NOAA Technical Memorandum NMFS-F/NEC-94

Summary of the Symposium on the Northeast U.S. Shelf Ecosystem: Stress, Mitigation, and Sustainability

12-15 August 1991,
University of Rhode Island,
Narragansett, Rhode Island

U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
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Woods Hole, Massachusetts

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Summary of the Symposium on the Northeast U.S. Shelf Ecosystem: Stress, Mitigation, and Sustainability

12-15 August 1991,
University of Rhode Island,
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PREFACE

A symposium on "The Northeast U.S. Shelf Ecosystem: Stress, Mitigation, and Sustainability" was held during 12-15 August 1991 at the University of Rhode Island's Graduate School of Oceanography in Narragansett, Rhode Island. The symposium was convened by the Northeast Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce. It was sponsored by the Environmental Protection Agency; National Marine Fisheries Service; Marine Mammal Commission; American Fisheries Society; Marine Affairs Program, Graduate School of Oceanography, University of Rhode Island; and Minerals Management Service.

The remainder of this document is a summary of the symposium's proceedings.

BACKGROUND

A symposium on the Northeast U.S. Shelf Ecosystem, extending from the Gulf of Maine to Cape Hatteras, North Carolina, was held on the Bay Campus of the University of Rhode Island's Graduate School of Oceanography during 12-15 August 1991. The symposium was attended by 149 individuals from several state and national organizations. A list of attendees and the symposium program are given in Appendix A. The objective of the symposium was to bring pertinent science to aid in the mitigation of severe stress imposed on the sustainability of the Northeast U.S. Shelf Ecosystem and its wetlands, estuaries, coastal zone, fisheries, marine mammals, and other resources.

The National Oceanic and Atmospheric Administration (NOAA) has collaborated with the U.S. Environmental Protection Agency (EPA) and other agencies in developing the concept of large marine ecosystems (LME) in relation to both marine research and management of marine resources. Since 1984, NOAA has convened five symposia, published three volumes, and obtained expert syntheses of the principal driving forces controlling the biomass yields of 29 LMEs, including five within the U.S. Exclusive Economic Zone (EEZ), *i.e.*, Northeast U.S. Shelf, Southeast U.S. Shelf, Gulf of Mexico, California Current, and Eastern Bering Sea. On a global basis, 49 LMEs account for 95 percent of the annual yield of the global fisheries.

One of the positive findings from the LME studies is the recognition by a growing number of experts in marine science that the LME is a useful area of ocean space for linking mitigating actions among the local, regional, and global scales to reduce the cumulative impact of pollution, habitat loss, and overexploitation. It is at the LME regional scale that physics, chemistry, and biology interact to shape the character of ocean productivity. This has placed the focus on LMEs as an appropriate scale for regional management.

This symposium provided a means for improving the coordination and integration of pertinent marine programs underway by NOAA, EPA, U.S. Geological Survey, Minerals Management Service, and other federal agencies as well as the states and academic institutions.

The benefits from the symposium included: (1) the introduction of adaptive management techniques to aid in rebuilding depleted fish stocks; (2) introduction of a NOAA-EPA monitoring strategy; (3) review of mitigating actions to restore damaged wetlands, stressed estuaries, and coastal zone subsystems; (4) savings of state and federal government expenditures through improved cooperation among those groups pursuing complementary studies of marine resources; and (5) clarification of ecologically oriented strategies for protecting marine mammals and endangered species.

The symposium provided a forum to examine the utility of the LME approach to the mitigation of problems related to resource sustainability within the U.S. EEZ and in other LMEs where actions are being pursued to reduce stress on marine ecosystems from human interventions and naturally imposed perturbations. The symposium participants reached consensus on the desirability for reviewing the status of resource sustainability of the Northeast U.S. Shelf Ecosystem at intervals of about three years.

AGENCY AND ACADEMIC PERSPECTIVES OF LMEs

The opening speaker, Dr. John Knauss, Under Secretary for Oceans and Atmosphere, U.S. Department of Commerce, indicated that the holistic approach inherent in the LME concept encourages agencies to address issues of overfishing, habitat loss, pollution, and recreation needs from a multidisciplinary ecosystems perspective. He stressed the importance of organizing a set of regional programs, each designed for a specific LME, with the goal of monitoring the system to determine how humans may be perturbing the system, thereby providing a basis for appropriate mitigating action.

His presentation was followed by statements supporting the regional LME approach to marine resources research and monitoring by Dr. Norbert Jaworski of the EPA's Environmental Research Laboratory - Narragansett, and Mr. Thomas DeMoss representing EPA's Region III headquarters in Philadelphia. The speaker opening the afternoon session was Dr. Charles Peterson of the University of North Carolina who reviewed the recent Sustainable Biosphere Initiative (SBI) of the Ecological Society of America. Dr. Peterson emphasized the positive relationships between SBI and the application of the Global Ocean Ecosystems Dynamics Program (GLOBEC) of the National Science Foundation (NSF) planned for the Northeast U.S. Shelf Ecosystem. He described how the principles of SBI and GLOBEC applied to the Northeast U.S. Shelf Ecosystem with emphasis on seven points being addressed by government and academic scientists:

1. Species do not exist, and cannot be managed, in isolation.

2. Process-based ecosystem models must be created, incorporating trophic interactions and physical dynamics as a substitute for the lack of capacity for the replication of a specific LME.

3. Ecosystem models must include key human interactions relating to exploitation, nutrient and pollutant inputs, and climate change.

4. Rigorous experimental and analytical methods of manipulative ecology need to be applied in "adaptive management."

5. Modelers must be charged with, and agencies made responsive to, the need for identifying precisely those state variables which will require monitoring to test

model predictions and assess ecosystem health.

6. Enhanced attention to inclusion of prey dynamics, such as forage fish and zooplankton, is critical to fisheries management.

7. Studies and models must evaluate the roles of biodiversity and indirect interactions (those other than direct predator-prey relations) in ocean ecosystems dynamics to allow for the simplification of a diverse system.

SCIENTIFIC ISSUES

The physical forces influencing productivity and sustainability of the Northeast U.S. Shelf Ecosystem were reviewed on the first day of the symposium by several investigators. Dr. R. Duce of the University of Rhode Island described the wide extent and importance of air-sea exchange of pollutants. He was followed by speakers who considered environmental forces influencing ecosystem structure and function, including: weather and climate (O. Hertzman), water-mass structure (D. Brooks), cross-shelf carbon flux (P. Falkowski), and long-term oceanographic trends (R. Armstrong; F. Godshall). On day two, following the presentations of trends in coastal physics, a summary of decadal trends in populations was given for phytoplankton and zooplankton (J. Jossi; M. Berman), benthos (R. Theroux), fish (M. Fogarty), and cetaceans (H. Winn and eight coauthors; R. Kenney). A review of the dynamics of zooplankton was given by E. Durbin.

On the third day, a summary was given during the morning session of the results of NOAA's nearcoast contaminants monitoring program on: the relative magnitude and content of toxic discharges into the Northeast U.S. Shelf Ecosystem from drainage basins (D. Farrow), the distribution of contaminants in sediments and biological indicator organisms (T. O'Connor), the bioeffects of contaminants (A. Robertson), and biological indicators of contaminant effects (J. Stein). In the afternoon session, discussions were focused on nutrient enrichment of the estuarine and nearcoastal areas of the Northeast U.S. Shelf Ecosystem (T. Malone), as well as in other LMEs around the globe. Possible linkages between eutrophication and biotoxic effects of plankton blooms on living marine resources were stressed by T. Smayda, A. White, and L. Fortier. The late afternoon and evening sessions addressed stress and mitigation issues, including the influence of the extensive watershed drainage on the water quality of the nearcoastal zone in relation to metal transport (*e.g.*, copper, lead, nickel, cadmium, and zinc) and annual flux with regard to naturally occurring metals, and metal contamination resulting from human activities (H. Windom). Other papers focused on the effects of perturbed habitats on reproductive success of species selected as bioindicators of pollution stress (F. Thurberg), the effects of Polychlorinated Biphenyl (PCB) contamination of a nearcoastal environment (J. Capuzzo), and the characterization of the recovery of a former continental-shelf sludge dumpsite (M. Ingham). These papers were followed by a panel discussion on mitigation of stress that addressed: marine mammal issues, including bycatch in commercial fisheries in relation to recent legislation (R. Hoffman); water quality improvement efforts addressed by EPA (M.L. Scotia); and overexploitation and strategies for recovery of depleted fish stocks (S. Edwards). The topic of mitigation of stress from a global LME perspective was considered (T. Laughlin), as were policy implications of mitigation (L. Juda), coastal zone mitigation actions relating to energy development (W. Long), and public concern in regard to growing problems of coastal pollution (K. Spaulding).

