NOAA Technical Memorandum NMFS-F/NEC-100

Emerging Theoretical Basis for Monitoring the Changing States (Health) of Large Marine Ecosystems

Summary Report of Two Workshops: 23 April 1992, National Marine Fisheries Service, Narragansett, Rhode Island, and 11-12 July 1992, Cornell University, Ithaca, New York

U. S. DEPARTMENT OF COMMERCE
Ronald H. Brown, Secretary
National Oceanic and Atmospheric Administration
D. James Baker, Administrator
National Marine Fisheries Service
Rolland A. Schmitten, Assistant Administrator for Fisheries
Northeast Region
Northeast Fisheries Science Center
Woods Hole, Massachusetts

September 1993

NOAA Technical Memorandum NMFS-F/NEC-100

This TM series is used for documentation and timely communication of preliminary results, interim reports, or special purpose information, and has not undergone external scientific review.

Emerging Theoretical Basis for Monitoring the Changing States (Health) of Large Marine Ecosystems

Summary Report of Two Workshops: 23 April 1992, National Marine Fisheries Service, Narragansett, Rhode Island, and 11-12 July 1992, Cornell University, Ithaca, New York

Kenneth Sherman, Editor

Narragansett Lab., National Marine Fisheries Serv., Narragansett, RI 02882-1199

U. S. DEPARTMENT OF COMMERCE
Ronald H. Brown, Secretary
National Oceanic and Atmospheric Administration
D. James Baker, Administrator
National Marine Fisheries Service
Rolland A. Schmitten, Assistant Administrator for Fisheries
Northeast Region
Northeast Fisheries Science Center
Woods Hole, Massachusetts

September 1993

Table of Contents

Appendices

Tables

Figures

WORKSHOP OBJECTIVE

In a continuing effort to develop a strategy for monitoring the changing states of large marine ecosystems (LME), a workshop was convened at Cornell University, Ithaca, New York, on 11 and 12 July 1992. The agenda and list of attendees are given in Appendix A. The workshop was a followup to an initial workshop held at the National Marine Fisheries Service, Narragansett, Rhode Island, on 23 April 1992. A summary report of the April workshop is given in Appendix B. The specific objective of the July workshop (hereafter "workshop") was to review the state of the art in ecological theory pertinent to how time-series data and information obtained from LMEs could be used to monitor the changing states of ecosystem health. It was hoped that at the conclusion of the workshop, the topic would have been developed far enough to reach a consensus on strategies for linking theory to a supporting field program.

The workshop coincided with a month-long series of summer school lectures and discussions at Cornell focused on ecosystem time-series data, analyses, and interpretation. Participants from these lectures (*e.g.*, Simon Levin, John Magnuson, John Steele, Andrew Solow) joined in the workshop discussions. A general summary of the summer school lectures and discussions is given in Appendix C, and a list of summer school attendees, discussion leaders, and topics is given in Appendix D.

OVERVIEW AND BACKGROUND

During the morning session of the first day of the workshop, the discussions began with an overview of the interests of the NOAA Under Secretary for Oceans and Atmosphere to develop characterizations of ecosystem-level change (Appendix E). Specific reference was made to the Northeast U.S. Shelf Ecosystem, and to the changes occurring within the system during the past three decades. The principal argument was for an acceptable method for monitoring the changing states of LMEs in a manner that allowed for a collapse of a large number of state-variables to a reduced group of indicators or indices of ecosystem change.

Following the overview remarks, background information was provided by Bryon Norton on the relationship of policy to the research on ecosystem health being proposed by the contributors to the volume, "Ecosystem Health," to be published shortly by Island Press. The arguments for ecosystem health as a new paradigm for measuring and evaluating environmental gains and losses are based on the assumption that "society" has an obligation to protect the health and integrity of ecological systems. The premise for proceeding with the ecosystem health-integrity paradigm is that self-organizing systems maintain a degree of stable functioning across time that should not be destabilized through human activity. According to Norton, this premise is based on the recognition that: (1) processes are related in an unequal hierarchical organizational structure, (2) energy flows through the system in a manner that generates repetition and duplication, and (3) ecosystems are fragile in their capacity for absorbing disturbance. Until scale and perspective can be built into ecosystem theory, there can be no precise explanation of why particular indicators correlate with ecosystem characteristics.

Norton concluded that ecosystem-level management is distinguished by its concern for characteristics of the whole system that are not reduced by aggregated characteristics of its parts and that the idea of ecosystem health is valuable as it focuses on the entire system and away from particular interest groups. It is considered by Norton as a high priority to encourage partnership among biologists, economists, and the public. Since ecosystem health is both an evaluative and descriptive concept, both ecologists and economists must work to inform the public about management options. It is, therefore, according to Norton, a high priority to develop new methods of valuation that contribute to the dynamic process of defining and protecting ecosystem health.

NORTH SEA ECOSYSTEM CASE STUDY

The discussions that followed focused on case studies of ecosystems under stress. Hein Skjoldal provided convincing evidence of eutrophication around the coasts of the North Sea Ecosystem. He provided information on the flux of nitrates and phosphates, insights on the effects of elevated levels of nutrient inputs, and efforts underway to mitigate the stress on the ecosystem caused by eutrophication. The approach he outlined for the North Sea is indicative of the growing interest of governments to address the monitoring and management of LMEs. As described by Dr. Skjoldal, the environmental ministers (hereafter "council of ministers") of eight countries bordering on the North Sea (*e.g.*, Belgium, Denmark, France, Germany, Netherlands, Norway, Sweden, United Kingdom) have since 1987 adopted a holistic ecosystems approach "to carry out work leading, in a reasonable time-scale, to a dependable and comprehensive statement of circulation patterns, inputs, and dispersion of contaminants, ecological conditions, and effects of human activities in the North Sea." Among the tasks to be addressed by a designated North Sea Task Force are nine topics including the need for more knowledge of general ecosystem effects on plankton, benthos, birds, fish, and mammals (Table 1).

A primary responsibility of the North Sea Task Force is the production of a holistic assessment of the North Sea and its subregions based on data acquired using internationally comparable methods, state-of-the-art modeling, and results of the latest research on the North Sea environment. The assessment is to be completed by the end of 1993. The subregions and lead countries are shown in Figure 1. A conceptual model for assessing the changing states of ecosystems developed by Dutch scientists (TenBrink, Hosper, and Colijn) was described by Dr. Skjoldal. A bibliographic reference for the Dutch effort is given in Table 2. The ecosystem-level contributions to the North Sea quality status report are listed in Table 3. The North Sea Task Force has been requested by the council of ministers to develop

Table 1. Gaps in knowledge as identified in the 1987 quality status report of the North Sea Task Force. (From: North Sea Task Force. 1991. Scientific activities in the framework of the North Sea Task Force. *North Sea Environ. Rep.* No. 4; 54 p. Available from: North Sea Task Force, New Court, 48 Carey St., London, England WC2A 2JE United Kingdom.)

1. A need for better-quality input data.
2. An improved understanding of nutrient dynamics and, in particular, their relation to occurrences of exceptional algal blooms.
3. More epidemiological information and a greater understanding of the factors causing diseases in marine organisms, including fish, birds, and mammals.
4. An increased knowledge of the different ways in which classes of contaminants behave in the North Sea, and of those contaminants' sources and fates.
5. An assessment of the critical load of nutrients and persistent, bioaccumulable, and toxic substances (metals and organic compounds).
6. More information on the levels of contaminants in the marine environment obtained on an internationally comparable basis.
7. More knowledge of general ecosystem effects on plankton, benthos, birds, fish, and mammals, especially North Sea seal stocks.
8. Increased emphasis on quality assurance of mathematical models used in North Sea assessments.
9. Other specific problems: as examples, the problem of estimating inputs of contaminants to coastal waters from estuaries, and the significance of sediment movement in the context of contaminant transport.

