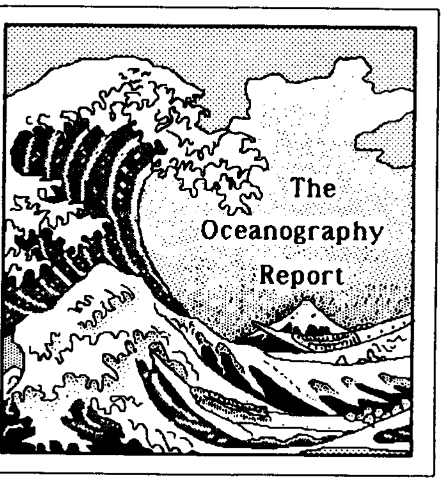
The Oceanography Report



The Oceanography Report: *The focal point for physical, chemical, geological, and biological oceanographers.*

Editor: Robin D. Muench, SAIC, 13400B Northrup Way, Suite 36, Bellevue, WA 98005

GLOBEC

Global Ecosystem Dynamics

PAGES 82–84

Objective: To understand ocean ecosystem dynamics and how they are influenced by physical processes so that the predictability of population fluctuations in a changing global climate can be assessed.

Though it is likely that human activity plays a significant role in marine population fluctuations, determination of the relative importance of humans and nature in these changes has not, to date, been possible. Many correlations between population variability and associated biological and physical variables have been reported. However, these correlations are generally unsuccessful predictors of population variability, and, hence, of limited usefulness.

Progress toward prediction requires a better understanding of the fundamental causes and effects underpinning the linkages between natural and anthropogenic driving forces and population fluctuations. Of considerable scientific import, the problem is also critical to society's long-term agenda. As a consequence of having available only a correlative understanding of the fluctuations in marine populations, policy formation in global fisheries, climate effects, and pollution can be addressed with neither confidence nor vigor.

To address this problem, some 90 scientists representing physical, biological, and chemical oceanography gathered in April 1988 in Wintergreen, Va., at a workshop on Global Ecosystem Dynamics. Interdisciplinary working groups were formed to consider the results of earlier GLOBEC workshops on oceanography and modeling, benthos, food chain, genetics, and sampling technologies. The first section of this report contains an introduction that summarizes the Wintergreen discussions and recommendations. Subsequent sections include reports of the initial workshops and reports of the Wintergreen interdisciplinary working groups.

At Wintergreen the scientists concluded that:

- fundamental knowledge of the interrelationships among physical processes, population dynamics, and other relevant phenomena could be materially improved;
- new approaches are available to energize significant increases in knowledge; and
- such a program should begin immediately.

The fundamental ideas expressed at the Wintergreen meeting were that advances in understanding the coupling of natural and anthropogenic effects on the dynamics of populations would depend upon bringing together the fields of physical oceanography and population dynamics and biology, and that past impediments to this interdisciplinary activity could be eliminated because it is now possible to end the decades of undersampling of biological and physical phenomena in the world ocean and thereby create a new suite of empirical measurements that will accelerate theoretical development. The interdisciplinary unity initiated at Wintergreen will make a significant contribution to our understanding of the total biological productivity of the sea and set the stage for developing more effective environmental policies than those previously implemented regarding the use of the sea.

The workshop participants agreed that surprisingly little is known about how physical and biological factors fit together in the puzzle of marine ecosystem variability. A key problem is that large gaps in knowledge occlude a comprehensive understanding of biological prediction even though some elements of the puzzle are relatively well known. For example, while primary production and mesoscale (on the order of 100 days and 100 kilometers) physics are relatively well known, little is known about zooplankton production and smaller scale physics.

The unevenness of knowledge constrains addressing the true complexity of the biodynamic system. Consider the consequences of the fact that the dynamics and population biology of the copepods, most abundant of the large zooplankton in the world ocean, is poorly known. How can fluctuations in primary production be explained when the cause of fluctuations in animals that feed upon or contribute to nutrients for primary production are not well understood? How can we understand the dynamics of secondary production or of fish larvae (for which various copepods can be food competitors or predators) with a limited understanding of the dynamics and biology of copepods? More generally, how can variations in production be understood when population-dynamic nonlinearities are not considered? How can population dynamic variability in its own right be understood if a major source of this variability, the effects of physical forcing, has not been taken into account? And, finally, how can the relative importance of anthropogenic and natural factors be differentiated without an understanding of the functioning of major components of the ecosystem?