During the fourth day, discussions were aimed at long-term sustainability of habitats and living resources, including: status of wetlands (J. Thomas), fisheries sustainability (S. Murawski), habitat stress and fish productivity (F. Cross), habitat restoration (T. Bigford), and legal aspects of habitat restoration (M. Matera). The afternoon session was an open forum, mediated by the three conveners with reviews on: productivity, eutrophication, and biotoxic stress (T. Smayda); living marine resources and ecosystem health (K. Sherman); and habitat loss due to pollution and efforts under way to improve water quality (N. Jaworski).

POLLUTION STRESS

Based on the information presented to the symposium, river basin drainage is undergoing some degree of improvement. However, a large number of the sewage treatment plants discharging effluent into the Northeast U.S. Shelf Ecosystem are antiquated and cannot deal adequately with storm-induced overflows of combined sewage systems that introduce raw sewage and toxics into LMEs. It was concluded, however, based on NOAA's Status & Trends Program information, that large-scale biological consequences from existing levels of toxics were unlikely. Levels of lead and DDT have declined. Elevated levels of toxics are limited to the vicinities of large urban outfalls with a few relatively small areas that can be described as biological "hot-spots." Evidence of neoplasms in fish and shellfish has been found. No linkage has, as yet, however, been made to allow for extrapolation from individual specimens showing relatively high levels of toxic substances and any significant biofeedback at the population level, to increased levels of contamination. Diagnostics are improving so as to make more effective surveys of pollution effects on individual organisms and populations than those presently in use.

PHYSICAL STRESS

The results of two investigations conducted independently (P. Jeffries of the University of Rhode Island and

Walker and Godshall of the EPA) suggested that northeast coastal waters are in a warming trend. In recognition of the need for augmenting funds available to academic institutions for conducting retrospective and prospective long-term studies in relation to global climate change, NSF will be accepting proposals in support of GLOBEC. This program is designed to assist scientists in academia to support longer-term research and monitoring efforts than are currently being supported. It is against this background of an apparent warming trend that the effects of pollution and overfishing at the population level should be addressed.

EUTROPHICATION

With regard to eutrophication, T. Malone indicated, based on case history studies in the Hudson and Chesapeake Bays, that in the former system there is no consistent pattern of any surplus production attributable to measured increased eutrophication. In the offing of the Hudson, in some years, it has been possible to recognize the effects of eutrophication in the discharge plume that contributed periodically to anoxia, significant benthic mortalities, and economic losses of shellfish in the 1970s and 1980s. Phytoplankton blooms in the Chesapeake seem to vary in extent and intensity, but at the present time, no evidence is apparent for encroachment out onto the relatively open waters of the Mid-Atlantic Bight subarea of the Northeast U.S. Shelf Ecosystem.

In contrast, T. Smayda provided evidence of increases in the frequency and extent of unusual plankton blooms within several LMEs, including the Baltic Sea, the Sea of Japan, the North Sea, and the Adriatic Sea. He also provided evidence of increases in nutrient loadings within these LMEs, suggesting a possible linkage between nutrient enhancement and the increased frequency of phytoplankton blooms of toxic algae. Within the Northeast U.S. Shelf Ecosystem, there is evidence of increasing frequency of biotoxin-related mortalities in marine mammals, along with recent closures of offshore shellfish beds because of increased levels of paralytic shellfish poisoning. Two other speakers underscored the growing incidence of toxins causing mortalities in larval fish (L. Fortier), and possibilities of additional closures of shellfishing grounds (A. White).

ECOSYSTEM STRESS AND MITIGATION

A comprehensive assessment of increased burdens of heavy metals resulting from riverine input to the Northeast U.S. Shelf Ecosystem was presented by H. Windom who indicated that the discharges of rivers carry loadings of copper, nickel, cadmium, lead, and zinc into the nearshore environments from the adjacent watersheds. The data base is now improving and should allow for analyses aimed at separating amounts of naturally occurring heavy metals relative to those heavy metals which result from manufacturing and other activities, to provide a basis for directing mitigation actions.

Studies to measure effects of contaminated inshore spawning sites of winter flounder on the reproductive success of that species were described by F. Thurberg. Early developmental stages of winter flounder were in poorer physiological condition in the more heavily polluted coastal waters of several sites sampled, including Boston Harbor and several ports in Long Island Sound. As yet, however, no quantitative information is available on the effects of pollution on populations of winter flounder. In another study, it was argued by P. Jeffries that temperature and predators have operated synergistically to shift the dominance from winter flounder in Narragansett Bay to rock crab, based on a 25-year time series of weekly trawl collections.

Coastal sites used to dump sludge from New York City waste treatment plants are showing signs of repopulation and recovery of water quality (M. Ingham), indicating that mitigating actions that result in dump closures will result in a degree of recovery of stressed benthic communities. Sites contaminated with PCBs, however, do not show rapid recovery following mitigation actions to eliminate the disposal of PCBs. Residence times of PCBs in sediments of New Bedford Harbor are quite long and adverse effects on shellfish species continue to be detected several years after banning the disposal of PCBs in coastal waters (J. Capuzzo).

Actions to mitigate and to protect marine mammals from incidental mortalities associated with commercial fishing operations have recently been enacted by the U.S. Congress. Studies are funded and underway to evaluate actions taken by Congress (R. Hofman). Scientific projects have been funded for Fiscal Year 1992 (1 October 1991 - 30 September 1992) to determine the catch and mortality levels of marine mammals entangled in nets, and the status of humpback whale, right whale, and pilot whale populations. With regard to fishery resources, recent model simulations based on biological and economic data suggest that fishing effort will need to be reduced by 50-70 percent if long-term sustainability of preferred high-demand and high-priced species is to be realized (S. Edwards). The effect on the present fishing fleets of reaching this level of reduction was the topic of considerable discussion, but little resolution.

The programs of the Minerals Management Service to support scientific studies of areas and populations at risk from gas and oil exploration and development on the Northeast U.S. Shelf Ecosystem were described by W. Lang.

With regard to policy implications of LME management, it was argued that public involvement in the decision-making process should be encouraged and that scientists need to do a better job of informing the public of problems requiring mitigating action (K. Spaulding). The utility of the LME approach to the conservation and management of living marine resources and their habitats around the globe was described. Several case studies were examined, including the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) which is presently managing Antarctic marine populations at risk from exploitation. The CCAMLR has based recent management actions on ecosystem considerations. The management of fishery biomass yields is presently being practiced in two other LMEs: the Yellow Sea and the Northwest Australia Shelf (T. Laughlin). The legal mandate of the United Nations Convention on the Law of the Sea as a basis for supporting marine resources management from an ecosystems perspective was described by L. Juda.

On the final day, presentations were focused on the importance of wetlands as nursery areas for many of the fish species of economic importance (J. Thomas). Efforts now underway to use penalties and fines collected from polluters to support ecosystem restoration projects were described (T. Bigford), along with the legal implications of habitat mitigation (M. Matera). The loss of coastal habitat used by fish as feeding and nursery grounds was emphasized by F. Cross. For the offshore waters of the Northeast U.S. Shelf Ecosystem, a major shift among dominant species was reported by S. Murawski; over the past two decades, dominant species have shifted from predominately gadoids to a state where elasmobranch and pelagic species dominate the fish community. This shift in ecosystem state serves to reduce the turnover rates of fish, as elasmobranchs are longer lived than gadoids, thereby imposing a long-term reduction in the production levels of the fish community in relation to long-term resource sustainability. The Northeast U.S. Shelf Ecosystem continues to be highly productive at the lower end of the food chain.

HEALTH STATUS OF THE NORTHEAST U.S. SHELF ECOSYSTEM

Concluding remarks were presented in the final plenary session by the three conveners, T. Smayda, N. Jaworski, and K. Sherman. Based on reports presented at the symposium, the conveners concluded that:

1. The Northeast U.S. Shelf Ecosystem is stressed in the nearshore areas from growing eutrophication and pollution. Relatively small areas considered toxicological "hot spots" have been identified from the monitoring efforts of NOAA and EPA. In these hot-spots, contaminant loadings of the sediments are quite high. Toxicological effects are expressed in pathological conditions among fish and shellfish. However, no persistent population mortalities are associated with present "toxic pollution" levels.

2. Signs of increasing levels of nutrient overload or eutrophication, resulting in depletion of dissolved oxygen, are evident in estuaries and coastal estuarine plumes. The cumulative effects on the nearshore ecology of the Northeast U.S. Shelf Ecosystem are unknown.

3. It is not clear if the increasing incidence of biotoxins causing mortalities among marine fish, shellfish, and mammals is associated with an increased frequency and extent of phytoplankton blooms.

4. Loss of estuarine habitat for spawning and feeding areas by several species continues to be of concern. It is a problem that can be addressed by judicious application of funds accrued from fines levied on polluters to support restoration ecology projects. Restoration projects to reclaim loss of habitat due to pollution have been initiated.