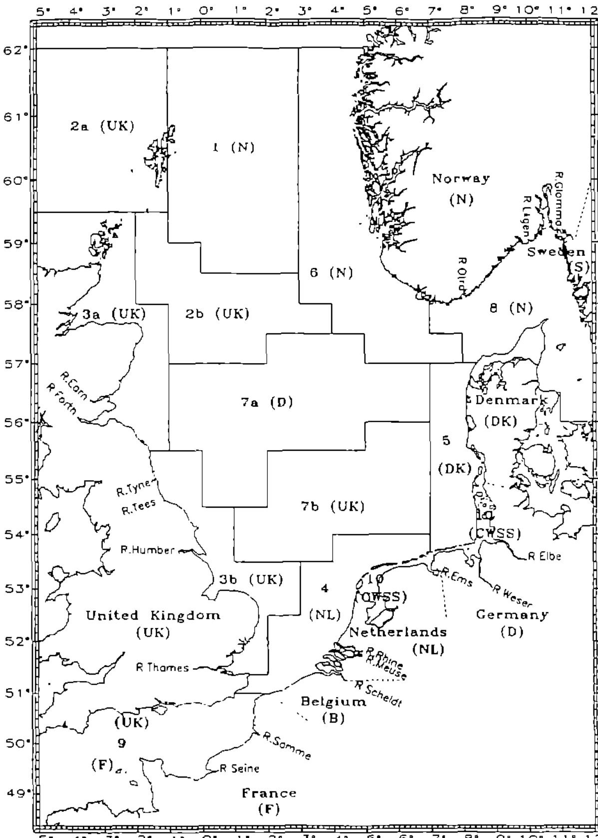

Figure 1. Subregions of the North Sea by the North Sea Task Force based on the natural hydrographic variations of the North Sea, and lead countries (abbreviations in parentheses) for conducting pertinent ecological research activities in support of the task force objectives. (From: North Sea Task Force. 1991. Scientific activities in the framework of the North Sea Task Force. *North Sea Environ. Rep.* No. 4; 54 p. Available from: North Sea Task Force, New Court, 48 Carey St., London, England WC2A 2JE United Kingdom.)

techniques for treating the North Sea from a total ecosystems perspective. The discussions of the workshop were most pertinent to initiatives underway by the North Sea Task Force to define ecological objectives for describing the changing states of the North Sea.

GREAT LAKES BASIN ECOSYSTEM CASE STUDY

Dr. Henry Regier kindly provided the participants with his perspective on changing ecosystem states and the concept of ecosystem integrity as related to the Great Lakes Basin Ecosystem. In this case, the fish component of the ecosystem was used as a surrogate for measuring change in the integrity or natural self-regulating processes leading to an "advanced state of self-integration or integrity" as described in the 1978 Great Lakes Water Quality Agreement which called for restoration and maintenance of the chemical, physical, and biological integrity of the waters of the Great Lakes Basin Ecosystem [see Regier (1992), Table 2]. Article II of the International Joint Commission (IJC) Great Lakes Water Quality Agreement of 1978 is given in Table 4.

The number of management regimes that have broad objectives aimed at protection of the "integrity" or "wholeness" of the ecosystem is growing. However, the theoretical basis for quantifying the value judgements for "integrity" and "health" concepts remains in a highly developmental stage as one moves from single-species management theory to multispecies/community management, to total ecosystem-level management efforts. The IJC is a good example of a program that introduced successful mitigation efforts to improve the water quality of the Great Lakes, but is continuing to refine the health and integrity concept in relation to ecological theory. Several important

Table 2. List of reference papers at the Workshop on Changing States and Health of Large Marine Ecosystems, 11-12 July 1992, Cornell University, Ithaca, New York. Copies available from the authors.

Chapman, P.M. 1992. Ecosystem health synthesis: can we get there from here? *J. Aquat. Ecosyst. Health* 1: 69-79.

Lee, B.J.; Regier, H.A.; Rapport, D.J. 1982. Ten ecosystem approaches to the planning and management of the Great Lakes. *J. G. Lakes Res.* 8(3): 505-519.

National Research Council of the United States and The Royal Society of Canada. 1985. The Great Lakes water quality agreement: an evolving instrument for ecosystem management. Washington, DC: National Academy Press; 244 p.

North Sea Task Force. 1991. Scientific activities in the framework of the North Sea Task Force. *North Sea Environ. Rep.* No. 4; 54 p. Available from: North Sea Task Force, New Court, 48 Carey St., London, England WC2A 2JE United Kingdom.

Regier, H.A. 1992. Ecosystem integrity in the Great Lakes basin: an historical sketch of ideas and actions. *J. Aquat. Ecosyst. Health* 1: 25-37.

Regier, H.A. 1993. The notion of natural and cultural integrity. Toronto, ON: Institute for Environmental Studies, University of Toronto; 220 p.

TenBrink, B.J.E.; Hosper, S.H.; Colijn, F. [1992?] A quantitative method for description & assessment of ecosystems: the AMOEBA-approach. Unpublished report available from: Tidal Waters Division, Ministry of Transport and Public Works, P.O. Box 20907, 2500 EX The Hague, The Netherlands.

papers were made available by Dr. Regier to the group. They are listed in Table 2.

THEORETICAL FRAMEWORK

The presentations by Simon Levin and John Steele on the state of the art in ecological theory in relation to indexing changing ecosystem states emphasized the importance of matching time-series measurements to the scale of events pertinent to the ecological problem being addressed. From the discussions at the Cornell Summer School on long time series, John Steele indicated that the variance in a data set increases with the length of record, and that it is not desirable to define a baseline and consider deviations from an earlier mean as an index to the consequence of external influences. However, he indicated that extended data sets provide the basis for improving the understanding of the underlying system. The long-term physical data on climate change extending from the little ice age through the Milankovich cycles were given as an example of the great utility of time-series data. From a biological perspective, the example given was the continuous plankton recorder (CPR) data sets and analysis, proving the value of extended biological and physical data sets for enhanced understanding of the biofeedback of North Atlantic plankton to climate change.

Table 3. Participating and lead countries to prepare the 1993 quality status report of the North Sea Task Force. (From: North Sea Task Force. 1991. Scientific activities in the framework of the North Sea Task Force. *North Sea Environ. Rep.* No. 4; 54 p. Available from: North Sea Task Force, New Court, 48 Carey St., London, England WC2A 2JE United Kingdom.)

Subregion	Interested countries	Lead country (abbreviation)
Area 1	Norway, United Kingdom	Norway (N)
Area 2	Norway, United Kingdom	United Kingdom (UK)
Area 3	United Kingdom	United Kingdom (UK)
Area 4	Belgium, France, Germany, Netherlands, United Kingdom	Netherlands (NL)
Area 5	Denmark, Germany, Netherlands, Norway, Sweden	Denmark (DK)
Area 6	Norway	Norway (N)
Area 7a	All North Sea states	Germany (D)
Area 7b	All North Sea states	United Kingdom (UK)
Area 8	Denmark, Germany, Norway, Sweden	Norway (N)
Area 9	Belgium, France, Germany, United Kingdom	France, United Kingdom (F/UK)
Area 10	Denmark, Germany, Netherlands (CWSS)	Common Wadden Sea Secretariat

Both Drs. Steele and Levin suggested that with regard to the theoretical basis for monitoring changing states of LMEs, the positive relations between space/time scales and aggregation theory support arguments for deriving emergent properties of ecosystems using the LME concept for aggregating ecosystem components. However, they caution that the losses of information on smaller scales need to be assessed. They agreed that models which contain multiple equilibria, such as bistable systems, can describe the essential features of certain systems including the spruce budworm and the switches in fish stock abundance. John Steele was of the opinion that, by implication, these simple models could serve as metaphors for more complex switches that can occur in community structure. The empirical evidence from the CPR data series provides a basis for recognizing alternate states in plankton communities, and thereby serves to broaden the use of stability, resilience, and diversity as ecosystem concepts.

