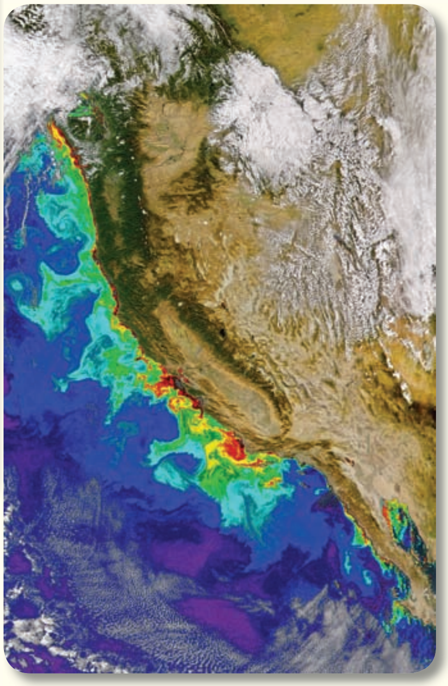
Ecosystem Research and Coastal Management

Making the Connection at the Regional Scale

Case studies



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Cover photos (left to right): LandSat image of South Florida, NASA; 2004 chlorophyll concentrations along the California coast, image by SeaWiFS satellite, NASA; Mississippi River delta, image by Terra/MODIS satellite, NASA/Goddard Space Flight Center Scientific Visualization Studio.

INTRODUCTION

Coastal management in the U.S. is in transition toward a stronger, ecosystem-based approach implemented at the regional scale and supported by strong scientific synthesis and prediction. For over a decade, the National Oceanic and Atmospheric Administration (NOAA) and other government agencies have conducted a number of regional ecosystem research (RER) efforts in support of mission requirements. The tremendous decision-support challenge of providing scientific information at the regional scale provided the motivation to undertake an evaluation of robust processes and best practices that could efficiently and effectively be used to ensure coastal research and management linkages.

A best practices workshop of approximately 50 national leaders in coastal research, management, and policy was convened to identify the key elements of an effective RER program and policy actions to enhance future RER efforts. The workshop provided a forum in which the diversity of issues and approaches for planning, managing, and conducting RER could be discussed. Additionally, the workshop provided an opportunity to gather lessons learned, both positive and negative, from RER efforts over the past decade.

Case studies presented by managers and scientists

Eight case studies were presented to workshop participants that highlighted lessons learned in conducting regional-scale research and incorporating this information into management (Figure 1). The case studies represent a wide variety of physical and ecological contexts; these include the Great Lakes (Lake Erie), a river-dominated coast (northern Gulf of Mexico), tropical lagoon systems (Micronesia and South Florida), and coastal ocean systems (California coast, Bering Sea, Gulf of Maine, and the Northwest Atlantic). Case studies were chosen to display the variety of issues, funding, and participation involved in regional ecosystem research (Table 1). Each case study provides perspectives on planning and implementation of regional ecosystem research from the point-of-view of scientists and managers.

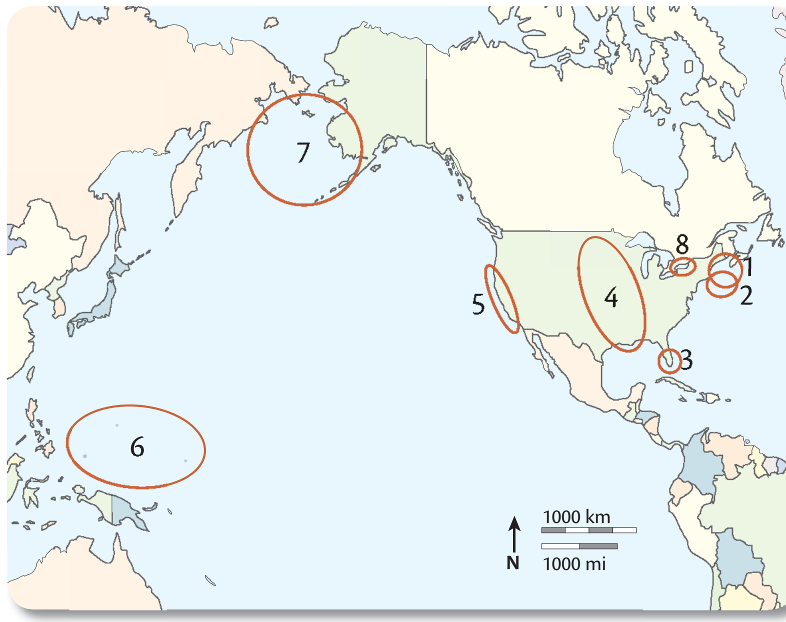


Figure 1. Locations of case studies chosen to highlight specific regional ecosystem research issues.

Table 1. Summary of case study issues, funding, and participation. Case studies also span the three phases of regional ecosystem research. Table data are for illustrative purposes only and may not contain the full extent of the duration, funding, and participant level for each case study.