5. The more-open waters of the Northeast U.S. Shelf Ecosystem are "healthy." The structure and function of the lower end of the food chain is highly productive.

6. Major shifts in the dominance of the finfish community from gadoids (Atlantic cod, haddock, pollock, hakes) in the 1960s to a predominately elasmobranch (spiny dogfish and skates) and pelagic biomass in 1991 are attributed to perturbations due to excessive fishing mortality on gadoids and flatfish. The loss of consistently high recruitment of high- value gadoids and flounders contributes to the depleted state of the economically desirable fish stocks.

7. Consideration is being given to "adaptive management" strategies focused on the effects of directed removals of low-economic-yield predators (*e.g.*, spiny dogfish and skates) to enhance recovery of the depleted gadoid and flounder stocks.

8. Marine mammal populations at risk from fishery-caused mortalities are being subjected to increasing research and monitoring efforts by NOAA/National Marine Fisheries Service and other scientific groups and institutions in an effort to ensure recovery of depleted populations and to eliminate bycatches in the fisheries that could be detrimental to reproductive and recruitment success, as well as to the rebuilding of depleted populations.

9. Coordinated programs of principal federal agencies are under way as a result of the symposium to improve monitoring strategies aimed at supporting efforts to mitigate detrimental effects of habitat loss, coastal pollution, eutrophication, and overexploitation of marine resources. These programs include NOAA's Status & Trends Program and Marine Resources Monitoring, Assessment, & Prediction Program, and the EPA's Environmental Monitoring & Prediction Program. In addition, the NSF's GLOBEC, which is designed to study the effects of physical variability on biological populations, has a Northwest Atlantic component and will be funding studies on Georges Bank.

10. Pending legislation to provide funds for additional waste-treatment facilities for municipalities, and best-management practice for nonpoint sources of pollution along the coast of the Northeast U.S. Shelf Ecosystem, will aid in reducing the loadings of nutrients which lead to eutrophication within the estuaries of the region.

11. Dumping urban sludge within the EEZ has been legislated as unlawful; illegal dumping is now subject to Federal penalties.

12. A followup symposium will be scheduled to review the status of the health of the Northeast U.S. Shelf Ecosystem in 1994.

APPENDIX A

LIST OF SYMPOSIUM ATTENDEES AND PROGRAM

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PROGRAM

DAY 1 -- MONDAY, 12 AUGUST 1991
CHAIRMAN -- KENNETH SHERMAN

8:30 - 9:45 a.m. ON-SITE REGISTRATION

10:00 a.m.

R.A. Duce, Dean
Graduate School of Oceanography
University of Rhode Island
— Welcome

J. Knauss, Under Secretary
for Oceans and Atmosphere
U.S. Department of Commerce
— Keynote Address

K. Sherman
National Marine Fisheries Service
— LMEs: A Perspective

N. Jaworski
Environmental Protection Agency
— EPA and the Coastal Ocean

T. DeMoss
Environmental Protection Agency
— EPA Regional Ecosystem Perspectives

2:00 p.m.

C. Peterson
University of North Carolina
— Ecological Research for a Sustainable Biosphere

J. Klein National Ocean Service	Extent and Effects of Flux from Estuaries into the Coastal Zone
R. Duce University of Rhode Island	Air/Sea Exchange of Pollutants
J. Paul Environmental Protection Agency	Estuarine/Coastal Monitoring

DAY 2 – TUESDAY, 13 AUGUST 1991
CHAIRMAN – NORBERT JAWORSKI

8:30 a.m.	SHELF DYNAMICS
O. Hertzman Dalhousie University	Weather and Climate
David Brooks Texas A&M University	Patterns of Water Movement
P. Falkowski Brookhaven National Laboratory	Cross-Shelf Processes: Regulation and Fate of Carbon within the Northeast U.S. Shelf Ecosystem
R. Armstrong National Marine Fisheries Service	Long-term Oceanographic Trends of the Northeast U.S. Shelf Ecosystem
H. Walker and F. Godshall Environmental Protection Agency	Climate Variations and Responses of Coastal Ecosystems
1:00 p.m.	DECADAL POPULATIONS: ASSESSMENTS AND TRENDS
J. Jossi National Marine Fisheries Service	Phytoplankton Time Series
M. Berman National Marine Fisheries Service	Zooplankton Time Series
E. and A. Durbin University of Rhode Island	Zooplankton Dynamics
R. Theroux National Marine Fisheries Service	Benthos
M. Fogarty National Marine Fisheries Service	Fish
D. Heinemann Manomet Bird Observatory	Birds

H. Winn, A. Durbin, E. Durbin, R. Kenney, and K. Wishner (University of Rhode Island); R. Beardsley (Woods Hole Oceanographic Institution); and R. Limeburner and M. Macaulay (University of Washington) — SCOPEX and Ecosystem Analysis in Relation to Right Whales

H. Winn (University of Rhode Island); and D. Heinemann (Manomet Bird Observatory) — Recent Shifts in the Distribution of Cetaceans

H.P. Jeffries, University of Rhode Island — Coastal Fishes Responding to a Warmer Habitat

DAY 3 -- WEDNESDAY, 14 AUGUST 1991
CHAIRMAN -- T. SMAYDA

8:30 a.m. — STRESSES ON THE NORTHEAST U.S. SHELF ECOSYSTEM: CONTAMINANTS

D. Farrow, National Ocean Service — Inventorying Discharges

T. O'Connor, National Ocean Service — Distribution of Contaminants

A. Robertson, National Ocean Service — Bioeffects of Contaminants

J. Stein, National Marine Fisheries Service — Biological Indicators of Contaminant Effects

1:00 p.m. — NUTRIENT ENRICHMENT

T. Malone, University of Maryland — Trends in Nutrient Loading and Eutrophication: A Comparison of Chesapeake Bay and the Hudson Estuarine Systems

T. Smayda, University of Rhode Island — Creeping Eutrophication: Global Perspective Relative to the Northeast U.S. Shelf Ecosystem

A. White, National Marine Fisheries Service — Biotoxins and the Health of Living Marine Resources

L. Fortier, Laval University — Biotoxins in Early Life Stages of Fish Populations

5:00 p.m.	STRESS AND MITIGATION
H. Windom Skidaway Institute of Oceanography	Contribution of Heavy Metals to Riverine Input in the Northeast U.S. Shelf
F. Thurberg National Marine Fisheries Service	Effects of Perturbed Habitats on the Reproductive Success of Fishery Resources
M. Ingham National Marine Fisheries Service	Effects of Closure and Change of a Continental Shelf Dumpsite
J. Capuzzo Woods Hole Oceanographic Institution	Responses of Mollusks to Coastal Pollution Stress
End of Day 3	PANEL DISCUSSION ON MITIGATION
L. Alexander University of Rhode Island	Panel Chairman
R. Hoffman Marine Mammal Commission	Marine Mammal Mitigation Actions
M. Scotia Environmental Protection Agency	Coastal Mitigation Actions
S. Edwards National Marine Fisheries Service	Overexploitation and Recovery of Depleted Stocks
T. Laughlin National Oceanic and Atmospheric Administration	Mitigation from an LME Perspective
L. Juda University of Rhode Island	Policy Implications of Mitigation
W. Lang Minerals Management Service	Coastal Zone Mitigations
K. Spaulding Save The Bay	Ocean Stress & Public Awareness

DAY 4 – THURSDAY, 15 AUGUST 1991
CHAIRMAN – TED SMAYDA

8:30 a.m.	FISHERIES AND HABITAT SUSTAINABILITY
S. Murawski and S. Clark National Marine Fisheries Service	Fisheries Sustainability
J. Thomas National Marine Fisheries Service	Status, Trends, and Health of Wetlands

F. Cross National Marine Fisheries Service	Relating Habitat Stress to Fish Productivity -- Problems and Approaches
T. Bigford National Marine Fisheries Service	Habitat Restoration
M. Matera National Oceanic and Atmospheric Administration	Legal Aspects of Habitat Mitigation and Restoration
1:00 p.m.	STATUS OF THE HEALTH OF THE NORTHEAST U.S. SHELF ECOSYSTEM: REVIEW, SUMMARY, AND RECOMMENDATIONS
T. Smayda University of Rhode Island	Productivity Issues and Eutrophication Stress within the Northeast U.S. Shelf Ecosystem
K. Sherman National Marine Fisheries Service	Living Marine Resources Overfishing, Stress, and Mitigation
N. Jaworski Environmental Protection Agency	Other Human Interactions:Pollution, Habitat Loss, Water Quality, Recreation
End of Day 4	RECOMMENDATIONS
	Monitoring Programs: MARMAP, S&T, EMAP, States, Sea Grant, "Mitchell Bill," Marine Centers, and Others
	Periodic Reviews of Ecosystem Health
Adjourn	

APPENDIX B

KEYNOTE ADDRESS: THE NORTHEAST U.S. SHELF ECOSYSTEM – STRESS, MITIGATION, AND SUSTAINABILITY

John A. Knauss
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Good morning. I am always pleased to return here to the Narragansett Bay Campus where I spent so many wonderful years trying to stir things up. I am delighted to have a chance to be here today to stir up discussion about large marine ecosystems, a subject that, as near as I can judge, had its genesis here in Rhode Island with Ken Sherman and Lew Alexander. It is an idea, a concept that I believe merits further stirring, which is what this symposium is all about. And it is an idea, a concept, that I believe may be ready for more than discussion. Maybe the time has come to think about implementation. My intention today is to help stir up some discussion, and to get you thinking about implementation.