Table 4. Article II of the International Joint Commission Great Lakes Water Quality Agreement of 1978. (From: National Research Council of the United States and The Royal Society of Canada. 1985. The Great Lakes water quality agreement: an evolving instrument for ecosystem management. Washington, DC: National Academy Press; 244 p.)

PURPOSE

The purpose of the [p]arties is to restore and maintain the chemical, physical, and biological integrity of the waters of the Great Lakes Basin Ecosystem. In order to achieve this purpose, the [p]arties agree to make a maximum effort to develop programs, practices[,] and technology necessary for a better understanding of the Great Lakes Basin Ecosystem and to eliminate or reduce to the maximum extent practicable the discharge of pollutants into the Great Lakes System.

Consistent with the provisions of this [a]greement, it is the policy of the [p]arties that:

(a) [t]he discharge of toxic substances in toxic amounts be prohibited and the discharge of any or all persistent toxic substances be virtually eliminated;

(b) [f]inancial assistance to construct publicly owned waste treatment works be provided by a combination of local, state, provincial, and federal participation; and

(c) [c]oordinated planning processes and best[-]management practices be developed and implemented by the respective jurisdictions to ensure adequate control of all sources of pollutants.

PLANKTON RECORDER TECHNOLOGY

Dr. Robert Williams described the use of instrumented CPRs for monitoring the changing states of plankton communities in the North Sea. The CPRs equipped with solid-state data loggers for temperature, salinity, depth, chlorophyll, nutrients, and light have been deployed from a commercial ship-of-opportunity on routes from Grimsby to Aberdeen, from Aberdeen to Stavanger, and from the southern North Sea to the Kattegat since 1988. The operations are conducted by the Plymouth Marine Laboratory of the Natural Environmental Research Council (NERC) of the United Kingdom, and by the Sir Alister Hardy Foundation for Marine Science in Plymouth, England.

An undulating oceanographic recorder (UOR) has been in operation between Grimsby and Aberdeen since 1989. The project is supported by a contract from the Ministry of Agriculture, Fisheries, and Food's Lowestoft Laboratory to monitor conditions off the northeast coast of Great Britain where outbreaks of paralytic shellfish poisoning were caused by shellfish feeding on toxic dinoflagellates. A project funded under the Global Environmental Facility of the World Bank which will use instrumented CPRs and UORs for monitoring the changing states of the Gulf of Guinea Ecosystem is presently being developed. Instrumented CPRs and UORs will be deployed in studies of the Northeast U.S. Shelf Ecosystem in collaboration with NERC's Plymouth Marine Laboratory.

DATA ANALYSES

The utility of alternative statistical approaches to describing ecosystem-level condition was addressed by Andy Solow. He suggested that while principal-component analyses were most often used for reducing large data sets into directions of change, other statistical approaches were available that include more information on the nature of relationships among parameters, including canonical analyses, lagged correlation analyses, and orthogonal smoothing techniques. The concept of collapsing many variables into a few indices for characterizing changing ecosystem states is a newly emerging discipline that will benefit from case-study analyses of long time series and data sets.

Dr. Solow will develop diversity and other related indices (*e.g.*, stability, resilience, productivity, yield) using the Northeast U.S. Shelf Ecosystem data sets of the National Marine Fisheries Service. Examples of the extensive data sets available on the demography of marine mammals of this region and in adjacent ocean waters were presented by Gordon Waring. It was evident from Waring's presentation that information on the seasonal movements of dolphins, seals, and whales was essential in developing strategies for minimizing bycatch of marine mammals by commercial fishermen. He described the development of sighting surveys to estimate marine mammal abundance levels, and presented a series of excellent overlays depicting how marine mammal species distributions can be interpreted as demonstrating spatial and temporal separations to reduce density-dependent competitive interactions.

SUMMARY

In summary, the North Sea case study, the Northeast U.S. Shelf study, and the Great Lakes case study provided examples of using empirical evidence to focus discussions on three key issues:

1. Does the aggregation theory support the concept of changing ecosystem states and emergent properties gained through the aggregation of state variables in LMEs?

2. Does the "integrity" concept introduced in the management of the Great Lakes Basin Ecosystem hold promise for indexing the health of LMEs?

3. Will the CPR and fish trawling surveys recommended by the report of the 1991 Cornell workshop on LME monitoring provide useful generic models for monitoring the changing states of LMEs [see Sherman and Laughlin (1992), Table B2]?

The discussions supported the LME approach as a "real benefit" for detecting changing states in biological communities. The use of the CPR and trawling surveys in detecting changing ecosystem states is validated by the results of useful case studies describing different ecosystem states based on fisheries and CPR studies. The general consensus was that indexing the health of ecosystems was a useful idea that should be retained, but that it should be considered a value judgment, best left to the managers of ecosystems based on the emergent ecosystem properties of, for example, productivity, diversity, yield, stability, and resilience, and that further effort was warranted for quantifying these properties.

APPENDIX A

Agenda and Attendees:

Workshop on Changing States and Health of Large Marine Ecosystems, 11-12 July 1992, Cornell University, Ithaca, New York

AGENDA

Topic	Speaker
11 July 1992 (morning)--Ecosystem Health: Theory and Application to the LME Concept	
Brief Overview	K. Sherman
Ecosystem Health: An Emerging Management Concept	B. Norton
Changing States and Health of the Great Lakes Ecosystem	H. Regier
Eutrophication in the North Sea Ecosystem	H. Skjoldal
11 July 1992 (afternoon)-- Ecosystem Theory and Application for LMEs	
Scale and the Problems of Ecosystem Health	S. Levin
Scale Selections for Biodynamics of Marine Ecosystems	J. Steele
Time-series and Ecosystem Perturbations	A. Solow
CPR, Ocean Physics, and Ocean Climatology	R. Williams
12 July 1992 (morning)--Ecosystem Monitoring	
Strategies for Monitoring Recovery of Depleted Mammal Stocks Including Siting Surveys	G. Waring
LMEs and the Global Ocean Observing System	K. Sherman
Drafting of Report: Changing States and Health of LMEs	

ATTENDEES

Mark S. Berman
Narragansett Laboratory
National Marine Fisheries Service
28 Tarzwell Drive
Narragansett, RI 02882-1199
U.S.A.

Frederick Holland
South Carolina Marine Resources Research Institute
P.O. Box 12559
Charleston, SC 29422
U.S.A.

Simon A. Levin
Department of Ecology & Evolutionary Biology
203 Eno Hall
Princeton University
Princeton, NJ 08544-1003
U.S.A.

John J. Magnuson[a]
Center for Limnology
University of Wisconsin
680 North Park Street
Madison, WI 53706
U.S.A.

Thomas W. Powell[a]
Division of Environmental Sciences
University of California
Davis, CA 95616
U.S.A.

Henry A. Regier
Institute for Environmental Studies
University of Toronto
170 College Street
Haultain Building
Toronto, ON M5S 1A4
CANADA

Kenneth Sherman
Narragansett Laboratory
National Marine Fisheries Service
28 Tarzwell Drive
Narragansett, RI 02882-1199
U.S.A.

Hein R. Skjoldal
Institute of Marine Research
P.O. Box 1870
N5024 Bergen
NORWAY

Andrew Solow
Marine Policy Department
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
U.S.A.

John Steele
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
U.S.A.

Gordon Waring
Woods Hole Laboratory
National Marine Fisheries Service
166 Water Street
Woods Hole, MA 02543
U.S.A.

John R. Vande Castle[a]
Long-term Ecological Research Network
College of Forest Resources
University of Washington, AR-10
Seattle, WA 98195
U.S.A.