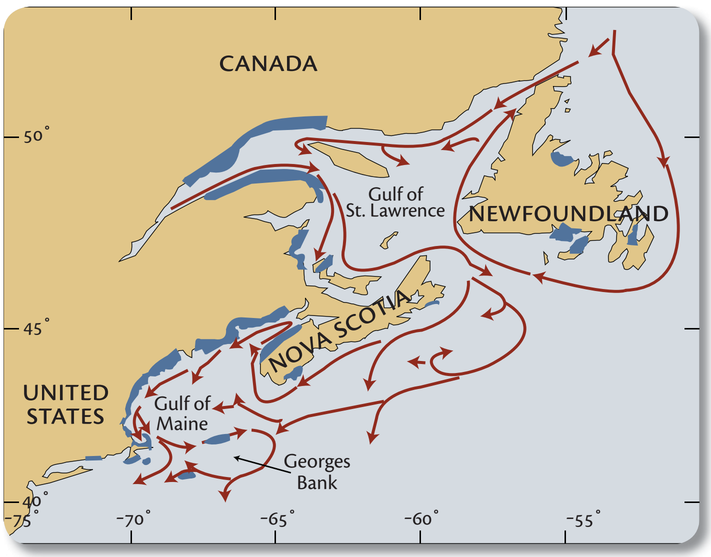
Case study region	Issue	Time period	Core funding	Personnel
1. Gulf of Maine	Harmful algal blooms	1997–2010	~$11 million	34 participants 21 institutions
2. Northwest Atlantic	Food web	1993–2008	~$11 million	87 participants 23 institutions
3. South Florida	Habitats	1994–2008	~$23 million	147 participants 42 institutions
4. Gulf of Mexico	Hypoxia	1990–2009	~$28 million	95 participants 31 institutions
5. California	Marine Protected Areas	1999–Ongoing	~34 million	266 participants N/A institutions
6. Micronesia	Coral reefs	2002–2006	~$1.4 million	14 participants 12 Institutions
7. Bering Sea	Fisheries	1991–2002	~$11 million	74 participants 22 institutions
8. Lake Erie	Eutrophication	2006–2010	~$5 million	20 participants 9 institutions

Gulf of Maine toxic algal blooms: Developing forecasting tools for shellfish contamination by red tides

Donald M. Anderson, Woods Hole Oceanographic Institution
Darcie Couture, Maine Department of Marine Resources

***Focus:** Provide fisheries managers with information about long-term toxicity trends and short-term observations of toxic cell abundance and dynamics related to harmful algal blooms (red tides) in the Gulf of Maine region.*

The cold waters of the Gulf of Maine support highly productive fisheries, including commercially important species such as Atlantic herring and American lobster, and vast shellfish resources. There are three major basins: Wilkinson Basin to the west, Jordan Basin in the northeast, and Georges Basin in the south. Both Massachusetts Bay and the Bay of Fundy are included in the system. The watershed of the Gulf of Maine encompasses an area of 179,008 km² including large portions of three U.S. states (Maine, New Hampshire, and Massachusetts) and two Canadian provinces (New Brunswick and Nova Scotia).



Map of Gulf of Maine and the areas where paralytic shellfish poisoning has occurred (blue areas).

Coastal management

Shellfish resources of the Gulf of Maine and the adjacent New England shelf are frequently contaminated with paralytic shellfish poisoning (PSP) toxins produced by the dinoflagellate *Alexandrium fundyense*. Annual closures of shellfish harvesting are common along the New England coast, in some years stretching from the Canadian border to southern Massachusetts, and including thousands of km² of offshore shellfish resources as well. Recent efforts to exploit the offshore surf clam and ocean quahog resources on George's Bank and Nantucket Shoals have been stymied by PSP toxins detected in those shellfish and the recent discovery of major offshore blooms of *A. fundyense*. Other toxic algae also occur in the region (i.e., *Pseudo-nitzschia* species responsible for Amnesic Shellfish Poisoning). Current management imposes harvesting restrictions over large expanses of coastline that may include both toxic and non-toxic areas.

Ecosystem science

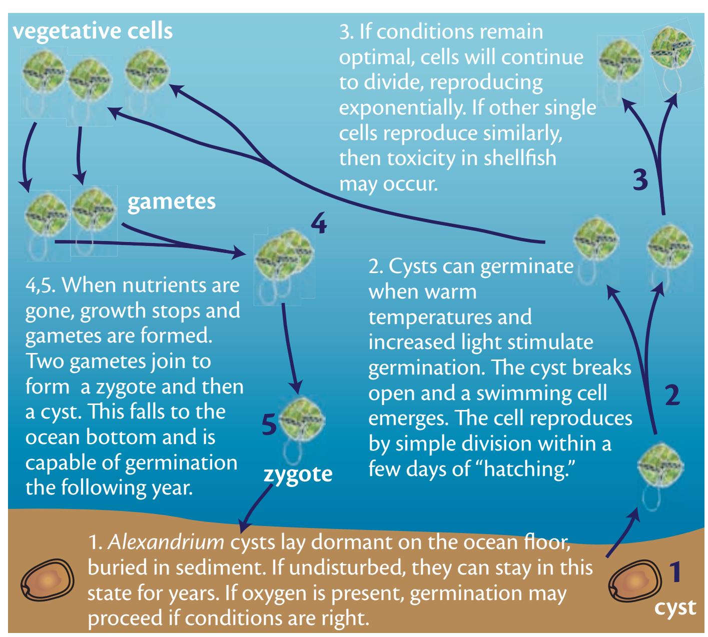
The structure and dynamics of the Gulf of Maine ecosystem are strongly influenced by local, regional, and basin-scale environmental drivers—from severe storms to interannual changes in hydrography to climate variability, climate change, and ocean acidification. Nearshore waters are subject to intense fishing pressure, inputs of anthropogenic nutrients and pollutants, outbreaks of introduced, harmful, and/or nuisance organisms, and a variety of other human-related stresses.

Important questions that needed to be addressed included:

- How do human activities, including those affecting climate, affect the *Alexandrium* populations and toxicity patterns?
- Are there strategies that can be used to suppress or control toxic blooms within the region, thereby reducing impacts?
- What tools or strategies can be used to refine the harvesting closures to include only the areas affected by toxic blooms?
- What management tools are needed to maintain and expand a viable shellfish industry despite the recurrent outbreaks?