"The Northeast U.S. Shelf Ecosystem: Stress, Mitigation, and Sustainability." It is a big subject and a timely subject. We know that our environment, at least our coastal environment, is stressed, and that in spite of our best efforts, that stress is likely to increase. Certainly mitigation is a concept we are trying hard to apply in many areas, more successfully in some applications than in others, in large part depending on how well we understand the situation.

Sustainability is, well, I'm not convinced it's actually on the horizon, more likely just over the horizon, just beyond our view. Nevertheless, increasing numbers of us are convinced that we must set our course now for sustainability, as there are most assuredly other, far less palatable, options lurking over the horizon as well.

We are a population of an incredible five-billion people and growing; almost all with boundless aspirations of increasing our standard of living. We have been operating under the paradigm that growth is good and necessary--the faster the better. In doing so, we have tended to function with a view limited to short-term gratification, while ducking the growing pressure to consider long-term sustainability. I would venture to presume that most of you here share with me the uneasy sense that human-induced environmental stresses have the potential to reduce the long-term carrying capacities of the very systems which support us.

We are here to explore our role with respect to the health of the ecosystems. I am not so much concerned with the distant open ocean, whose present health I believe is relatively good, if only because of its enormous volume and capacity for dilution. It is the systems on the edges of the world's oceans about which I am concerned, and about which I suspect most of you are concerned, for they are experiencing the lion's share of our disruptive impacts--our consumptive appetites, our wastes, and our penchant for physically altering the land-sea interface in the name of economic and social comfort.

Many of us wonder what is the most intelligent way to approach the question of the health of our coastal oceans, and the role we might play in helping to maintain it. According to Webster's dictionary, health is defined as that "condition of being sound in body, mind, or spirit." That sounds pretty good.

In the field of medicine, we have some experience dealing with health which may provide some useful ideas. Medicine is defined by Webster as "the science and art of dealing with the maintenance of health and the prevention, alleviation, or cure of disease." That sounds applicable. Let me push that analogy a bit further. Perhaps we can equate medicine for the oceans with good stewardship of the oceans and its resources.

Imagine that an unconscious patient is wheeled into an emergency room unable to communicate what is wrong. The first actions taken by nurses, technicians, and physicians involve hooking up a multitude of monitors, and taking dozens of samples of every body fluid imaginable.

They measure heart rate, blood pressure, temperature, blood oxygen levels, brain waves, a whole suite of biochemical indicators related to the functioning of specific organ systems. They test for bacteria, viruses, and toxic substances. They also solicit anecdotal information regarding the activities and functioning of the patient from those familiar with the patient. They attempt to obtain a family history as well, in an effort to apprise themselves of the patient's normal idiosyncrasies, or unique hereditary vulnerabilities.

Armed with information gleaned from this process, the physician is able to respond, with what an ecologist must view as an enviable degree of confidence. In most instances in which a human body has received some sort of insult, the physician can go about placing the patient on the path to health.

It is the physician's intensive monitoring which supplies the information making it possible for him or her to diagnose what problem, or array of problems, require immediate attention. It is this knowledge that enables the physician to fulfill his or her role of furnishing remedial influence and promoting health.

This is a role we would like to play with regard to promoting the health of our coastal oceans, and exerting a remedial influence where and whenever necessary. The difficulty for us lies in the fact that we do not have some of the critical information which we need to do this properly.

What the physician has that we do not have is a good understanding of what is normal. Decades, even centuries, of experience have provided the physician with a highly reliable understanding of normal parameters, including the parameters of normal variation. We simply do not have a comparable knowledge base for ocean ecosystems. Many times we do not know what is normal. As importantly, we seldom know the range of normal variability. This makes it extremely difficult for us to be the confident and accurate diagnosticians we would like to be.

It was 15 or 20 years ago when we experienced a scare about the mercury content in the flesh of swordfish. Our initial assumption was that this was abnormal, and was the result of human introduction of mercury into the oceans. As it turned out, it was a question of our not knowing that swordfish normally concentrate the mercury that occurs naturally in the oceans. We made a false-positive diagnosis due to a lack of sufficient understanding of the normal parameters. If swordfish are dangerous to eat, then they have probably always been dangerous to eat. It is simply that previously we had never gotten around to measuring the mercury content of swordfish flesh.

Another example of our inability to distinguish between natural and unnatural, or anthropogenic, processes in our coastal oceans lies in the increased incidence of paralytic shellfish poisoning which has intermittently shut down the clam industry in the Georges Bank area. Are the responsible blooms of toxic dinoflagellates caused by natural ocean variability such as changing current patterns, or are they the result of nearshore to offshore movement of nutrients introduced from anthropogenic sources? We simply do not know.

We need to know these things. Until we can distinguish between that which is natural, or normal--whatever that means--and perturbations which are anthropogenic, we can hardly fulfill the roles of diagnosticians, suppliers of remediation, or stewards of ocean health.

I am particularly concerned about two important ways in which we differ from our counterparts in the field of human medicine. The first relates to the question of time scales. The physician appropriately thinks in terms of a human lifetime. We know that human lives are finite, and we have a very good idea of what a normal lifespan is likely to be. Most individuals are monitored and assessed periodically during their lives, beginning when they are born, thereby providing their physicians with an excellent basis on which to judge changes in health. This is to say that they have a time series of data which is virtually complete.

But over what time-scale do we need to monitor our coastal oceans? Decadal scales at a bare minimum. Our efforts to determine whether changes we observe over a few years are the result of pollution, overfishing, or natural environmental changes require longer-term time-series monitoring than we presently have accomplished; very likely a good deal longer than the average lifespan of a person.

A second critical difference lies in the fact that for physicians, the choice of a convenient and appropriate unit of study is such an obvious and widely accepted one--the human body. Things are not so simple for those of us trying to get a better grasp of ocean systems.

We have a long way to go before we have, in our black bags, the wealth of background knowledge, the understanding of the normal state, and of natural variability in our field of study that physicians have in theirs. But, while we may not have done a very good job of observing ocean variability thus far, we are not completely ignorant. More importantly, I believe we have a much better understanding of what we need to know and are busily formulating strategies which will gain us that knowledge.

Let me be very clear, however, about the limitations of monitoring. Monitoring is no substitute for understanding the physical and biochemical processes that occur in a human body or an ecosystem. But monitoring does alert you to possible problems. And long time series can often put some bounds on what changes are likely to be within the normal range of an ecosystem and which are beyond.

Which brings me to the subject of large marine ecosystems. The growing interest in developing and applying the concept of large marine ecosystems represents one such strategy of monitoring and understanding the health of the coastal ocean. And, a point I continue to make to those concerned about the health of the world ocean is that we need to concentrate on the ocean edges, the coastal oceans. The effects of humankind on the ocean will first and most intensively be seen along the coasts and in the near offshore. To the extent that they are healthy, I believe we can be relatively sanguine about the health of the vast central ocean regions.

The concept of LMEs begins by defining coherent systems characterized by distinctive physical, chemical, and oceanographic features, productivity, and community trophodynamics. It gives us a well-defined regional unit for research, monitoring, and management, allowing us to focus on the health of entire marine ecosystems. This is a critical first step.

We in government, both state and federal, have much to answer for. Traditionally, coastal zones and their resources have been studied and managed by a wide range of single-function agencies and institutions concerned with fisheries, or transportation, or conservation, or water quality, or waste disposal, or recreation, or minerals management and development, and more. This practice of working independently, within agency boundaries, can lead, and has led, to significant progress, but it is often an inefficient approach to address the interrelated, multidisciplinary issues facing our coastal oceans.

I believe the LME concept has much to offer in this respect. LMEs are relatively large areas of 200,000 square kilometers, or more, and are typically located in waters adjacent to land masses, therefore encompassing the areas under greatest stress from overexploitation, pollution, and habitat alteration. Taking an ecosystem approach highlights the interrelatedness of the different parameters of each system and encourages cooperative dialogs across traditional disciplinary boundaries. I believe that this is not only a good idea, but it is essential if we are sincere in our desire to address this increasingly complex suite of coastal ocean issues--issues such as coastal zone management, pollution reduction, fisheries productivity and sustainability, and habitat protection.