Robert Williams
Plymouth Marine Laboratory
Prospect Place, West Hoe
Plymouth, England PL1 3DH
UNITED KINGDOM

[a] Observers

APPENDIX B

Summary Report:

Workshop on the Health of Large Marine Ecosystems, 23 April 1992, National Marine Fisheries Service, Narragansett, Rhode Island

WORKSHOP OBJECTIVE

The workshop was convened as a forum for a multidisciplinary group of scientists to examine the feasibility of developing a series of "indicators" or "indices" of changing states and health of LMEs to provide a quantitative basis for comparing "health" conditions among ecosystems. The 26 participants represented several disciplines, including ecological theory, mathematics, statistics, population biology, fisheries ecology, systems analyses, physiology & biochemistry, ecological modeling, philosophy of science, planktology, physical oceanography, and program planning. They also represented academic, government, and private institutional perspectives. A list of invited participants is given in Table B1. The agenda topics considered and a list of background papers for the workshop are given in Table B2.

PERSPECTIVE ON ECOSYSTEM HEALTH

Increasing attention has been focused over the past few years on synthesizing available information on factors influencing the natural productivity of the fishery biomass and general "health" of LMEs in an effort to identify principal, secondary, and tertiary driving forces causing major changes in ecosystem states and biomass yields. Ecosystem "health" is a concept of wide interest for which a single precise scientific definition is problematical. Ecosystem "health" is used herein to describe the resilience, stability, and productivity of the ecosystem in relation to ecosystem change. In present practice, assessing the health of LMEs relies on a series of indicators and indices (Costanza 1992; Rapport 1992; Norton and Ulanowicz 1992; Karr 1992). The overriding objective is to monitor changes in "health" from an ecosystems perspective as a measure of the overall performance of a complex system (Costanza 1992). The "health" paradigm is based on comparisons of ecosystem resilience and stability (Pimm 1984; Holling 1986; Costanza 1992), and is an evolving concept. Definitions of several variables important to the health of marine ecosystems are given in Table B3. Following the definition of Costanza (1992), to be healthy and sustainable, an ecosystem must maintain its metabolic activity level, its internal structure and organization, and must be resistant to external stress over time and space frames relative to the ecosystem (Table B3). These concepts were discussed at the workshop.

Discussion topics during the morning session were focused on the concept of ecosystem health. Introductory presentations were made by J. Garber of the U.S. Environmental Protection Agency, and K. Sherman of the National Marine Fisheries Service (NMFS), followed by discussions of several aspects of ecosystem health dealing with: (1) scale issues and hierarchial perspectives of the "health" concept (B. Norton); (2) an operational definition of ecosystem health (R. Costanza); and (3) clinical ecology (D. Rapport). Norton emphasized the importance of solving boundary problems to include appropriate physiological (biological) parameters, economic considerations, and the importance of marshaling public policy elements if an ecosystem "health" paradigm is to be successful. He advocated the importance of what he referred to as a self-generating or "autopoesis" concept as: (1) important for supporting arguments dealing with the long-term sustainability of ecosystems, and (2) a positive response to public awareness and support for maintaining or restoring ecosystem health. He also advocated that models should be developed to clarify what is to be protected. The summation view presented by Norton was that the concept of "ecosystem health" be utilized as a bridge linking marine science to public policy. His background paper with R. Ulanowicz (Norton and Ulanowicz 1992) is available from the senior author.

The perspective presented to the workshop by Costanza emphasized the utility of ecosystem health indices for marking progress in achieving a long-term view of sustainability. Among the measurements for making evaluations, the following ecosystem indices were considered by the participants as useful: (1) diversity, (2) stability, (3) yield (economic), (4) productivity, and (5) resilience. A single index of ecosystem health was advocated by Costanza consisting of an integration of ecosystem "vigor," "organization," and "resilience" (Table B4). The "ecosystem health" concept is considered by Costanza as an important policy issue to which scientists should be providing state-of-the-art indicators or indices that can be used as practical and quantitative means for comparing the changing states among ecosystems. His background paper (Costanza 1992) is available from the author.

CLINICAL ECOLOGY

A new perspective of clinical ecology, using the analogy to human health, was presented by Rapport. His analyses have focused on changes in ecosystem structure and function. The

Table B1. Invited participants at the Workshop on the Health of Large Marine Ecosystems, 23 April 1992, National Marine Fisheries Service, Narragansett, Rhode Island

Andy Bakun
Pacific Fisheries Environmental Group
National Marine Fisheries Service
P.O. Box 831
Monterey, CA 93942-0831
U.S.A.

Mark Berman
Narragansett Laboratory
National Marine Fisheries Service
28 Tarzwell Drive
Narragansett, RI 02882-1199
U.S.A.

Jim Bisagni
Narragansett Laboratory
National Marine Fisheries Service
28 Tarzwell Drive
Narragansett, RI 02882-1199
U.S.A.

Donna Busch
Narragansett Laboratory
National Marine Fisheries Service
28 Tarzwell Drive
Narragansett, RI 02882-1199
U.S.A.

Dan Campbell
U.S. Environmental Protection Agency
27 Tarzwell Drive
Narragansett, RI 02882
U.S.A.

Robert Costanza
Chesapeake Biological Laboratory
University of Maryland
P.O. Box 38
Solomons, MD 20688
U.S.A.

David Dow
Woods Hole Laboratory
National Marine Fisheries Service
166 Water Street
Woods Hole, MA 02543-1097
U.S.A.

Mike Fogarty
Woods Hole Laboratory
National Marine Fisheries Service
166 Water Street
Woods Hole, MA 02543-1097
U.S.A.

Mike Fraser
National Marine Fisheries Service
1335 East-West Highway
Washington, DC 20910
U.S.A.

Wendy Gabriel
Woods Hole Laboratory
National Marine Fisheries Service
166 Water Street
Woods Hole, MA 02543-1097
U.S.A.

Jonathan Garber
U.S. Environmental Protection Agency
27 Tarzwell Drive
Narragansett, RI 02882
U.S.A.

Jack Gentile
U.S. Environmental Protection Agency
27 Tarzwell Drive
Narragansett, RI 02882
U.S.A.

Jack Green
Narragansett Laboratory
National Marine Fisheries Service
28 Tarzwell Drive
Narragansett, RI 02882-1199
U.S.A.

Don Hoss
Beaufort Laboratory
National Marine Fisheries Service
101 Pivers Island Road
Beaufort, NC 28516-9722
U.S.A.

Jim Kremer
Biological Sciences Department
University of Southern California
University Park
Los Angeles, CA 90089-0371
U.S.A.

Herman Kumpf
Panama City Laboratory
National Marine Fisheries Service
3500 Delwood Beach Road
Panama City, FL 32407
U.S.A.

Bryan Norton
Georgia Institute of Technology
225 North Avenue, N.W.
Atlanta, GA 30332-0345
U.S.A.

John Paul
U.S. Environmental Protection Agency
27 Tarzwell Drive
Narragansett, RI 02882
U.S.A.

Jerry Pesch
U.S. Environmental Protection Agency
27 Tarzwell Drive
Narragansett, RI 02882
U.S.A.

Susan Pultz
National Oceanic and Atmospheric Administration
Herbert C. Hoover Building
14th & Constitution Avenue, N.W.
Washington, DC 20230
U.S.A.

David Rapport
Biology Department
University of Ottawa
550 Cumberland Street
Ottawa, ON K1N 6N5
CANADA

Andy Robertson
National Ocean Service
6001 Executive Boulevard
Rockville, MD 20852
U.S.A.

Ken Sherman
Narragansett Laboratory
National Marine Fisheries Service
28 Tarzwell Drive
Narragansett, RI 02882-1199
U.S.A.

Andrew Solow
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
U.S.A.

John Steele
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
U.S.A.

Fred Thurberg
Milford Laboratory
National Marine Fisheries Service
212 Rogers Avenue
Milford, CT 06460-6499
U.S.A.