Lessons learned

- Frequent Principal Investigator meetings with clearly identified research theme leaders and research teams provided good direction and oversight which was critical to constructing a complex biophysical model.
- Using the media to highlight research and management successes gave visibility to the program and NOAA sponsors and raised public awareness of the issue.
- A strong partnership between the resource management community, NOAA program managers, research scientists, and industry ensured that research was focused on the most important management and industry needs.



Reproductive cycle of the dinoflagellate, *Alexandrium fundyenses*, that causes PSP.

Northwest Atlantic food web: Predicting the influence of environmental and climate factors on fisheries recruitment

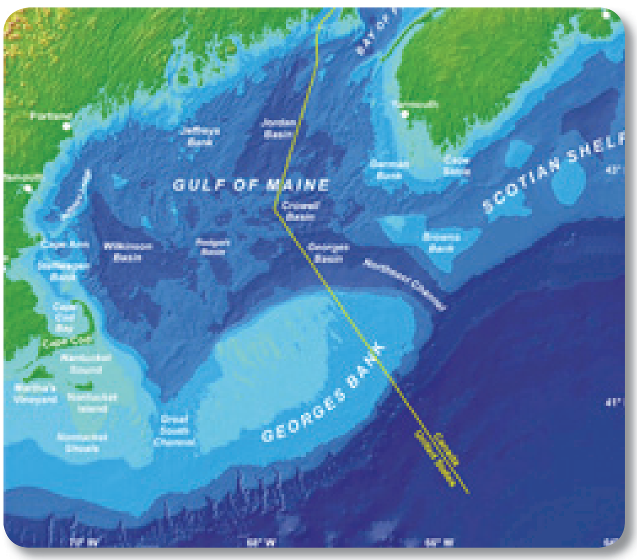
Cabell Davis, Woods Hole Oceanographic Institution
David Mountain, NOAA's National Marine Fisheries Service

Focus: *Understand impact of climate on marine ecosystems by studying population dynamics of key plankton and fish species, using Georges Bank as a model system.*

Georges Bank is a shoal area east of Cape Cod, about 300 km by 150 km in size, with shallow (<60m), well-mixed waters. The Bank lies at the southern extent of the Gulf of Maine, and it straddles the boundary between boreal and temperate climate regimes. As a consequence, this ecosystem is subjected to a high degree of climatic variability. Upwelling and on-bank mixing support high primary productivity in the ecosystem and high concentrations of small copepods. Cod and haddock spawn on the northeast peak in February, and oceanographic conditions and high copepod abundance enhance growth and survival of the larval stages. Historically, Georges Bank supported large fisheries of these species.

Lessons learned

- Strong collaboration between NOAA and academic personnel was invaluable, enabling GLOBEC research to help establish the concept of an ecosystem approach to management.
- Basic research leads to fundamental new insights and tools that are critically important for management, and funding must be provided to help with the transition of key results to application.
- Dissemination of results through peer-reviewed scientific literature is essential for establishing a rigorous, scientifically credible, research program.



Map of Northwest Atlantic study area, with a foucs on Georges Bank.

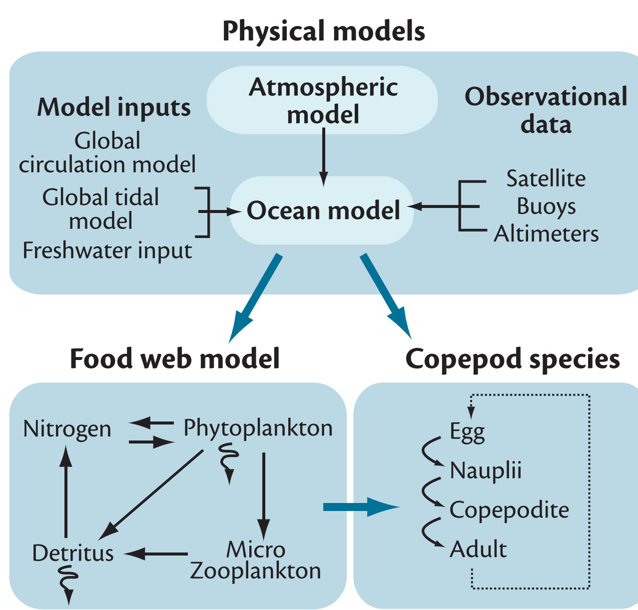
Coastal management

Significant shifts in fisheries dynamics and ecological processes accompanied increased fishing pressure by distant water fleets in the 1960s and by domestic fleets after the extension of U.S. jurisdiction to 200 miles in the 1970s. Methods of assessing adult population abundance for fishery management in current use generally do not consider changes in environmental conditions and in the state of other components of the ecosystem, such as the abundance of prey, that influence recruitment success.

Ecosystem science

The U.S. Global Ocean Ecosystem Dynamics (GLOBEC) was designed as a research program in marine ecology to help broaden the perspective of coastal ocean management beyond its traditional focus on fisheries. The goal of the GLOBEC Northwest Atlantic/Georges Bank program is to understand the population dynamics of selected zooplankton and larval fish populations on Georges Bank, and with that understanding, be able to evaluate the potential effects of climate variability and change on the Bank's ecosystem. The program addressed this objective by investigating the underlying physical and biological processes that control the population dynamics of four target species: the egg and larval stages of two commercially important groundfish species, Atlantic cod and haddock, and their prey, including *Calanus, Pseudoclanus*, and other copepods.

The research program was designed to study biological-physical interactions affecting recruitment processes in selected "model" species and systems in order to better understand processes controlling populations of other marine organisms. Early research attempted to relate ecosystem productivity to fish yields using a trophodynamic-biogeochemical approach. However, attempts to use bulk primary production and zooplankton community grazing rates to predict fish production met with limited success. GLOBEC uses an alternative approach, focusing on recruitment processes in key species to obtain a better understanding of factors regulating their population size. Survival during early life stages is critical in determining population size for a wide range of marine species.



