientific review and public discussion, the NPFMC recommends TAC levels for the upcoming year, which have to be approved and subsequently implemented by NOAA Fisheries. Alaska groundfish managers always set TAC at less than or equal to ABC, and ABC at less than OFL. Catch is usually less than TAC, almost always less than ABC, and is always less than OFL. Agency scientists are currently working on the development of objective rules for incorporating uncertainty in estimated stock biomass, catch rates, stock structure, and productivity. These rules, as noted earlier in this paper, must balance the risk of populations becoming depleted against the benefit to society of resource utilization.

The NPFMC's groundfish management strategy is designed to preserve biodiversity by protecting target species along with non-target species that are impacted by the fisheries. The FMPs identify four groups of species: prohibited species, target species, other species, and forage fish. The NPFMC is currently reviewing these categories in an effort to comply with proposed revisions to the guidelines for National Standard 1. Anticipated changes include a split of the "other species" complex into species assemblages that share common life history characteristics. Scientists from NOAA Fisheries' Alaska Fisheries Science Center produce annual or biennial SAFE reports that document the status and trends of target and non-target species (e.g., other rockfish, other flatfish and other species) and provide ABC recommendations for both target and non-target species.

The NPFMC's groundfish FMPs also include constraints stemming from the ESA. Managers imposed time, area, and gear restrictions on the groundfish fishery to reduce direct and indirect mortality of Pacific salmon, short-tailed albatross, and Steller sea lions. These constraints, coupled with deterrents to the development of directed fisheries for forage species, act to mitigate adverse impacts of fishing on endangered species. A biomass control rule was established for pollock, Pacific cod, and Atka mackerel to preserve the forage base for Steller sea lions.

The NPFMC groundfish FMPs have recently been reviewed with respect to protection of EFH. In Alaska, large areas are protected from the effects of fishing through seasonal or year-round closures (Witherell, 2005). The review of EFH found that current levels of harvest are not producing a measurable impact on the reproduction, growth, or distribution of managed species in Alaska. Despite this finding, the NPFMC recommended preemptive measures to protect habitats of particular concern and deep water corals.

The practices of the NPFMC and ARO also comply with the goals of seeking public input on management decisions. The NPFMC and ARO recently completed a programmatic environmental impact statement on groundfish fisheries management in Alaska. Alternatives reviewed in this document were identified at public meetings. The document provided a clear assessment of the tradeoffs between management alternatives and the expected environmental impacts associated with each alternative. This process illustrates that compliance with the NEPA provisions contributes towards the goal of seeking and incorporating public input into decision-making.

In conclusion, this brief review of Alaskan groundfish management illustrates that managers are taking incremental steps towards implementing EAM. The review also illustrates that, when these steps are taken, fisheries can be managed in a sustainable manner while providing economic benefits to the Nation.

Appendix D: Legal Mandates

- Clean Water Act (33 U.S.C. § 1268)
- Coastal Zone Management Act (16 U.S.C. §§ 1451 *et seq.*)
- Endangered Species Act (16 U.S.C. §§ 1531-1543)
- Establishment of Great Lakes Research Office (33 U.S.C. § 1268(d))
- Establishment of the National Estuarine Research Reserve System (16 U.S.C. § 1461)
- Estuary (Estuarine) Protection Act (16 U.S.C. §§ 1221-1226)
- Estuary Restoration Act (33 U.S.C. §§ 2901-2909)
- Fish and Wildlife Conservation Act (18 U.S.C. §§ 2901-2911)
- Global Change Research Act (15 U.S.C. §§ 2921-2961)
- Harmful Algal Bloom and Hypoxia Research and Control Act (16 U.S.C. § 1451)
- Marine Migratory Gamefish Act (16 U.S.C. § 760(e))
- National Aquaculture Act (16 U.S.C. §§ 2801-2810)
- National Climate Program Act (15 U.S.C. §§ 2901-2908)
- National Coastal Monitoring Act (33 U.S.C. §§ 2801-2805)
- National Contaminated Sediment Assessment and Management Act (33 U.S.C. § 1271)
- National Environmental Policy Act (42 U.S.C. §§ 4321-4347)
- National Marine Sanctuaries Act (16 U.S.C. §§ 1431 *et seq.*)
- Nonindigenous Aquatic Nuisance Prevention and Control Act, and National Invasive Species Act (16 U.S.C. §§ 1431-1445)
- Oceans and Human Health Act (33 U.S.C. §§ 3101-3104)
- Regional Marine Research Programs (16 U.S.C. § 1447(b))
- Water Resources Development Act: Great Lakes habitat remediation (33 U.S.C. § 2326(b))
- Water Resources Development Act (33 U.S.C. § 2572)

Appendix E: Examples of NOAA Ecological Forecasts
(Operational and in Development)