Table B2. Agenda and background papers for the Workshop on the Health of Large Marine Ecosystems, 23 April 1992, National Marine Fisheries Service, Narragansett, Rhode Island

AGENDA

Time	Topic	Speaker
0830	EPA Northeast U.S. Shelf Ecosystem Perspective	J. Garber
	NMFS Northeast U.S. Shelf Ecosystem Perspective	K. Sherman
	Scale and Biodiversity: A Hierarchial Perspective	B. Norton
	Discussion	
	Toward An Operational Definition of Ecosystem Health	R. Costanza
	Discussion	
	Clinical Ecology: A Perspective	D. Rapport
	Discussion	
	Ecological Theory and Changing Ecosystem States	J. Steele
1200	Working Lunch (catered): Discussion on Measurement Parameters	J. Kremer
	Multispecies Predator-Prey Models	M. Fogarty
	Multispecies Fish Community Models	W. Gabriel
	Indexing Changing States or Health of LMEs	
	Plankton	K. Sherman
	Fish	M. Fogarty
	Hydrography/Satellite Oceanography	J. Bisagni
	Environmental Quality	F. Thurberg
	Ecosystem Health Indices	A. Robertson

BACKGROUND PAPERS[a]

Costanza, R. 1992. Toward an operational definition of ecosystem health. In: Costanza, R.; Norton, B.G.; Haskell, B.D., eds. Ecosystem health: new goals for environmental management. Washington, DC: Island Press; p. 239-256.

Holling, C.S. 1973. Resilience and stability of ecological systems. Vancouver, BC: Institute of Resource Ecology, University of British Columbia; 23 p.

Holling, C.S. 1986. The resilience of terrestrial ecosystems to local surprise and global change. In: Clark, W.C.; Munn, R.E., eds. Sustainable development of the biosphere. London, England: Cambridge University Press; p. 292-317.

Karr, J. 1992. Ecological integrity: strategies for protecting earth's life support system. In: Costanza, R.; Norton, B.G.; Haskell, B.D., eds. Ecosystem health: new goals for environmental management. Washington, DC: Island Press; p. 223-238.

Norton, B. 1992. A new paradigm for environmental management. In: Costanza, R.; Norton, B.G.; Haskell, B.D., eds. Ecosystem health: new goals for environmental management. Washington, DC: Island Press; p. 23-41.

Pimm, S.L. 1984. The complexity and stability of ecosystems. *Nature* 307: 321-326.

Rapport, D.J. 1992. Defining the practice of clinical ecology. In: Costanza, R.; Norton, B.G.; Haskell, B.D., eds. Ecosystem health: new goals for environmental management. Washington, DC: Island Press; p. 144-156.

Sherman, K. 1991. The large marine ecosystem concept: a research and management strategy for living marine resources. *Ecol. Appl.* 1(4): 349-360.

Sherman, K.; Jaworski, N.; Smayda, T., editors. 1992. 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. *NOAA Tech. Memo. NMFS-F/NEC-*94; 30 p. Available from: National Marine Fisheries Service, 28 Tarzwell Dr., Narragansett, RI 02882-1199, U.S.A.

Sherman, K.; Laughlin, T.L., eds. 1992. Large marine ecosystems monitoring workshop report, 13-14 July 1991, Cornell University, Ithaca, New York. *NOAA Tech. Memo. NMFS-F/NEC-*93; 22 p. Available from: National Marine Fisheries Service, 28 Tarzwell Dr., Narragansett, RI 02882-1199, U.S.A.

Steele, J.H. 1988. Scale selection for biodynamic theories. In: Rothschild, B.J., ed. Toward a theory on biological-physical interactions in the world ocean. Dordrecht, The Netherlands: Kluwer Academic Publishers; p. 513-526.

Ulanowicz, R.E. 1992. Ecosystem health in terms of trophic flow networks. In: Costanza, R.; Norton, B.G.; Haskell, B.D., eds. Ecosystem health: new goals for environmental management. Washington, DC: Island Press; p. 189-196.

[a]Copies available from the authors.

Table B3. Definitions of some variables important to the health of marine ecosystems. (Adapted and expanded from: Costanza, R. 1992. Toward an operational definition of ecosystem health. In: Costanza, R.; Norton, B.G.; Haskell, B.D., eds. Ecosystem health: new goals for environmental management. Washington, DC: Island Press; p. 239-256.)

Variable	Definition	Units
	STABILITY	
Homeostasis	Maintenance of a steady state in living organisms by the use of feedback control processes.	
Stable	A system is stable if, and only if, the variables all return to the initial equilibrium following their being perturbed from it. A system is locally stable if this return applies to small perturbations, and globally stable if it applies to all possible perturbations.	Binary
Sustainable	A system that can maintain its structure and function indefinitely. All nonsuccessional (*i.e.*, climax) ecosystems are sustainable, but they may not be stable (see resilience below). Sustainability is a policy goal for economic systems.	Binary
Resilience	1. How fast the variables return toward their equilibrium following a perturbation. Not defined for unstable systems (Pimm 1984). 2. The ability of a system to maintain its structure and patterns of behavior in the face of disturbance (Holling 1986).	
Resistance	The degree to which a variable is changed, following a perturbation.	Nondimensional and continuous
Variability	The variance of population densities over time, or allied measures such as the standard deviation or coefficient of variation (*i.e.*, standard deviation divided by the mean).	
	COMPLEXITY	
Species richness	The number of species in a system.	Integer
Connectance	The number of actual interspecific interactions divided by the possible interspecific interactions.	Dimensionless
Interaction strength	The mean magnitude of interspecific interaction: the size of the effect of one species' density on the growth rate of another species.	
Evenness	The variance of the species' abundance distribution.	
Diversity indices	Measures that combine evenness and richness with a particular weighting for each. One important member of this family is the information theoretic index, H.	Bits
Ascendency	An information theoretic measure that combines the average mutual information (a measure of connectedness) and the total throughput of the system as a scaling factor (see Ulanowicz 1992).	
	OTHER	
Perturbation	A change to a system's inputs or environment beyond the normal range of variation.	Varies
Stress	A perturbation with a negative effect on a system.	
Subsidy	A perturbation with a positive effect on a system.	

Table B4. Indices of vigor, organization, and resilience, derived from various fields, which could be used to index ecosystem health. (From: Costanza, R. 1992. Toward an operational definition of ecosystem health. In: Costanza, R.; Norton, B.G.; Haskell, B.D., eds. Ecosystem health: new goals for environmental management. Washington, DC: Island Press; p. 239-256.)

Component of health	Related concepts	Existing related measures	Field of origin	Probable method of solution
Vigor	Function	Gross primary production, net primary production, & gross ecological production	Ecology	Measurement
	Productivity	Gross national product	Economics	Measurement
	System throughput	Metabolism	Biology	Measurement
Organization	Structure	Diversity index	Ecology analysis	Network
	Biodiversity	Average mutual information predictability	Ecology	Network analysis
Resilience		Scope for growth	Ecology	Simulation modeling
Combinations		Ascendancy	Ecology	

interesting observation made by Rapport is that on the extremes of very "good" health or "very bad" health one can expect agreement among medical practitioners. However, it is within the range of these dramatic changes where the definition of health becomes more subjective. Earlier efforts to address this issue by Rapport *et al.* (1985) resulted in a proposed core group of systems describing structural and functional properties of ecosystems to serve as diagnostic indicators of stress or lack of stress on the system. The role of *indexing* was questioned by Rapport who favors the development of *indicators* and risk assessment methods rather than a single index to characterize the complexity of entire ecosystems.