This study linked physical and food web models together to help aid management decisions.

South Florida habitats: Understanding downstream consequences of freshwater diversions into Florida Bay and Florida Keys waters

Peter Ortner, University of Miami
David Rudnick, South Florida Water Management District
Brian Keller, NOAA's National Marine Sanctuary Program

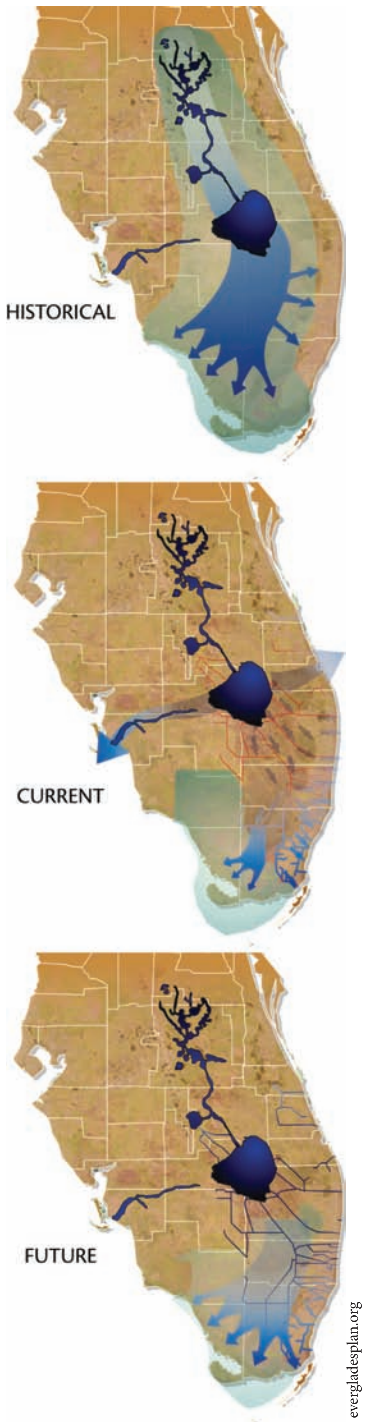
Focus: *Maintain the health of subtropical, oligotrophic coastal ecosystems adjacent to a major and growing urban center while ensuring freshwater supplies to meet the needs of terrestrial ecosystems (the Everglades), estuaries, mangrove forests, and increasing human demands.*

Florida Bay is intimately connected with the Florida Keys and the adjacent marine systems of the Southwest Shelf and the Florida Straits/Gulf Stream. Over 85% of the Bay's 2,200 km² area lies within Everglades National Park, and the Florida Keys National Marine Sanctuary (FKNMS) contains much of the rest. These waters support numerous protected species and provide critical habitat for commercially important species, such as spiny lobsters, stone crabs, and many important finfish species. Florida Bay is the principal nursery for the Tortugas pink shrimp fishery.

Coastal management

Restoration and preservation of the Everglades, Florida Bay, and adjacent coastal ecosystems is the overarching goal of a regional initiative in South Florida. The South Florida Ecosystem Restoration Trask Force of state and federal agencies and representatives of other stakeholder groups heads this initiative.

Several trends indicate that the environmental health of Florida Bay has deteriorated in recent decades. One of these inidcators is the die-off of seagrass beds, especially in the period following the summer of 1987. Following seagrass die-off, there have been atypical and periodic algal blooms across much of Florida Bay extending into the Florida Keys. Related issues concern specific marine resources in the FKNMS, Florida Bay, the Dry Tortugas, and Biscayne Bay. One possible cause of this deterioration is changes in the quantity, quality, timing, and distribution of the inflow of freshwater from the Everglades, which has been altered over the past century by a large-scale water management program.



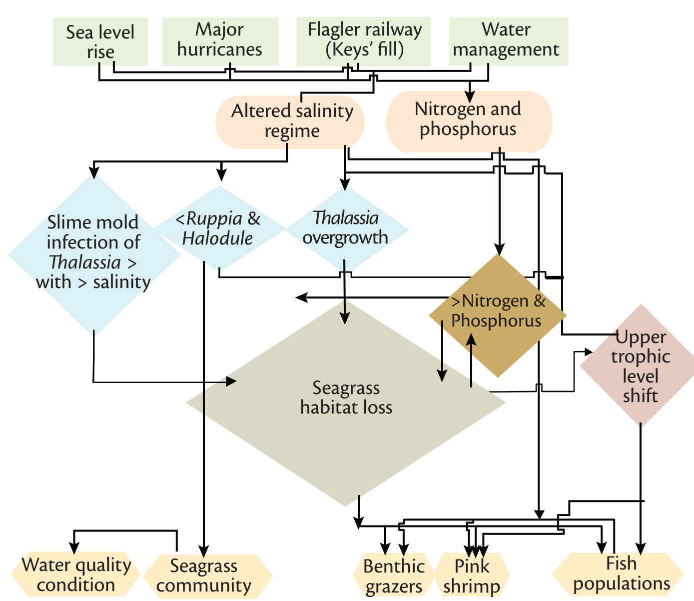
The historical, current, and future hydrology of South Florida.

Lessons learned

- A committee composed of members from resource management agencies in the region, with input from a scientific expert panel, helped direct and coordinate research activities to address management questions.
- Resource managers carefully translated management objectives into widely disseminated research questions which guided and focused research efforts.
- Regular science conferences helped maintain a research focus on management questions and served to recruit new scientists and ideas into the program.