Ecological Forecast Categories/ Type	Driver - Need	Frequency of Forecast	Spatial Extent of Forecast	Products - Outputs	User Community	Status
Predicting movement of hazardous spills	-Disaster Planning -Living Resource Impact -Human Health Impact	-Near-real time	-Event Specific -Local -Regional	-Trajectory of movement -Risk to living resources and humans	-State managers -Federal managers -Emergency response personnel	-In Development -In Transition -In Operation
Forecasting the distributions, abundance, and health of living resources	-Stock Assessments -Living Resource Impact	-Seasonal -Scenario	-Regional -Species Distribution Range	-Species distribution maps -Species abundance -Probability of rebuilding overfished species -Projects distribution and abundance	-Fishery managers -Fishery management councils -State managers -Resource managers	-In Development -In Transition -In Operation
Forecasting the effectiveness and optimal placement of MPA's	-Stock Assessments -Living Resource Impact	-Scenario	-Regional -Local	-Species abundance, distribution, size structure and habitat maps -Optimal location of MPA's	-MPA managers -Resource managers	-In Development
Predicting coral reef health and recovery after disturbance	-Living Resource Impact	-Scenario	-Regional	-Species survival probability -Habitat maps	-Marine Sanctuary managers -Resource manager	-In Development

Ecological Forecast Categories/ Type	Driver - Need	Frequency of Forecast	Spatial Extent of Forecast	Products - Outputs	User Community	Status
Predicting larval transport and survival	-Stock Assessments -Living Resource Impact	-Daily to weekly	-Regional	-Trajectory of movement -Probability of survival at a given location	-Marine Sanctuary managers -MPA managers -Fishery managers	-In Development -In Transition -In Operation
Predicting organism distributions based on habitat mapping	-Stock Assessments -Essential Fish Habitat -Living Resource Impact -Human health impacts	-Scenario	-Local -Regional	-Species distribution maps -Habitat maps	-Local and state managers -Resource managers	-In Development -In Transition -In Operation
Development, persistence, movement and landfall of harmful algal blooms	-Living Resource Impact -Human health impacts	-Near real time -Daily -Scenario	-Local -Regional	-Trajectory of movement -Bloom identification -Probability of bloom initiation	-Local and state managers -Resource managers	-In Development -In Transition -In Operation
Coral bleaching forecasts	-Living Resource Impact	-Seasonal -Scenario	-Regional -Global	-Species survival probability	-Marine Sanctuary managers -Resource manager	-In Development
Effectiveness of habitat restoration	-Living Resource Impact - Essential Fish Habitat	-Seasonal -Yearly -Scenario	-Local -Regional	-Metric measuring restoration effectiveness	-Resource managers -State managers -Federal managers	-In Development -In Transition
Effectiveness of hydropower system modifications for survival of migrating fish	-Living Resource Impact -Endangered Species Act	-Scenario -Yearly	-Local	- Probability of individual fish survival -Probability of species recovery	-Local managers -State managers	-In Operation In Development

Ecological Forecast Categories/ Type	Driver - Need	Frequency of Forecast	Spatial Extent of Forecast	Products - Outputs	User Community	Status
Projections of extinction risk for protected species	-Living Resource Impact -Endangered Species Act	-Scenario -Yearly	-Local -Regional	-Probability of species recovery	-Resource managers	-In Operation -In Development
Forecasts of the coastal ecosystem effects associated with upstream water management alternatives	-Living Resource Impact	-Daily -Seasonal -Yearly -Scenario	-Regional	-Metrics for impacts to the ecosystem under study	-City planners -Local managers -State managers -Federal managers	-In Development
Beach closure forecasting	-Human health impacts	-Near real time -Daily	-Local -Regional	-Probability of exceeding health standards	-Local managers -State managers	-In Development
Impact of climate change on coastal ecosystems	-Human health impacts -Living resource impact	-Months -Decades -Scenario	-Local -Regional	-Habitat inundation maps -Metrics for impacts to the ecosystem under study	-City and state planners -Local, state, Federal managers	-In Development
Forecasts of physical dynamics and their impacts on the ecosystem	-Living Resource Impact -Human health impact	-Near real time -Daily -Seasonal -Scenario	-Regional	-Forecast maps and time-series of key physical parameters -Metrics of impacts to ecosystem under study	-Resource managers -Federal managers -State managers	-In Development -In Transition -In Operation
New non-native species introductions	-Living Resource Impact	-Scenario	-Local -Regional	-probability of species invasion	-State managers -Federal managers	-In Development
Drinking water quality and quantity	-Human health impact	-Scenario	-Local -Regional	-Probability of exceeding health standards	-Local managers -State managers	-In Development
Onset, extent and impact to living resources of hypoxia in coastal areas	-Living Resource Impact	-Near real time -Seasonal -Scenario	-Local -Regional	-spatial / temporal maps of hypoxia -metrics for living resources	-State managers -Federal managers	-In Development

Ecological Forecast Categories/ Type	Driver - Need	Frequency of Forecast	Spatial Extent of Forecast	Products - Outputs	User Community	Status
Water quality forecasts	-Living Resource Impact -Human health impact	-Near real time -Daily -Seasonal -Scenario	-Local -Regional	-spatial and temporal maps of key water quality variables	-State managers -Federal managers	-In Development -In Transition -In Operation
Ice thickness/extent and ecological impacts	-Living Resource Impact	-Scenario	-Local -Regional	-Metrics for impacts to the ecosystem under study	-Resource managers	-In Development
Water quantity impact on living resources	-Living Resource Impact	-Daily -Seasonal -Scenario	-Local -Regional	-Metrics for impacts to the ecosystem under study	-State managers -Federal managers -Resource managers	-In Development
Forecast of shellfish toxicity	-Living Resource Impact -Human health impact	-Near real time -Daily	-Local	-toxin accumulation in shellfish	-State managers -Resource managers	-In Development

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