The discussions on health indices and indicators was followed by a presentation by J. Steele on ecological theory and ecosystem states. If a medical analogy were to be used, he suggested that it would be prudent to consider the importance of the greater number of cold-blooded communities of organisms more directly connected to the physical environment in the ocean in contrast to warm-blooded terrestrial populations. The spatial coupling and responses to ecosystem changes are much more rapid in marine than terrestrial environments. The LMEs are considered by Steele as useful management units that represent systems that have coherence with regard to ecosystem structure and function. The background paper by Steele (1988) that addresses the biophysical scales of concern in examining ecosystem structure and function is available from the author. The question of availability of appropriate spatial and temporal data adequate to make management decisions is of significance. In summary, Steele suggested that state-of-the-art management decision making is a combination of human judgment and expert opinion. However, the decision process can be enhanced with improvements in the quality of data that will allow for greater understanding of the interaction among key components of LMEs. Within this context, decision making is an iterative process that depends on consideration of: (1) the boundary conditions of the system, (2) physiology of the system, (3) public opinion with regard to risk, and (4) risk assessments from the perspective of public trust institutions responsible for ensuring the sustainability of marine resources.

ECOSYSTEM HEALTH INDICES

Among the indices discussed by the participants were five that can be considered as useful measures of ecosystem health: (1) diversity, (2) stability, (3) yields, (4) production, and (5) resilience. The data from which to derive the five indices will be obtained from the LME "core" monitoring surveys recommended by the July 1991 workshop at Cornell University sponsored by NOAA/NMFS (Table B5).

WORKSHOP SUMMARY

The afternoon session focused on discussions of the ecosystem health concept, including measurement parameters (J. Kremer), component models of predator-prey and community-level interactions (M. Fogarty and W. Gabriel), and options for applying ecosystem indices and/or indicators (all participants).

From the discussions kindly summarized by Kremer, several consensus issues emerged:

1. The pursuit of ecosystem health indices and indicators is useful and should be developed further in the LME context.

2. Component models of LMEs incorporating measurements of health indicators are more useful than single, large models that generally have limited prediction capability.

3. Models using health indicators should be developed that are directly applicable to management decisions. They should be simple in construction, allow for interaction with resource managers, and provide sufficient flexibility for testing hypotheses for a range of scenarios.

The topic of emergent properties was discussed for several ecosystems including the species shifts in the Great Lakes in response to excessive fishing mortality and the growing problem of eutrophication in the Baltic Sea. Other topics discussed included the importance of pathological indicators in studies of the Northeast U.S. Shelf Ecosystem and the North Sea Ecosystem for detecting the effects of pollutant stress on fish populations; other indications of pollution stress on the ecosystem are spatial gradient measurements of concentrations of contaminants (*e.g.*, heavy metals, organochlorines, and the nutrients phosphate and nitrate) as reported by F. Thurberg, J. Paul, and A. Robertson.

Participants during the late-afternoon recapping session agreed that it would be useful to develop, as soon as possible, a series of indices or indicators that could be used to compare the changing states of health in LMEs, and to use theses indices or indicators to allow for more quantitative comparison of biofeedback responses to stress among ecosystems.

Although no single series of indices or indicators was found by the workshop participants as universally applicable to LMEs, several candidate components emerged from the discussion (including "integrity," "organization," "resilience," and "vigor" as defined by Costanza in his background paper) that were considered promising for future application. The need for encouraging the collection of decadal time series of empirical information on key ecosystem components and processes was underscored by the participants as a prerequisite to useful comparisons of ecosystem health. In this regard, the results of the July 1991 Cornell University workshop on LME monitoring were considered by the participants as a useful starting point.

In summary, it was concluded by the participants that: (1) the concept of ecosystem health was a valid scientific pursuit; (2) indices or indicators of ecosystem health would provide a useful quantitative means for comparing changing states of LMEs; and (3) through the use of the "comparative method," understanding of ecosystem response to natural and human-induced stress could be advanced.

Table B5. Candidate parameters for the core marine ecosystem monitoring program based on samples, measurements, and observations collected during: (1) transect sampling with undulating oceanographic recorders (UOR) or instrumented continuous plankton recorders (CPR), supplemented by satellite measurements; and (2) systematic bottom trawl and pelagic acoustic surveys. (Adapted from: Sherman, K.; Laughlin, T.L., eds. 1992. Large marine ecosystems monitoring workshop report, 13-14 July 1991, Cornell University, Ithaca, New York. *NOAA Tech. Memo. NMFS-F/NEC-93*; 22 p. Available from: National Marine Fisheries Service, 28 Tarzwell Dr., Narragansett, RI 02882-1199, U.S.A.)

Means of collection	**Parameter to be monitored**
CPR/UOR transect	Chlorophyll fluorescence[a]
	Primary production[a,b]
	Diatom/flagellate ratio[a]
	Zooplankton composition & biomass
	Copepod diversity[a]
	Salinity structure[a]
	Nutrients, including NO_2 as well as NO_3[a]
	Pollution index (*e.g.*, hydrocarbons, sewage)
	Temperature structure[a]
	Stratification index[a]
	Transparency[a]
	Photosynthetically active radiation[a]
	Rainfall or runoff
	Wind strength & direction
Trawl/hydroacoustic survey	Stock assessment & biology
	Distribution
	Abundance
	Length
	Age & growth
	Predator-prey interactions
	Gross pathologic conditions
	Physical oceanography
	Temperature
	Salinity
	Chemical oceanography
	Water samples for nutrients, productivity, & pollutants

[a]From UOR/instrumented CPR sensors.
[b]With a double-flash pump and probe system.

REFERENCES CITED

Costanza, R. 1992. Toward an operational definition of ecosystem health. In: Costanza, R.; Norton, B.G.; Haskell, B.D., eds. Ecosystem health: new goals for environmental management. Washington, DC: Island Press; p. 239-256.

Holling, C.S. 1986. The resilience of terrestrial ecosystems to local surprise and global change. In: Clark, W.C.; Munn, R.E., eds. Sustainable development of the biosphere. London, England: Cambridge University Press; p. 292-317.

Karr, J. 1992. Ecological integrity: strategies for protecting earth's life support system. In: Costanza, R.; Norton, B.G.; Haskell, B.D., eds. Ecosystem health: new goals for environmental management. Washington, DC: Island Press; p. 223-238.

Norton, B.G.; Ulanowicz, R.E. 1992. Scale and biodiversity policy: a hierarchical approach. *AMBIO* 21(3): 244-249.

Pimm, S.L. 1984. The complexity and stability of ecosystems. *Nature* 307: 321-326.

Rapport, D.J. 1992. Defining the practice of clinical ecology. In: Costanza, R.; Norton, B.G.; Haskell, B.D., eds. Ecosystem health: new goals for environmental management. Washington, DC: Island Press; p. 144-156.

Rapport, D.J.; Regier, H.A.; Hutchinson, T.C. 1985. Ecosystem behavior under stress. *Am. Nat.* 125: 617-640.

Sherman, K.; Laughlin, T.L., eds. 1992. Large marine ecosystems monitoring workshop report, 13-14 July 1991, Cornell University, Ithaca, New York. *NOAA Tech. Memo. NMFS-F/NEC*-93; 22 p. Available from: National Marine Fisheries Service, 28 Tarzwell Dr., Narragansett, RI 02882-1199, U.S.A.

Steele, J.H. 1988. Scale selection for biodynamic theories. In: Rothschild, B.J., ed. Toward a theory on biological-physical interactions in the world ocean. Dordrecht, The Netherlands: Kluwer Academic Publishers; p. 513-526.

APPENDIX C

General Summary:

Long Time-Series Analysis and Interpretation in Terrestrial, Marine, and Freshwater Ecosystems, A Summer School at Cornell University, 21 June - 17 July 1992[1]

The time-series school dealt with a variety of concepts, but many of the lectures concerned the description and analysis of marine, freshwater, and terrestrial data sets. A major conclusion from the reviews by the lecturers is that, quite generally, the variance in a data set increases with the length of the record. This can be expressed in various ways: as autocorrelations, reddened power spectra, fractal dimension, and other indices. Thus,the "bad news" is that it is not usually possible to define a baseline and consider deviations from an earlier mean as indices to the consequences of external influences.

The "good news" is that extended data sets, because of the increased variance, provide the basis for greater understanding of the underlying system. Thus, we do not have a law of diminishing returns with increasing record length. Rather, the opposite is true. This can be seen clearly in physical records. For climate, the longer-term scales from the Little Ice Age through the Younger Dryas to the Milankovich cycles all add to our appreciation of present climate issues.