Ecosystem science

The research of the Florida Bay Science Program focuses on the ecosystem consequences of anticipated alterations in freshwater input related to continued development, and to the regional ecosystem restoration initiatives. The scope of the program now includes adjacent coastal and marine ecosystems. The results of the Science Program are used by the Comprehensive Everglades Restoration Plan (CERP) and individual resource management agencies (e.g., the South Florida Water Management District, Everglades National Park, FKNMS, and Florida Fish and Wildlife Conservation Commission) to support management and restoration planning; assess ecosystem status, trends, and progress toward restoration goals; and address regulatory issues in the estuarine and coastal systems.



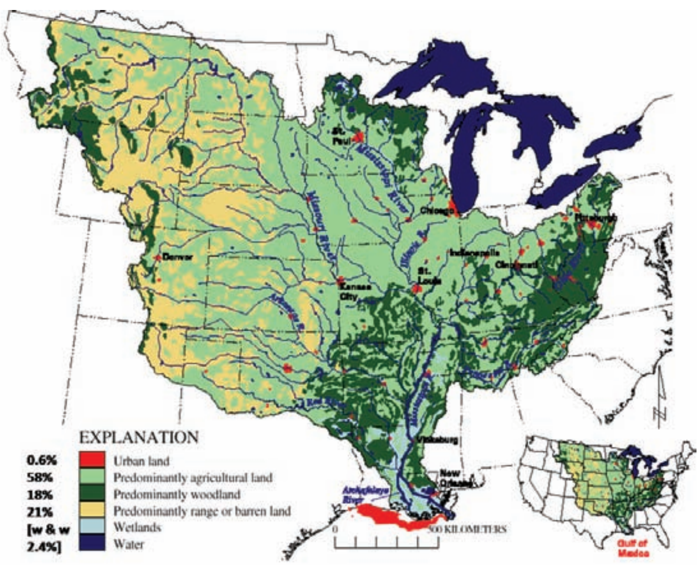
Scientists in South Florida use Conceptual Ecological Models to identify needed information and help determine priorities for research.

Gulf of Mexico hypoxia: Predicting hypoxic water ‘dead zones’ as a result of nutrient over-enrichment in runoff from the Mississippi watershed

Nancy N. Rabalais, Louisiana Universities Marine Consortium
Bryon Griffith, U.S. Environmental Protection Agency’s Gulf of Mexico Program

Focus: *Develop a predictive capability for the Mississippi River-influenced continental shelf ecosystem within an adaptive management framework that connects research, monitoring, data analysis, model predictions, and management actions.*

The area of the northern Gulf of Mexico influenced by the discharge of the Mississippi River (approx. 30,000 km²) extends from the state of Mississippi through the entire Louisiana coast and into the upper Texas coast. The Mississippi River delivers freshwater discharge, sediments, and nutrients from a watershed that encompasses 41% of the contiguous 48 lower United States (approx. 2.9×10^6 km²). This drainage enters the Gulf through two deltas, the Birdfoot Delta southeast of New Orleans and the Atchafalaya River Delta, which discharges about one-third of the flow 200 km to the west on the central Louisiana coast.



Map of the Mississippi River watershed and associated land type. The hypoxic area in the Gulf of Mexico is in red.

Coastal management

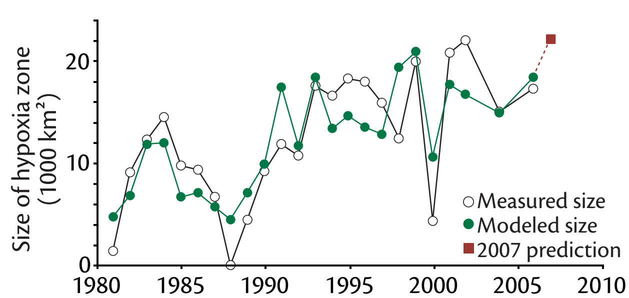
The northern portion of the Gulf of Mexico ecosystem has undergone profound changes due to excess nutrients in Mississippi River water from land-based sources. Watershed landscape alterations over two centuries have lessened the buffering capacity of the watershed. Anthropogenic addition of nutrients in an intensely cultivated, tile-drained area in the center of the watershed is the primary cause of eutrophication in coastal waters and the development of hypoxia in the last half of the 20th century. This increased nutrient supply has led to excessive production of phytoplankton, including noxious and toxic forms. Large areas of hypoxic bottom water, commonly known as the ‘Dead Zone,’ are a recurrent feature in the Gulf during spring and summer. The hypoxic area in the northern Gulf of Mexico (annual maximum extent of about 16,000 km² on average) is the second largest human-caused dead zone in the world’s coastal ocean. Eutrophication and associated hypoxia in coastal ecosystems can cause stress and/or death to marine organisms, shifts in abundance and composition of commercial harvests and loss of commercial and recreational fishery income.

Lessons learned

- Long-term regional research findings helped drive a management commitment, in this case legislation and formation of an interagency task force.
- A management commitment can, in theory, sustain research funding and management action over the long time frames required for adaptive management of large ecosystems.
- Multi-jurisdictional management, insufficient restoration guidelines, and inconsistent nutrient management scenarios can pose challenges to devising a large-watershed nutrient reduction strategy.

Ecosystem science

The goal of ecosystem research in the northern Gulf of Mexico is to understand the causes and effects of the hypoxic zone, predict its future extent, and assess its impact of coastal resources. Research supported by the NOAA Northern Gulf of Mexico Hypoxic Research Program seeks to determine quantitatively the degree to which primary productivity has been enhanced in areas receiving inputs of nutrients from terrestrial sources, determine the impact of enhanced production on water quality, and determine the fate of fixed carbon in coastal areas. Current studies address the dynamics of the hypoxic zone and seek to refine our understanding of biological, chemical and physical processes that influence development of the hypoxic zone, its annual extent and impacts on fisheries. Research conducted by the U.S. Environmental Protection Agency Gulf Breeze Environmental Laboratory seeks an understanding of coastal hypoxia and options for coastal management.