I do not want to suggest there is no room for the individual specialist any more than there is no room for the individual agency requirement. An LME approach to understanding and managing the coastal ocean is no panacea, but I do believe it can help. The problems here are seldom single-issue, single-answer problems. In this respect particularly, the holistic approach inherent in the LME concept encourages us in the right direction.

In an address at MIT last fall, I made a proposition. I had tried it out previously in Monaco with representatives from a number of different European countries. Some of you may have heard it already, but let me reiterate it here again, because I still like it.

If one set out to design a coastal ocean monitoring system to monitor the health of the ocean, are LMEs an appropriate geographical unit? If they are, would it be useful to organize a set of regional programs, each designed for a specific LME? Each nation, or set of nations, bordering on an LME would be responsible for the design and implementation of the program. The goal of the programs would be to monitor the system and understand how the system works, what its normal parameters are, and how humans are perturbing the system.

Those responsible for the program of each LME could meet locally on a regular basis. Perhaps every few years representatives from each region could come together internationally to compare notes and report on the health of all of the LMEs. By doing this, they would, in effect, be reporting on the health of the ocean.

I went on, in Monaco, to suggest that such a program could be organized through one, or some combination of, United Nations agencies and, further, that the development of such a program could be considered at the U.N. Conference on Environment and Development (UNCED) in Brazil in 1992. I am pleased to say that the LME approach to coastal ocean research, monitoring, and management is, in fact, being incorporated into the U.S. delegation's ocean issues paper for the 1992 UNCED meeting.

The LME approach lends itself to international application well. Focusing fisheries, pollution, and coastal zone studies on some 49 LMEs in which pertinent studies are already underway, and financed by national interests, will promote more coherent and effective national and U.N. ocean research and monitoring programs.

Today there is clear interest on the part of developing countries, as well as industrialized nations, to develop some form of coastal zone management in order to improve the prognosis for sustainable development of their coastal resources.

LMEs provide an approach which is flexible enough to account for the fact that the economic values of the coastal zone within LMEs differ from nation to nation. In some areas, such as in the deltas of Egypt and Bangladesh, coastal agriculture is of primary importance. In Peru and Chile, fishing is more important; and in other areas, such as in the Mediterranean, the Pacific Islands, or the Caribbean Islands, marine-related tourism is critically important. Regional LME management plans can be tailored to meet the multiple-use needs of the bordering nation or nations.

Around the world, management efforts have been initiated which embrace this ecosystem approach. These include the Yellow Sea Ecosystem, where principal effort is underway by China; the multispecies fisheries of the Benguela Current Ecosystem under the management of the government of South Africa; the Great Barrier Reef Ecosystem and the Northwest Australian Continental Shelf Ecosystem under management by the state and federal governments of Australia; and the Antarctic Marine Ecosystem under the Commission for the Conservation of Antarctic Living Marine Resources and its 21-nation membership.

By comparing results of research among the LMEs, it should be possible to accelerate an understanding of how the systems work and how they respond to, and recover from, stress. Such comparisons will allow us to narrow the context of unresolved problems and to capitalize on research efforts underway in different ecosystems.

But--the global perspective will be only as good as the regional and local efforts that go into studying and understanding each of the large marine ecosystems.

This gathering represents an effort to bring together those federal and state agencies, academic institutions, and individuals who are contributing to, or simply interested in, a better understanding of the Northeast U.S. Shelf Ecosystem.

I believe it is especially appropriate that this first symposium on the health of a particular LME is focusing on this particular LME. The reason I say this is because of a great deal of work has been focused on the Northeast U.S. Shelf Ecosystem in the past, which is well-suited to the LME approach, particularly with respect to efforts to obtain a long time series of monitoring data in terms of interdisciplinary and intergovernmental collaboration.

The scientists here at the University of Rhode Island's Graduate School of Oceanography, or GSO, have some of the longest time series for the coastal waters in the United States. Professor Ted Smayda has concluded, from his analysis of a 25-year time series of phytoplankton collections in Narragansett Bay, that major changes have occurred that may be implicated in the greater frequency and extent of unusual plankton blooms. And Professor Perry Jeffries has concluded, from his analysis of a 25-year time series of bottom fish collections, that significant changes have taken place. The once dominant flounder are being replaced by rock crab and other large benthic invertebrates. These are significant findings, and they underscore the importance of time-series monitoring efforts. Continuing such efforts will enable us to determine whether these changes are the result of pollution, overfishing, or natural environmental variability so that appropriate mitigating actions can be taken.

Other long time series are available for analysis in other parts of the Northeast U.S. Shelf Ecosystem as well, including Long Island Sound, Massachusetts Bay, and, more recently, the Gulf of Maine. The findings from these studies will lead to mitigating actions designed to reduce the input of pollutants into the shelf ecosystem.

One of the longest time series of all is NOAA's National Marine Fisheries Service trawling survey for the Georges Bank. These are being used to develop strategies for aiding in the recovery of depleted groundfish resources of the Northeast shelf. And our NOAA National Marine Fisheries Service will be reinstituting the 11-year Marine Resources Monitoring, Assessment, and Prediction Program, or MARMAP, next year.

As I mentioned, this is also a region in which there is a relatively long history of interdisciplinary and intergovernmental cooperation and collaboration in dealing with coastal-zone-related issues. The National Sea Grant College Program was born here in Rhode Island some 25 years ago. The idea, initially suggested by Athelstan Spilhaus at the University of Minnesota, was picked up by those of us here at the University of Rhode Island. Congressional support was championed by Rhode Island's Senator Claiborne Pell, and the National Sea Grant College Act was signed into law by President Johnson in 1966.

From the very beginning, the Sea Grant program has combined the best of what a university-federal partnership should be: research into problems, education about issues, and outreach to those affected and concerned. Sea Grant has contributed enormously to increasing our understanding of ocean and coastal environments over the past 25 years. And I believe Sea Grant can take considerable credit for ensuring that much of this understanding has not been left on dusty library shelves, but has been used for public benefit through Sea Grant's education and outreach programs. Sea Grant, and other groups such as Save the Bay, and programs like the Volunteer Salt Pond Watchers provide models for other regions, lending insight into the benefits of establishing a wide circle of participation in addressing the issues facing our coasts.

Further evidence of coordination and cooperation are found in EPA's national estuary programs and NOAA's Coastal Zone Management Program where federal, state, and local governments, as well as academic institutions, industry, and environmental interest groups are brought together on technical and nontechnical advisory committees to help formulate regional and local management plans.

NOAA and EPA are also joining forces and combining NOAA's Status and Trends and its MARMAP time-series monitoring programs with the pollution monitoring efforts of EPA's new EMAP program.

What all this means to the Northeast U.S. Shelf Ecosystem is that here we needn't start from scratch in our efforts to embrace the LME approach. Much is already in place in terms of a leg up on long-term monitoring and the breaking down of institutional boundaries in recognition of the benefits of collaboration. Adjacent to what has historically been, and continues to be, the most densely populated region of the United States, studies of this LME can provide a model for other regions which may not have had the same head-start.

Let me close with a few words about the urgency of this effort. We are here because we have, over the past few years, suspected that some of the unpleasant phenomena we have witnessed, such as decreasing water quality, declining fisheries stocks, and alarming losses of wetlands, coral reefs, or sea grasses, are indicative of systems under stress--stress which we humans are imposing on our support systems.

The oceans are not constant. They have certainly changed over geologic time, as has the life within them. We believe that most of those changes have been very slow, however, allowing for the necessary compliance by the systems and life forms affected. But mankind's changes have been virtually instantaneous in terms of geologic time. As NOAA's Chief Scientist, Sylvia Earle, is fond of saying "We humans have hit the fast forward button, and risk the fate of bacteria in a culture dish, or locusts, who consume themselves out of business."

Let me return briefly to the medical analogy. Remember that physicians have a good idea of to what extent a system, such as the cardiopulmonary system, can compensate for a chronic or acute insult before reaching its limit and collapsing. Experience has taught them where the thresholds lie. This experience has come as the result of crossing such thresholds and of people dying.

An ecosystem analogy is an overfertilized pond or estuary. A small amount of extra phosphate or nitrates cause little harm. In many cases, it enhances the local productivity. But too much, and the system "dies." Or to be more explicit, that system dies and another one takes its place. Our knowledge of the tolerance level of marine ecosystems is very limited.

The lessons to be learned from exceeding the analogous ecosystem thresholds are not pleasant to contemplate. The collapse of the systems which sustain us would have catastrophic consequences.

It is time now to take stock, to determine what we have, how it works, how it doesn't work, and how to manage it for real, long-term health and benefits. Considering the human resources represented here in this room, I believe that the prognosis can be a good one. I applaud you for being here, and I applaud those of you whose dedication and hard work have made it possible. Thank you.