There are fewer examples in biology, but the CPR provides an outstanding illustration of enhanced understanding of physical biological interactions resulting from recent data additions to that long-term record. Comparisons of long series on fish populations from the west and east sides of the North Atlantic broaden our views of the relative roles of physical and human factors in influencing switches in stock abundances in both areas.

A more specific topic was the role of process models in enhancing the understanding of the underlying mechanisms. The Milankovich cycles are an excellent example of the importance of models in explaining time series. The periodicities provided by the space and time scales of ocean eddies are central to the description of plankton dynamics.

We do not have comparably long records in ecology, but many features of existing ecological time series suggest that simple models such as first-order autoregressive formulations are inadequate to capture the essence of the temporal patterns. Thus, process models are an essential component of the analysis and interpretation of ecological time series.

As one example of useful concepts, there was discussion of models that contain multiple equilibria. In particular, bistable systems can describe the essential features of certain terrestrial systems such as the spruce budworm, and of some of the switches in fish stock abundance. By implication, these simple models are a metaphor for more complex switches that can occur naturally in community structure. The existence of alternative states in communities, revealed by the long data sets such as the CPR, necessarily broaden concepts of stability, resilience, or diversity, and can increase the utility of these general ideas.

Because of the positive relations between space and time scales, the study of long time series focuses attention on the larger spatial scales. We had presentations on formal aggregation theory and its practical implications. There can be emergent properties at these larger scales, such as LMEs, and there are real benefits in such aggregation. But the consequent losses of information at smaller scales must be assessed. There is now a body of theory to handle these questions.

Lastly, there was considerable discussion of the use of past data, particularly in time series, to aid in the efficient planning of future surveys.

---

[1] Prepared by J. Steele, 22 July 1992.

APPENDIX D

Tentative Schedule, Organizers, Distinguished Lecturers, Cornell Participants, and Accepted and Confirmed Students:

Long Time-Series Analysis and Interpretation in Terrestrial, Marine, and Freshwater Ecosystems, A Summer School at Cornell University, 21 June - 17 July

---

TENTATIVE SCHEDULE

WEEK 1

Sunday, 21 June

2:00 - 6:00 p.m.	Registration	
8:00 p.m.	Reception	

Monday, 22 June

9:00 - 10:00 a.m.	General Introduction	J. Steele/ T. Powell
10:30 - noon	Time Series: From Epidemics to Evolution	C. Castillo-Chavez
1:30 - 3:00 p.m.	Dynamical Systems I	J. Guckenheimer
3:30 - 5:00 p.m.	Five Student Presentations	
5:00 - 7:00 p.m.	Mixer	

Tuesday, 23 June

9:00 - noon	Analysis of Time Series	A. Solow
2:00 - 3:00 p.m.	LTER Program	J. Hobbie
3:30 - 5:00 p.m.	Five Student Presentations	

Wednesday, 24 June

9:00 - 10:30 a.m.	Arctic Systems (long-term changes)	J. Hobbie
11:00 - noon	Dynamical Systems II	J. Guckenheimer
2:00 - 3:00 p.m.	Ocean's Role in Climate	J. Sarmiento
3:30 - 5:00 p.m.	Five Student Presentations	

Thursday, 25 June

9:00 - noon	Coupled Models of Ocean Circulation and Ecology	J. Sarmiento
2:00 - 3:00 p.m.	Environmental Extinctions	S. Pimm
3:30 - 5:00 p.m.	Five Student Presentations	

Friday, 26 June

9:00 - 10:30 a.m.	Long-term Population Variability	S. Pimm
11:00 - noon	Dynamical Systems III	J. Guckenheimer
2:00 - 3:30 p.m.	Working Groups Assigned	T. Powell

TENTATIVE SCHEDULE

WEEK 2

Monday, 29 June

9:00 - noon	Ocean's Role in Climate Change	W. Broecker
2:00 - 3:00 p.m.	Global Greening--Taking Place?	W. Broecker
3:30 -	Groups	

Tuesday, 30 June

9:00 - noon	Reconstruction of Past Vegetation and Climates from Pollen Data	T. Webb
2:00 - 3:00 p.m.	Physical/Biological Coupling: Comparison of Time Scales	J. Steele
3:30 -	Groups	

Wednesday, 1 July

9:00 - noon	How Long Is Long?	A. Solow
2:00 - 3:00 p.m.	Potential Impact of Orbital Forcing on Evolutionary Developments	T. Webb
3:30 -	Groups	

Thursday, 2 July

9:00 - 10:30 a.m.	Long-term Physical/Plankton Relationship	R. Dickson
11:00 - noon	Visualizing Marine Data	A. Michaels
3:30 -	Groups	

Friday, 3 July

9:00 - 10:30 a.m.	Long-term Ocean Flux Studies	A. Michaels
11:00 - noon	The Great Salinity Anomaly	R. Dickson
2:00 - 3:00 p.m.	Time-Series Techniques	T. Powell
3:30 -	General Discussion	

Saturday, 4 July Party

WEEK 3

Monday, 6 July

9:00 - noon	How Do Ecosystems at the Land-Sea Interface Work?	J. Cloern
2:00 - 3:00 p.m.	Disturbance, Fire, and Giant Sequoia	T. Stohlgren

Tuesday, 7 July

9:00 - noon	Research in the Rockies: Hearing Ecotones?	T. Stohlgren
2:00 - 3:00 p.m.	Central Pacific Study: Short or Not?	E. Venrick

Wednesday, 8 July

9:00 - noon	California Current: Forty Years On	E. Venrick
2:00 - 3:00 p.m.	How Do Human Impacts Confound Ecosystem Variability?	J. Cloern

TENTATIVE SCHEDULE

Thursday, 9 July

9:00 - noon	Marine and Terrestrial Time Series	J. Magnuson
2:00 - 3:00 p.m.	Handling Heterogeneous Data (?)	J. Vande Castle

Friday, 10 July

9:00 - 10:30 a.m.	Exploiting Fortuitous Records	J. Magnuson
11:00 - noon	Time Scales in LTER Programs	J. Vande Castle
2:00 - 4:00 p.m.	General Discussion	T. Powell

WEEK 4[a]

Monday, 13 July

9:00 - noon	Time Scales for Terrestrial Management	D. Pimentel
2:00 - 3:00 p.m.	Large Marine Ecosystem Management	K. Sherman

Tuesday, 14 July

9:00 - noon	Time Scales: Ecology *vs.* Evolution	S. Levin

Wednesday, 15 July

9:00 - noon	Commentaries	C. Castillo-Chavez *et al.*

Thursday, 16 July

All Day	Working Groups	

Friday, 17 July

All Day	Student Presentations	T. Powell
Evening	Party	

[a] Most of the time this week will be open for working groups, presentations, and discussions.

ORGANIZERS

Dr. Carlos Castillo-Chavez
Biometrics Unit, Warren Hall
Cornell University
Ithaca, NY 14853
Phone: (607) 255-5488
Fax: (607) 255-4698
E-mail: p56y@cornella.bitnet

Dr. John Guckenheimer
Center for Applied Mathematics
Cornell University, 305 Sage Hall
Ithaca, NY 14853
Phone: (607) 255-4335
Fax: (607) 255-9860
E-mail: gucken@macomb.tn. cornell.edu

Dr. Simon Levin
Ecology and Systematics, Corson Hall
Cornell University
Ithaca, NY 14853
Phone: (607) 255-4617
Fax: (607) 255-8088
E-mail: ihmy@cornellf.bitnet

Dr. Thomas W. Powell
Division of Environmental Sciences
University of California
Davis, CA 95616
Phone: (916) 752-1180 (Davis)
or (510) 559-8937 (Berkeley, home office)
Fax: (916) 752-3350
E-mail: t.powell@omnet.nasa.gov (best) or
tmpowell@ucdavis.edu

Dr. John H. Steele
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
Phone: (508) 457-2000 x2220
Fax: (508) 457-2184
E-mail: j.steele@omnet.nasa.gov

DISTINGUISHED LECTURERS

Dr. Wallace Broecker
Lamont-Doherty Geological Observatory
Palisades, NY 10964
U.S.A.