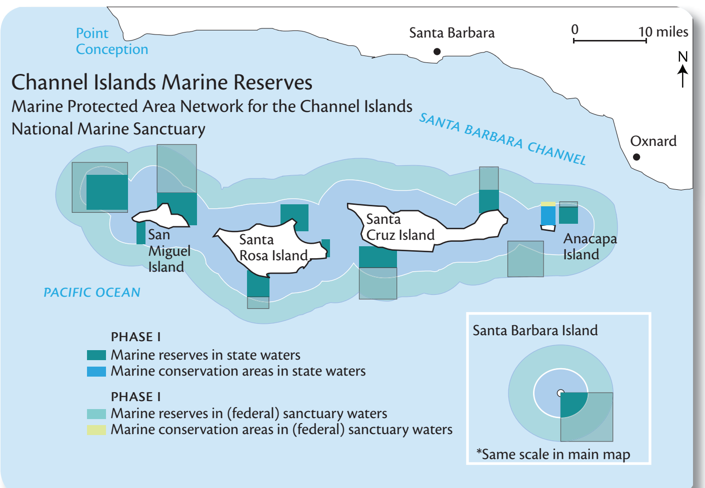
Summer hypoxia in the Gulf of Mexico is forecast using historical data. The hypoxia forecast for 2007 was 22,118 km² and the actual size was 20,461 km². Adapted from: Turner RE, Rabalais NN, Justic D (2006) Predicting summer hypoxia in the northern Gulf of Mexico: Riverine N, P, and Si loading. Mar Pollut Bull 52:139–148

California marine protected areas: Designing and implementing marine protected areas to sustain fisheries

Steve Gaines, University of California–Santa Barbara
Meg Caldwell, Stanford University

Focus: *Design and implement a network of Marine Protected Areas (MPAs) to sustain populations of commercially and recreationally important fish species.*

The California Marine Life Protection Act (MLPA), adopted in 1999, directed the state to re-design California's then existing collection of MPAs into a coherent and effective network. The MLPA Initiative for the south Central Coast region of California was the first of five regional initiatives. The South Central Coast region comprises over 200 miles of coastline and 1150 square miles in area between Pigeon Point to Point Conception. This region encompasses twelve existing MPAs representing <4% of region's state waters.



The Channel Islands Marine Reserves are part of the South Central Coast region MPAs.

Coastal management

Adoption of the MLPA marked a major shift in the California Department of Fish and Game's approach to ocean resource management, following 150 years of single-species management based on a traditional principle of maximizing catch of commercially and recreationally important species. The Act requires the advice and assistance of scientists, resource managers, experts, stakeholders, and members of the public. In addition, the act flipped the burden of proof for establishing MPAs by proactively requiring a network of MPAs, rather than authorizing their establishment only after "need" is proven. The MLPA Initiative for the South Central Coast region comprised an intensive two-year process largely funded through a public-private partnership, involving a science advisory team, a regional stakeholder group, an independent MLPA Initiative staff, a blue ribbon task force, the State Department of Fish and Game, California's Fish and Game Commission, and special public process consultants tasked with providing ongoing and end-of-process advice and feedback.

Ecosystem science

The MLPA also elevated the role of science in resource management decision making—mandating creation of a panel of scientific advisors to assist in MPA network design and requiring that decisions reflect the "best readily available science." The first phase of MLPA implementation relied on a variety of advisory and decision-making bodies, each challenged to apply scientific principles to MPA design as required by law. Substantial scientific information already existed for this region. For example, monitoring studies conducted along the entire west coast by the Partnership for Interdisciplinary Studies of the Coastal Ocean (PISCO) included existing MPAs and many sites inside and outside the proposed MPAs created under MLPA. PISCO also provided key insight into the scale of connectivity among locations via larval dispersal, which is a key driver of design guidelines for the emerging network. Despite the wealth of biological and physical data, information on non-consumptive uses and on the socioeconomic impact for both consumptive and non-consumptive uses were not easy to access, especially in spatially relevant formats.

Lessons learned

- It was important to begin with the following enabling conditions: a strong statutory mandate, secure funding sources, and rich foundational data.
- The key elements in effective integration of research into management planning were the development of a decision-support tool with accompanying hands-on training and the establishment and adherence to firm and tight deadlines.
- Project personnel were provided with clear and regular scientific briefings, a transparent management framework, and key political champions, which facilitated an entrepreneurial spirit.

The process by which the South Central Coast region's Marine Proteced Areas are created.

Micronesia coral reefs: Responding to land-based impacts on coastal coral reefs using a community-based process

Noah Idechong, Palau National Congress
Robert Richmond, University of Hawaii at Manoa's Kewalo Marine Laboratory

Focus: *To identify the key biological and physical factors affecting coral reef communities, policies needed to address threats to these reefs, and the societal aspects of policy development and implementation within adjacent human communities.*

This project involved work on three islands in Micronesia—Palau, Guam, and Pohnpei that represent a gradient of human impacts, cultural uses, and traditional governance. The populations range from about 21,000 on Palau and 34,500 on Pohnpei, to over 175,000 on Guam. Watersheds range from a few km² to over 100 km². The coral reefs of this region are among the most biologically diverse on the planet, and many are relatively intact.

Lessons learned

- Developing trust and mutual respect and clearly identifying roles and responsibilities of scientists, resource managers, and traditional leaders were key elements of the program.
- Constant communication and stakeholder participation were essential to bridging science to policy, and considerable effort was expended to develop and maintain lines of communication.
- Working within the cultural framework of various island nations was a key element of the program, and responsibility for overseeing the scientific integrity of the research was jointly performed by local and visiting researchers.