APPENDIX C

OPENING ADDRESS: ECOLOGICAL RESEARCH FOR A SUSTAINABLE BIOSPHERE

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ABSTRACT

In 1991, the Ecological Society of America published the society's recommendations for research priorities in the 1990s. The outcome of this two-year-long, grassroots planning process called for establishment of a Sustainable Biosphere Initiative. This proposed research initiative contains three priority research foci: (1) global change, (2) biological diversity, and (3) sustainable ecological systems.

For ocean ecosystems, the federal research program that is most responsive to this agenda is GLOBEC. GLOBEC is part of the U.S. Global Change Program, supported by multiple agencies. It combines all three research priorities identified within SBI to address how changing global climate might be expected to alter ecosystems dynamics and especially secondary production in the sea.

The initial field system identified for study by the GLOBEC steering committee is the Northwest Atlantic, essentially equivalent to the Northeast U.S. Shelf Ecosystem. This paper applies the principles extracted from the SBI and GLOBEC planning processes to the Northeast U.S. Shelf Ecosystem. Specifically, the lessons include: (1) species do not exist and cannot be managed in isolation; (2) process-based ecosystem models must be created, incorporating trophic interactions and physical dynamics as an antidote to the lack of replication of a specific large marine ecosystem; (3) ecosystem models must include key human interactions of exploitation, nutrient and pollutant inputs, and climate change; (4) rigorous experimental and analytical methods of manipulative ecology need to be applied in "adaptive management"; (5) modelers must be charged with, and agencies made responsive to, the need for identifying precisely those state variables that require monitoring to test model predictions and assess ecosystem health; (6) enhanced attention to inclusion of prey dynamics, such as forage fish and zooplankton, is critical to fisheries management; and (7) studies and models must evaluate the roles of biodiversity and indirect interactions (those other than direct predator-prey relations) in ocean ecosystems dynamics to allow tractable simplification of a diverse system.

INTRODUCTION

The intent of this paper is to apply the general recommendations of the Ecological Society of America's (ESA) recent review of research priorities for the 1990s (Lubchenco *et al.* 1991) to the specific case of developing a research agenda to understand and manage the Northeast U.S. Shelf Ecosystem. The Northeast U.S. Shelf Ecosystem is the coastal ecosystem stretching from the Gulf of Maine to Cape Hatteras (as defined by Sherman *et al.* 1988), a system whose important biological resources would doubtless benefit from ecologically informed management of the entire ecosystem as an LME (Sherman and Alexander 1986). I first describe briefly the major conclusions and research priorities put forward by the Ecological Society of America. I then demonstrate how the Initial Science Plan of GLOBEC [Joint Oceanographic Institutions (1991a)]--the most appropriate multiagency federal research initiative to respond in the marine environment to the appeal of the Ecological Society of America--is indeed responsive to the ESA's guidance. Finally, I go beyond the previously published general documents to apply their broad recommendations to develop some important specific guidelines for research and management of the Northeast U.S. Shelf Ecosystem.

THE SUSTAINABLE BIOSPHERE INITIATIVE

In response to a recognition that resources for scientific research are necessarily limited and that not all excellent research now proposed by scientists can be funded, the Ecological Society of America established in 1989 a broad-based committee of its members to review the discipline of ecology and to identify the priority areas for research emphasis in the 1990s. The committee met frequently and worked intensively for over a year to create a draft document describing research priorities and a research agenda for ecology in the coming decade. The draft document was then subjected to the review and scrutiny of the entire society through presentation at the ESA annual meeting in 1990 and through solicitation of written reviews from many individuals in allied disciplines who were not members of ESA. Throughout the process, community input and criticism were also sought through workshops and publication of announcements in the *ESA Bulletin* and *ESA Newsletter*. The inputs from numerous ecologists were ultimately incorporated into the final document accepted by and published by the Ecological Society of America (Lubchenco *et al.* 1991). This document presents the blueprints for a Sustainable Biosphere Initiative, the results of a successful grassroots process of research prioritization carried out by the practicing scientists in the discipline to guide the allocation of resources for research in the coming decade.

The Sustainable Biosphere Initiative reflects a recognition that the human population and its influence have grown to a point where the sustainability of ecological systems cannot be assumed: additional basic research must be performed to enhance our understanding of the functioning of ecological systems so that their important functions can be sustained through wise management. Public understanding of the mechanisms by which ecological systems function is critical to ensuring that ecological principles and knowledge are used appropriately in managing the biosphere, so the SBI calls for increased public education and ecological information transfer. Most importantly, the SBI contends that proper management of our natural resources demands that sound ecological knowledge be incorporated into management and policy (Risser *et al.* 1991).

The SBI is composed of three research priorities: global change, biological diversity, and sustainable ecological systems.

GLOBAL CHANGE

The SBI strongly endorses the ongoing global change research program (U.S. Committee on Global Change Research 1990). Understanding the ecological causes and consequences of global change is critical to furthering ecological understanding of ecosystem processes at all scales (local, regional, as well as global) and vital to wise development of national policy and informed management of ecosystems that deliver goods and services. Despite support for the presently formulated U.S. Global Change Program, the SBI also identifies one area of research that is not adequately addressed by the current research initiatives, the broad issue of how ecological conditions and processes control global processes. Quite simply, the composition, structure, and functioning of an ecosystem determine the biogeochemical fluxes, transfers, transformations, and storages of materials that occur within it and thereby contribute to global element cycles and global change. For example, the degree of success in reducing atmospheric CO_2 through stimulation of phytoplankton production by application of the limiting micronutrient of iron to the Southern Ocean depends upon the extent to which any enhanced primary production is respired back into the atmosphere by penguins, whales, and other consumers in the Antarctic food webs (Huntley *et al.* 1991). The question of how geochemical cycling is altered by changes in ecological community composition and function needs to be the target of explicit research in the global change program.

BIOLOGICAL DIVERSITY

Like the first research priority identified in the SBI, global change, the second priority, biological diversity, is also the focus of a large ongoing research program (Committee on International Science's Task Force on Global Biodiversity 1989). The SBI endorses these efforts, directed largely towards cataloging the species composition of various habitats and protecting areas of high biological diversity. However, this effort must be expanded in scope to address two additional issues. First, basic research on ecosystems is necessary to develop an understanding of how different patterns of biodiversity influence the functioning of ecological systems. For example, do more diverse ecosystems with longer food chains, like pelagic water-column ecosystems, respond differently from simple ecosystems with shorter food chains, such as those in estuarine benthic habitats, to various interventions, including the stresses of pollution? Second, we need to develop greater fundamental ecological appreciation for the processes by which ecological processes influence biodiversity. Without this improved understanding of the relationships between ecosystem function and biodiversity, reliable strategies to manage and maintain biological diversity required to support the biosphere cannot be developed.

SUSTAINABLE ECOLOGICAL SYSTEMS

In contrast to the first two research priorities identified by the Ecological Society of America's SBI, this third priority is new, not the focus of any direct integrated federal research program. The thrust of this recommended research effort is to develop the rigorous understanding of underlying ecological processes that are required to develop successful management and restoration of natural, exploited, and artificial (*e.g.*, timberlands, agricultural systems, aquaculture systems) ecosystems. There are, of course, numerous research activities designed to develop information required to manage particular exploited resources, such as fish stocks, crops, and timber. However, these efforts are fragmented rather than united through the basic ecological problems held in common, and often inappropriately directed towards single resources without incorporating adequately the entire ecosystem context. Effective management must incorporate an appreciation for function of the ecosystem in which the target resource is embedded. This task requires a large multidisciplinary effort and a strong foundation built on ecological principles to produce effective prediction-making and to avoid costly *ad hoc* repetition of efforts on every individual system. The development of this third priority of the SBI is crucial to sustain human activities, lifestyles, and societies.

GLOBAL OCEAN ECOSYSTEMS DYNAMICS

GLOBEC is a component research initiative of the U.S. Global Change Program. The core goal of this research initiative is to develop the necessary understanding of how physical processes affect, both directly and indirectly, marine ecosystems dynamics to be able to predict how global change might be expected to alter the structure, dynamics, and productivity of ocean ecosystems (Joint Oceanographic Institutions 1991a). The emphasis of the program falls most heavily upon secondary production, especially including fisheries resources. A scientific steering committee for GLOBEC was named in the spring of 1989, after numerous workshops in the preceding years on marine fish ecology, zooplankton ecology, benthic ecology, physical-biological coupling, and recruitment dynamics. In the spring of 1991, the GLOBEC steering committee published its Initial Science Plan (Joint Oceanographic Institutions 1991a).