Dr. James Cloern
Water Resources Division
U.S. Geological Survey
345 Middlefield Road, MS-496
Menlo Park, CA 95025
U.S.A.

Dr. Robert R. Dickson
Fisheries Laboratory
Ministry of Agriculture, Fisheries,
and Food
Lowestoft, Suffolk NR33 OHT
ENGLAND
Phone: 0502-562244, Ext. 4282
Fax: 0502-513865

Dr. John Hobbie
Ecosystem Center
Marine Biological Laboratory
Woods Hole, MA 02543
U.S.A.

Dr. Mimi Koehl
Department of Integrative Biology
University of California-Berkeley, Z001
Berkeley, CA 94720
U.S.A.

Dr. John J. Magnuson
Center for Liminology
University of Wisconsin
680 North Park Street
Madison, WI 53706
U.S.A.

Dr. Anthony F. Michaels
Bermuda Biological Station
17 Biological Lane
Ferry Reach GE 01
BERMUDA

Dr. David Pimentel
Department of Entomology
6126 Comstock Hall
Cornell University
Ithaca, NY 14853-0999
U.S.A.
Fax: (607) 255-3075
Prof. Stuart L. Pimm
Department of Zoology, M313 Walters
The University of Tennessee
Knoxville, TN 37996-0810
U.S.A.
Phone: (615) 974-1981
Fax: (615) 974-0978

Dr. Jorge Sarmiento
Geophysical Fluid Dynamics Program
Princeton University
Princeton, NJ 08542
U.S.A.
Phone: (609) 258-6585

Dr. Kenneth Sherman
Narragansett Laboratory
National Marine Fisheries Service
28 Tarzwell Drive
Narragansett, RI 02882
U.S.A.
Phone: (401) 782-3200

Dr. Andrew Solow
Marine Policy Center
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
U.S.A.
Phone: (508) 548-1400

Dr. Thomas Stohlgren
National Park Service
Natural Resource Ecology Laboratory
Colorado State University
Fort Collins, CO 80523
U.S.A.
Phone: (303) 491-1980

Dr. John R. Vande Castle
Long-term Ecological Research Network
College of Forest Resources
University of Washington, AR-10
Seattle, WA 98195
U.S.A.
Phone: (206) 543-6249
Fax: (206) 685-0790

Dr. Elizabeth Venrick
Marine Life Research Group, A-001
Scripps Institution of Oceanography
9500 Gilman Drive
LaJolla, CA 92093-0227
U.S.A.

Prof. Thompson Webb, III
Department of Geological Sciences
Brown University
Providence, RI 02912-1846
U.S.A.
Phone: (401) 863-3128

CORNELL PARTICIPANTS

Douglas Deutschman
Ecology and Systematics
339 Corson Hall
Cornell University
Ithaca, NY 14853
U.S.A.
Phone: (607) 255-3498

Jonathan Dushoff
Ecology and Systematics
339 Corson Hall
Cornell University
Ithaca, NY 14853
U.S.A.
Phone: (607) 255-3498

Karin Limburg
Ecology and Systematics
339 Corson Hall
Cornell University
Ithaca, NY 14853
U.S.A.
Phone: (607) 255-3498

Jianguo Wu
Theory Center, 520 Engineering
Theory Center Building
Cornell University
Ithaca, NY 14853
U.S.A.
Phone: (607) 254-8695

Jorge Velasco-Hernandez
Biometrics Unit
322 Warren Hall
Cornell University
Ithaca, NY 14853
U.S.A.
Phone: (607) 255-8103

ACCEPTED AND CONFIRMED STUDENTS

Put O. Ang, Jr.
Fisheries Research Laboratory
Department of Fisheries and Oceans
P.O. Box 550
Halifax, NS B3J 2S7
CANADA
Phone: (902) 426-7444
Fax: (902) 426-3479

Arturo H. Arino
Department of Ecology
Faculty of Sciences
University of Navarra
E-31080 Pamplona
SPAIN
Phone: 3448-252150
Fax: 3448-175500

Alfredo Ascioti
Biology Department
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
Phone: (508) 548-1400, Ext. 3398
Fax: (508) 457-2169

Tormod V. Burkey
Department of Ecology and
Evolutionary Biology
Guyot Hall
Princeton University
Princeton, NJ 08544-1003
U.S.A.
Phone: (609) 258-1712
Fax: (609) 258-1334

Bernard Cazelles
Unite de Recherches
Biomathematiques et Biostatistiques
INSERM U263
Universite Paris VII, Tour 53
75 251 Paris, Cedex 5
FRANCE
Phone: 331-43-25-92-26
Fax: 331-43-26-38-30

Dr. Michael Dodd
Biology Department, Walton Hall
The Open University
Milton Keynes MK7 6AA
UNITED KINGDOM
Phone: 0908-652501
Fax: 0908-654167

Jean-Marc Guarini
Laboratoire d'Oceanographie
Biologique Faculte des Sciences
Universite de Bretagne Occidentale
6 Avenue Le Gorgeu
29287 Brest Cedex
FRANCE
Phone: 98-31-62-65
Fax: 98-31-63-11

Patricia Himschoot
Biometrics Unit, 322 Warren Hall
College of Agriculture and Life Sciences
Cornell University
Ithaca, NY 14853
Phone: (607) 255-5488

Prof. Mitchel McClaran
School of Renewable Natural Resources
325 Biological Sciences East Building
College of Agriculture
University of Arizona
Tucson, AZ 85721
U.S.A.
Phone: (602) 621-1673
Fax: (602) 621-8801

Frederic Menard
Departement de Biostatistique
et Informatique Medicale
Hoptial Saint-Louis
1, av. C. Vellfaux
75475 Paris, Cedex 10
FRANCE
Phone: 331-42-49-97-42
Fax: 331-42-49-97-45

David Shafer
Division of Biological Oceanography
School of Ocean and Earth
Science and Technology
1000 Pope Road, MSB #632
University of Hawaii
Honolulu, HI 96822
U.S.A.
Phone: (808) 956-7498
Fax: (808) 956-9225

Konstantions I. Stergiou
Fisheries Laboratory
National Centre for Marine Research
Agios Kosmas, Hellinikon
Athens 16604
GREECE
Phone: 301-98-21-354
Fax: 301-98-33-095

Jason Stockwell
Department of Zoology
Erindale College
University of Toronto in Mississauga
3359 Mississauga Road North
Mississauga, ON L5L 1C6
CANADA
Phone: (416) 828-3987
Fax: (416) 828-5328

Susan Warner
Department of Biology
208 Erwin W. Mueller Laboratory
Eberly College of Science
The Pennsylvania State University
University Park, PA 16802
U.S.A.
Phone: (814) 865-2461
Fax: (814) 865-9131

Xiangming Xiao
Department of Range Science
Colorado State University
Fort Collins, CO 80526
U.S.A.
Phone: (303) 491-5269
Fax: (303) 491-7895

APPENDIX E

Excerpt from a Keynote Address by the NOAA Under Secretary for Oceans and Atmosphere

Given at the Symposium on the Northeast Ecosystem: Stress, Migration, and Sustainability, 12-15 August 1991, University of Rhode Island, Narragansett, Rhode Island

"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."

---

[1] Complete text is given in: Sherman, K.; Jaworski, N.; Smayda, T., editors. 1992. 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. *NOAA Tech. Memo. NMFS-F/NEC-94*; 30 p. Available from: National Marine Fisheries Service, 28 Tarzwell Dr., Narragansett, RI 02882-1199, U.S.A.