Coastal management

Coastal management addressed the linkages between activities within island watersheds and their impacts on the coral reefs downstream. The three island sites, Palau, Guam, and Pohnpei, offered similar biophysical characteristics but presented unique cultural attributes. On Palau, the buffering mangrove forest was being cleared and filled for housing, resulting in increased terrigenous sediments reaching and burying coastal coral reefs. On Guam, coastal impacts are related to controlled burning by hunters in the watershed and by overfishing of herbivorous fish on the reefs. On Pohnpei, impacts are related to the clearing of the upland rainforest to plant sakau, an important cash crop. In Palau, traditional leaders and villagers have worked with governmental and nongovernmental institutions, including the Palau International Coral Reef Center, the Palau Conservation Society, and the Airai State legislature and governor to protect and restore areas within the watershed. This experience has served as a model for other Palauan communities facing similar problems with their coastal resources. At all three sites, specific problems tied to human activities were responsible for sedimentation effects on the reefs, and a set of scientifically based approaches was recommended to each community for reversing the negative trends in reef health.

Detailed map of Palau, one of the three islands that are being compared for impacts from land use. Inset map shows the location of the 3 islands.

Ecosystem science

Ecosystem research gathered information on changes occurring in mangrove forests and coral reef communities and investigated the causes of these changes. For example, studies at Airai Bay, Palau, documented the growth in an area of coral mortality at inshore locations immediately following the removal of mangroves.

At all three sites, local communities were involved in determining the project scope and design, conducting the study, and applying the results to coastal management. The studies also addressed the question of how to translate scientific findings into policies and actions leading to coral reef sustainability.

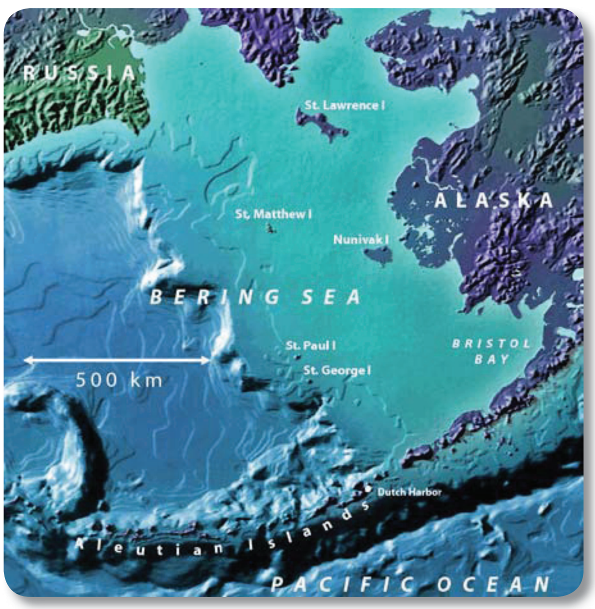
Local community leaders meet with coastal managers and scientists to work on environmental problem solving.

Bering Sea fisheries: Discerning the relationship between Walleye Pollock stocks and ocean processes under climate change

Anne Hollowed, NOAA's National Marine Fisheries Service/Alaska Fisheries Science Center
Allen Macklin, NOAA's Pacific Marine Environmental Laboratory

Focus: *Characterize the size and distribution of the pollock stocks in the Bering Sea, the biophysical processes that affect critical early life stages, and evaluate the effect of decadal-scale variation in climate on the annual recruitment of juvenile pollock to the fishery.*

Half the U.S. marine seafood harvest comes from Alaskan fisheries, much from the eastern Bering Sea. This region also hosts large seabird and marine mammal populations and provides subsistence for indigenous communities. Productivity is affected by the presence and extent of seasonal sea ice. Late in the 1970s and again around 2000 the region experienced major shifts in climate and changes in the ecosystem associated with warmer temperatures and changing sea ice patterns. These changes represent a transition from primarily cold Arctic ecosystems earlier in the 20th century, dominated by sea ice, to sub-Arctic conditions. This transition affects the distribution of food energy to the pelagic and benthic regions and the north-south range of some marine species. There was a major ecosystem reorganization following the late-1970s shift.



The Bering Sea spans the Pacific Ocean from Alaska to Russia.

Coastal management

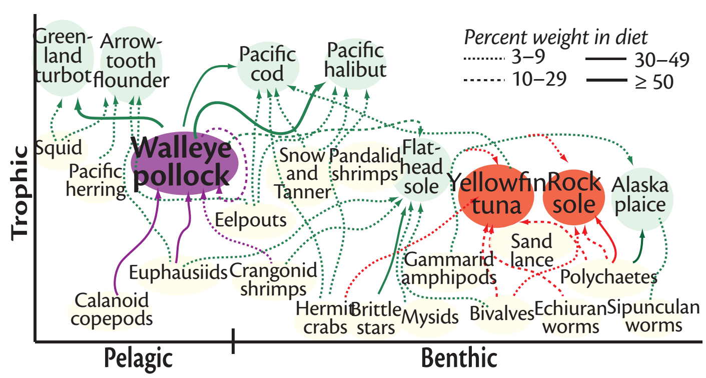
Bering Sea walleye pollock (*Theragra chalcogramma*) are one of the world's largest single species fisheries; about half of the catch occurs within the U.S. Exclusive Economic Zone (EEZ). The remainder comes from the central and western Bering Sea, areas outside the control of U.S. fishing regulations. It was believed that two coastal stocks (eastern and western) provided the majority of fish, with most of the fish caught in the U.S. EEZ supplied by spawning over the southeast Bering Shelf. However, it was not well known to what extent these stocks intermingled. Nor did we know the degree of influence of environmental factors in large interannual variations in year-class strength or how to predict these variations.