The U.S. GLOBEC Program is designed as a multiagency research initiative with the NSF, NOAA, and Office of Naval Research (ONR) providing most of the present support. Present projects funded under the GLOBEC umbrella include modeling efforts supported jointly by ONR and NSF Ocean Sciences, and retrospective analyses of particular ecosystems, biotechnology development, research on UV effects on larvae, and preparatory planning for field programs in the Northeast U.S. Shelf Ecosystem by NOAA's Marine Ecosystem Response Program. An NSF panel met in August 1991 to recommend decisions on proposed projects submitted in response to a call for proposals to develop biotechnological tools for assessing physiological status of zooplankters and for mechanizing counting of taxa of zooplankters. In addition to these specific projects, relevant laboratories of the National Marine Fisheries Service of NOAA are using internal resources to promote GLOBEC field projects within their purview. Despite this present level of GLOBEC activity within the United States, the GLOBEC-related projects abroad greatly exceed it, with Canadian, Norwegian, and French programs especially active.

The strategy adopted by the scientific steering committee for GLOBEC is to precede major field programs with efforts: (1) to produce appropriate models of relevant physical dynamics, population dynamics, and ecosystem processes that can serve to guide later field experiments; and (2) to develop new instrumentation that will allow biological sampling in the sea to occur more rapidly and over larger areas such that it can more closely match the scales of physical data collection and contributions of physical processes. With physical-biological models in hand to guide the conceptual hypothesis formation, and with new, more powerful biological sampling tools available, the GLOBEC steering committee plans to mount major field efforts in a small number of LMEs. These field programs will be designed to understand how the physical processes, including those sensitive to change at local, regional, and global scales, contribute directly and indirectly to ecosystems dynamics.

The initial field system identified for intensive study and hypothesis testing by the GLOBEC steering committee is the Northwest Atlantic ecosystem (Joint Oceanographic Institutions 1991b), essentially equivalent to the Northeast U.S. Shelf Ecosystem of Sherman *et al.* (1988). The intent is for U.S. efforts to focus on the Georges Bank area, while analogous Canadian efforts focus on other banks (*e.g.*, Browns Bank and the Flemish Cap) and the more physically open Scotian Shelf, and European efforts consider the shelf ecosystems of the Northeast Atlantic, so that the contrast of these physically different systems containing a similar biota can yield important insights into processes controlling marine ecosystems dynamics and their generality. This particular LME was chosen for the initial intensive field program for several reasons. Because the food chains in this system are topped by gadoid fishes of commercial importance, Atlantic cod and haddock, there is both practical importance to understanding this system and also availability of historical time-series data on key system variables. These data include not only fisheries catch statistics, but also a large amount of information on physical circulation, transport, and mixing processes. For the Georges Bank, there is clear evidence of overfishing and a consequent shift from a dominance of gadoid to relatively undesirable elasmobranch top predators (Clark and Brown 1977; Sissenwine 1986), implying a need for an ecosystems-oriented management approach. In addition, several lines of argument suggest that this region may be highly sensitive to global change, and therefore an appropriate choice for detection of a signal and testing hypotheses on ecosystem response. For example, general circulation models suggest that the North Atlantic is a region expected to experience a strong set of physical signals from global warming. Changing precipitation patterns and ice melt during warming would be expected to alter the buoyancy-driven currents that strongly affect the circulation patterns in this coastal, moderately high-latitude system. And finally, biogeographic changes in response to warming sea temperatures might be expected to alter the Georges Bank ecosystem dramatically given the narrow latitudinal range of this shallow coastal feature and the present biogeographic boundaries.

The Initial Science Plan for GLOBEC (Joint Oceanographic Institutions 1991a) responds remarkably well to the relevant appeals of the Ecological Society of America for an SBI (Lubchenco *et al.* 1991). All three priority research objectives of the SBI come together in the science plan for GLOBEC. First, GLOBEC is part of the U.S. Global Change Program with responsibility for assessing how marine ecosystems are expected to be altered by various processes of global change. As such, it responds, for ocean ecosystems, to the SBI's call for research on how ecosystem dynamics will respond to global change. Unless in combination with the Joint Global Ocean Flux Study, GLOBEC will probably not, however, have the resources to address the other key issue of how different ecosystems contribute differently to global materials budgets. Furthermore, although the long-range plans for GLOBEC include an intention to assess a suite of different types of ocean ecosystems, it is unclear what ultimate funding levels will permit. Second, GLOBEC necessarily and explicitly is addressing important aspects of the biodiversity problem. In particular, the ecosystem models to be tested by GLOBEC must answer the question of how important species diversity is to the functioning and dynamics of marine ecosystems because, as a practical matter, not all ecosystem variables can be continuously monitored. This one must address, in up-front modeling, how important the rarer components of ecosystems are in understanding and predicting systems behavior, and, conversely, to what degree the ecosystem can be conceptually simplified without loss of ability to predict its dynamics (Joint Oceanographic Institutions 1991c). Finally, the SBI's call for research on sustainable ecological systems is served explicitly by the GLOBEC intent to focus on exploited marine ecosystems. The need to further develop an ecosystems approach to model and understand the dynamics of important fisheries resources is a major motivation of GLOBEC. The novelty of incorporating the roles of physical dynamics, including variables responding to global change, into ecosystems models, which themselves include species under exploitative harvest, is a promising approach and perhaps the most important justification for support of GLOBEC. For ocean ecosystems, the science plan of GLOBEC depicts a process to bring together fisheries biologists, biological oceanographers, physical oceanographers, technologists, and ecosystems modelers to address explicitly the most serious void identified by the Ecological Society of America in its call for an SBI, namely the need to develop the fundamental scientific basis for managing and sustaining ecological systems.

APPLICATION OF SBI: RECOMMENDATIONS FOR THE NORTHEAST U.S. SHELF ECOSYSTEM

1. Do not model or manage species in isolation from their ecosystem context.

Although the classic quantitative modeling of exploitation effects on individual species populations (*e.g.*, Ricker, 1958) has lead to much insight into fisheries management and the impact of harvest on fish stocks, the Ecological Society of America's SBI document would argue that modeling and management that ignore the effects of the ecosystem dynamics are grossly incomplete and unlikely to be successful. This message came clearly from the Dahlem Conference on Exploitation of Marine Communities (May 1984) and has been embraced well in the concept of management at the level of the LME (Sherman and Alexander 1986; Sherman 1991).

For the Northeast U.S. Shelf Ecosystem, this dictum has several implications. Specifically, it implies that Atlantic cod and haddock should not be managed outside the context of the ecosystem in which they are found. Moreover, since the elasmobranch fishes that have come to dominate the demersal predator trophic level in the wake of overexploitation of gadoid stocks on the Georges Bank share prey resources with, and even prey upon, the juvenile life stages of the Atlantic cod and haddock (*e.g.*, Fogarty *et al.* 1987; Sherman *et al.* 1988), there are reasonable grounds on which to postulate that the recovery of the gadoid stocks may be strongly inhibited by the interactions with the elasmobranchs through the ecosystem. Basic research on the ecosystem dynamics of the Northeast U.S. Shelf Ecosystem is required to address this and other issues of how the gadoid dynamics are tied to other components in the ecosystem.

2. Develop ecosystems models based on understanding of processes of population changes in component species.

Although much insight can be gained by comparisons of LMEs, each individual LME is essentially unique. Consequently, the ability to employ replicated experiments and truly independent observations as the means of making rigorous inferences is limited. The only viable antidote to this problem of lack of replication is to develop an excellent understanding of the mechanisms by which the populations change within the ecosystem. This mechanistic appreciation for process must encompass the complete range of relevant scales across which population processes, as well as controlling physical dynamics, operate (*e.g.*, Steele 1988).

The implications of this recommendation for the Northeast U.S. Shelf Ecosystem are numerous. They include notably a need to incorporate the roles of physical dynamics directly and indirectly into models of ecosystem dynamics. Description of the circulation patterns of the currents from the Gulf of Maine through Georges Bank to the southern end of the Northeast U.S. Shelf Ecosystem, in combination with measurements of population processes, is required to establish the proper scales that define component populations, especially for the important zooplankton species such as *Calanus finmarchicus*. The importance of the seasonal stratification of the water column over Georges Bank, and the timing of wind-driven mixing to the feeding success of zooplankters, including larval and juvenile fishes, apparently needs to be included in models of population dynamics in this system. Nevertheless, the ecosystem models developed to predict dynamics in this ecosystem must achieve an accurate balance of the potentially conflicting impacts of physical mixing, which may alter feeding success of juvenile gadoids while simultaneously changing exposure and risk to their own consumers. Logic may suggest that the significance of mortality through immediate predation would dominate over effects on growth, but slower growth implies a longer period of exposure to size-dependent predators in this water-column environment. A proper ecosystem dynamics model is required to answer such critical questions.

3. Include anthropogenic influences explicitly into models of ecosystems dynamics.

Traditionally, academic models of ecosystem dynamics have tended to address natural systems in the absence of human influence, whereas models of the consequences of human activities, especially exploitation of resources, have tended to neglect the full range of important natural physical and biological variables. Sustaining important ecosystems demands that appropriate contributions of anthropogenic influences, in addition to the effects of natural processes, be explicitly included in our formalizations and studies of ecosystems dynamics. In general, the human influences that need consideration are harvest pressure (exploitation), nutrient and pollutant inputs, and signals of global change (warming, UV increase, changes in ocean circulation patterns, effects on upwelling intensity and turbulent mixing, CO_2 increase, *etc.*).