Lessons learned

- Interdisciplinary programs led to an acceleration of understanding, but did not always provide operational products.
- Co-location of a core group of Principal Investigators was very helpful and a strong project coordinator was critical.
- Maintenance of a core monitoring effort was coupled with staged process oriented research projects and synthesis of results, and this allowed for better focus in management and research.

Ecosystem science

Bering Sea Fisheries-Oceanography Coordinated Investigations (BS FOCI) addressed questions of pollock stock structure throughout the Bering Sea and survival of young fish in the eastern Bering Sea. Southeast Bering Sea Carrying Capacity (SEBSCC) was designed to conduct ecosystem research and transfer information to applied management of fish stocks. The BSFOCI studies focused on genetics, transport phenomena, and biophysical processes over the shelf. This project developed indices of various biophysical processes that occur during the early life history that can be used to assess the influence of environmental factors on population distribution and size. Expanding on the work of BS FOCI, SEBSCC had goals of understanding the changing physical environment and its relationship to the biota of the region, relating that understanding to natural variations in year-class strength of pollock, and transferring this information to fishery managers. SEBSCC resulted in a new paradigm relating the timing of the annual sea cycle with the ecosystem productivity surrounding pollock. Understanding was encapsulated in ecosystem indicators, many of which are included in annual "State of the Ecosystem" reports provided to the North Pacific Fishery Management Council.



Bering Sea food web indicating the different amounts of biomass in predator diets.

Lake Erie eutrophication: Creating new management goals in light of the reappearance of eutrophication symptoms

R. Peter Richards, Heidelberg University, Keely Dinse, University of Michigan
Gail Hesse, Ohio Environmental Protection Agency, Roger Knight, Ohio Department of Natural Resources

Focus: *Improve understanding and predictive capability related to causes, consequences and policy options for addressing hypoxia in Lake Erie.*

Lake Erie is the warmest and most biologically productive of the Great Lakes. By surface area Lake Erie is the 11th largest lake in the world and the fourth largest of the Great Lakes. It is the shallowest of the Great Lakes and the smallest by volume. The lake supports a highly valued walleye fishery.

Map of Lake Erie. Annual hypoxia occurs in the central area, with periodic hypoxia in the western lobe.

Coastal management

R. Everhart

Healthy walleye (*Sander vitreus*) populations are important for Lake Erie's ecology and recreational fishing economy.

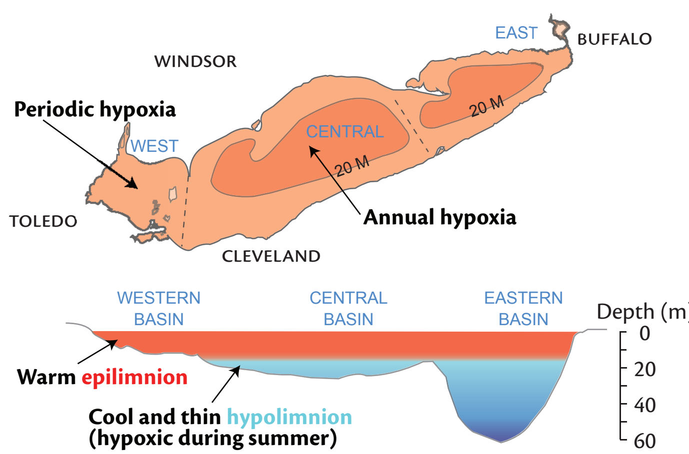
Despite prior success in managing excess nutrient inputs in Lake Erie, starting in the mid-1990's tributary loads of dissolved phosphorus (P) significantly increased while ecological conditions declined. Lake Erie first exhibited signs of severe eutrophication in the 1960s. These included massive harmful algal blooms (HABs) and recurring hypoxia that negatively affected resident flora and fauna in the Central Basin. The loss of *Hexagenia* spp. mayflies and reductions in sensitive fish species (such as walleye) were key indicators of a dysfunctional ecosystem. Recognizing this problem, the U.S. and Canada coordinated efforts to restore the lake ecosystem, targeting P inputs in this process. Restrictions were placed first on P discharges from point sources, such as industrial and municipal sewage treatment plants, and the use of P in household laundry detergents was banned. Controls on agricultural non-point sources of P were addressed later. These measures greatly alleviated the harmful effects of P nutrient overloading. Target P loads were attained by the early 1980s, and by the end of that decade, *Hexagenia* mayflies were becoming common once again. However, the recurrence of HAB blooms and hypoxia signaled the need to reassess nutrient management goals and practices in Lake Erie.

Lessons learned

- Ongoing monitoring served as an early warning of the reemergence of critical problems and accelerated the search for solutions.
- A strong (if complex and perhaps inadequately integrated) network of scientific and managerial entities was essential to addressing Lake Erie issues, and management was involved in establishing research priorities from the beginning, especially from a fisheries standpoint.
- The existence of a distinct management entity (Lake Erie Committee) that was already engaged with the issue facilitated research oversight and guidance from a fisheries standpoint.

Ecosystem science

International Field Years on Lake Erie (IFYLE) and Ecological Forecasting: Hypoxia Assessment in Lake Erie (ECOFORE) were two major research projects geared toward increasing our predictive understanding of the causes and consequences of Lake Erie hypoxia and HAB events. The objectives of the IFYLE program were to quantify the spatial extent of hypoxia across the lake; assess the ecological consequences of hypoxia to the food web; and identify factors that control the timing, extent, and duration of HAB (including toxin) formation. The objective of the ECOFORE program is to provide a better predictive understanding of the causes, consequences, and policy options for addressing hypoxia in Lake Erie. Key factors that are being addressed include phosphorus loading, lake levels, zebra mussel populations, and climate change. Ultimately, a set of management and policy options will be produced along with uncertainty assessments and technical guidance for implementation of a given course of action.



The structure of hypoxia in the lake is influenced by the bathymetry.