For the Georges Bank region of the Northeast U.S. Shelf Ecosystem, it is evident that the impacts of exploitation must be included in ecosystem dynamics models, whereas nutrient loading and pollution seem unimportant except in the estuarine areas (Sherman 1991). Impacts of global change on this system are probably also subtle at this time, but require incorporation to ensure that the goods and services provided by this important system be sustained indefinitely into the future. At the southern margin of the Northeast U.S. Shelf Ecosystem, the consequences of nutrient loading are evident where the discharge of the Chesapeake Bay enters the continental shelf north of Cape Hatteras, so for that region, eutrophication effects should not be ignored in the ecosystem modeling.

If these recommended analyses and models of the joint impacts of anthropogenic influences and natural variables are successfully incorporated into an integrative understanding of ecosystem dynamics for this LME, one very significant outcome could be derived: namely, the mechanistic understanding of the consequences of bycatch from relatively nonselective trawling gear. This would address an urgent management need.

4. Apply rigorous approaches of experimental ecology to "adaptive management" of exploited systems.

Fishing is a heavily regulated process. Such regulation can be treated as an ecosystem manipulation conceptually, such that the methods and analytical techniques of experimental ecology can be applied to test various impacts of fishing practices. These manipulations of fishing pressure rarely represent a controlled experiment because ecosystems differ sufficiently over space that control sites are never identical to the sites where exploitation is being manipulated. Nevertheless, this use of regulation of exploitation of natural ecosystems is a powerful technique and can be cleverly used to enhance our understanding of how specific exploited ecosystems function and thereby lead to improved management (Sugihara *et al.* 1984).

The design and use of regulation as an experiment has been termed "adaptive management" by Walters (1986). This approach to management is an excellent example of the application of the science of ecology to develop management for a sustainable ecosystem, as urged by the Ecological Society of America's SBI (Lubchenco *et al.* 1991). The National Research Council's panel on sea turtle conservation demonstrated how effectively and convincingly the consequences of manipulation of fishing regulations could be employed to test an impact of fishing in showing how the strandings of dead sea turtles in several localities was significantly associated with the precise period of shrimp trawling (National Research Council 1990). New methods for analysis of such environmental manipulations are continually being developed by ecologists and biostatisticians, a very significant recent example being the before-after-control-impact analysis of Stewart-Oaten *et al.* (1986), which helps deal with the problem of nonidentity between treatment and control sites, as well as the problem of a lack of replication of many environmental "experiments."

The application of this approach of adaptive management to the Northeast U.S. Shelf Ecosystem represents one important implication of the SBI for this exploited and clearly impacted system. Such a recommendation is consistent with the suggestion of Sissenwine and Cohen (1991) who similarly advocated consideration of a cautious experimental approach to regulation and management of the Georges Bank system to test those species interactions so critical to improving management and enhancing important overfished gadoid stocks. The actual experiments that should be employed must be carefully designed and are constrained by economics and many other practical considerations. Nevertheless, the SBI recommendations imply strong advocacy for this approach.

5. Charge modelers to identify the key biological, chemical, and physical parameters to be monitored to assess ecosystem status and health and to test the predictions of the ecosystem dynamics models. Incorporate these monitoring needs into agency monitoring programs.

One fundamental challenge faced by the academic modelers of ecosystems is to develop a defensible set of criteria that define accurately the status and health of an ecosystem. Despite substantial attention to this question, we still lack rigorous indexes of ecosystem stress, status, and health (Lubchenco *et al.* 1991). Furthermore, the ecosystem models required to understand the functional effects of anthropogenic influences on natural and exploited ecosystems must be tested, modified, and refined through interactive field-and-modeling programs. It is unrealistic to envision complete monitoring of all important biotic and abiotic components of the ecosystem, so identification of that minimal list of key parameters to monitor is a critical task for ecosystem modelers.

The modelers also need to communicate with the federal and state agencies charged with environmental monitoring. Federal agencies with important monitoring responsibilities and capabilities, such as NOAA, EPA, and National Aeronautics and Space Administration, should be encouraged to approach the leaders of the necessarily large research programs designed to develop ecological understanding and management strategies for specific LMEs to initiate development of a monitoring package that is feasible, yet appropriate and telling. The complexity of processes that jointly control ecosystem dynamics necessarily implies a challenge for monitoring. The task includes a need not only to identify what to monitor, but also the spatial and temporal scales (*e.g.*, Steele 1988). Without this partnership between the ecosystems modelers and the responsible agencies, inadequate testing of the ecosystems models will ensue and monitoring responsibilities will not be discharged in a fashion that yields the information required for sustainable management. Although modification of the monitoring of the Northeast U.S. Shelf Ecosystem may not be an immediate outcome of the application of this recommendation of the SBI to this ecosystem, following this advice will require a long lead time of interaction between the ecosystems modelers and leaders of monitoring programs. Now is the time to start.

6. Devote substantial effort to understanding controls on prey population dynamics, especially zooplankton and forage fish in LMEs.

The majority of past research effort in the field of fisheries has been directed towards developing an understanding of the population dynamics of exploited species (see Rothschild 1986). Recently fisheries research has broadened in scope to the degree that the term "fisheries oceanography" has evolved to describe this new focus. Fisheries oceanographic studies are intended to incorporate an integrative vision of exploited populations in a context of the complete physical and biological environment. Understanding the dynamics of exploited stocks in the context of the entire ecosystem is a key feature of the Ecological Society of America's SBI recommendations, as I have already indicated. Nevertheless, one specific aspect of this approach deserves special mention because of its importance and our lack of attention to it in past programs: the understanding of the controls on population dynamics of critical prey organisms, especially zooplankton and forage fish.

The key prey organism that requires explicit attention in the Northeast U.S. Shelf Ecosystem appears to be the zooplankter *Calanus finmarchicus* (Joint Oceanographic Institutions 1991b). This species of calanoid copepod is the primary prey for Atlantic cod and haddock during a critical early stage in their life history when food limitation could well influence the recruitment success of both gadoid species. As a general rule, much more must be known about the determinants of population fluctuations and variability in production of copepods to be able to advance further our understanding of how ecosystem dynamics help determine the year-class strength of exploited fish populations (Joint Oceanographic Institutions 1991a). The abundance of *Calanus* can influence the rate of starvation of young gadoids, their growth rate, and thus, indirectly, their survivorship by altering the length of time required in the small size class so vulnerable to predation, and the strength of many possible indirect interactions operating to determine gadoid abundance through a multitude of food chain interactions. Hypotheses involving prey species dynamics lie at the cutting edge of fisheries oceanographic research, and for the Northeast U.S. Shelf Ecosystem, demand a focused study of zooplankton dynamics, especially *Calanus finmarchicus*. In addition, key forage fishes, such as sand lance and capelin, deserve similar directed effort to assess the processes controlling their population dynamics and their role in affecting the dynamics and yields of exploited bottom fish.

7. Evaluate the significance of biological diversity to the functioning of marine ecosystems so that we know how much ecosystem models and studies can be simplified yet still reproduce accurate dynamics.

Perhaps the most critical decision that must be made prior to initiation of any ecosystem study is the decision of which components of the ecosystem to measure. The answer to this problem requires understanding of the role of biotic diversity in ecosystem and community dynamics, a question at the cutting edge of basic ecological research (Lubchenco *et al.* 1991). For example, it seems clear that any study of ecosystem dynamics should measure the population sizes of the most abundant species, but to how many trophic levels does that level of specific attention need be carried? When understanding the dynamics of an exploited fish species acting largely at a specific predatory trophic level is the ultimate goal of the study of an LME, is it sufficient merely to measure cell densities of major taxa of phytoplankton? What level of information on decomposers is needed? And how important are indirect species interactions (those not represented by direct predation or direct consumption) in ecosystem dynamics?

These questions are generic problems of ecosystems ecology, but they must be addressed specifically for the

Northeast U.S. Shelf Ecosystem as part of any effective ecosystem study. This doubtless implies the need for closely coordinated modeling and field study of this system. Fortunately, the marine planktonic ecosystems are probably well characterized by food web interactions without addition of the more complex and potentially indirect interactions involving habitat modification that would be required in marine benthic ecosystem models. Unfortunately, marine planktonic food chains tend to be long compared to other food chains (Schoener 1989), implying a need to measure more populations to understand the behavior of any marine planktonic ecosystem. For the Northeast U.S. Shelf Ecosystem, these issues need immediate attention to allow the effective design of a study of the controls on the dynamics of that vital ecosystem so that its important functions can be sustained in the face of obvious human impacts.

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