The workshop participants articulated the following new directions as GLOBEC guidelines:

- concentrate on first principles rather than correlative mechanisms,
- enhance a physical-biological partnership,
- take account of advances in population genetics and related biotechnology, and
- mount a major effort to further develop and fully utilize both advanced sampling technology and techniques for rapid identification of plankton.

Concentration on First Principles

A "first principles" understanding of how important processes at the level of individual organisms control population abundance requires that the interactions among ocean physics, trophodynamics (food chain relationships) of plankton populations, and the interrelationships among the individual populations of benthic and water column organisms be understood at the most fundamental and mechanistic levels. Special emphasis needs to be given to assessing the little-studied roles of ocean physics in feeding success, growth rates, reproductive output, mortality rates including losses to predators, and recruitment.

These results are necessary components of basic models of the often nonlinear and complex processes by which events at the level of the individual organism dictate the magnitude and direction of population change. We believe that through studying dynamic processes from first principles we will gain a much improved understanding of the way that biological production integrates population dynamics and the dependence of population dynamics on trophodynamics.

Enhancing the Physical-Biological Partnership

A major impediment to oceanographers interested in understanding population regulation of ocean organisms is a lack of physical data in appropriate times and places and on scales matching the biological processes. GLOBEC will bring physical and biological scientists together to facilitate a rigorous coupling between physics and population dynamics and biology. Particular emphasis will be placed on understanding mesoscale coastal circulation processes and fine-scale turbulence at the levels of an individual organism.

Despite the tremendous, economically important fluctuations in coastal populations, relatively little attention has been given to understanding physical circulation processes in the coastal zone. Without a greatly improved understanding of advective processes including some reconciliation of Eulerian (properties of flow measured at a fixed location) and Lagrangian (relating to the properties of freely drifting particles) data, biologists can never solve critical problems in transport, mixing, and retention of planktonic forms. Similarly, the small-scale physics of water motion and turbulence are not well enough known to allow accurate biological understanding of how physical events at the scale of the individual affect critical processes such as feeding success, predator-prey interaction, and larval settlement.

Population Genetics and Related Biotechnology

While population dynamics (in the classic sense) is about the way populations change in "real time," population genetics is the study of the way populations change in terms of the genetic constituency of their individual members. GLOBEC will incorporate modern methods of molecular genetics both to determine the importance of genotypic responses to physical and other driving forces and to exploit molecular tools for marking individuals, inferring physical mixing processes, and other activities.

Previous research on population change in marine organisms has treated the species as a unit of study, ignoring the importance of intraspecific variation. Because of observed high levels of genetic variability of marine organisms, it is impossible to reach a fundamental understanding of the processes driving population fluctuation, particularly over longer time scales, without assembling the role of natural selection and the response of different genotypes to the environment. The genetic understanding will be particularly vital for predicting the biological response to potential climate change, either local or global.

Sampling Technology and Techniques

The oceans are notoriously undersampled. In part, this is due to the simple magnitude of the effort required and the difficulty of introducing human observers into the environment for long periods with the ability to move quickly from place to place. In part, this has also been due to a lag in the introduction of high technology to the development of sensors for some of the more important ocean parameters, particularly those involving the living resources of the sea. Too often, technology available from other fields has tended to determine the kinds of questions that are asked, rather than questions setting the goals for technological developments.

While intuitive insight from individual scientists is always essential, progress can be significantly accelerated by the collection of data for the dual purposes of testing hypotheses and for adaptation of theory. For GLOBEC studies, it will be essential to collect, process, and synthesize oceanographic data on scales that resolve biological-physical interactions.

Substantive advances have been made over last decade in our ability to collect and analyze data in physical oceanography. For some of the important parameters of ocean physics, particularly for mesoscale parameters, the problem of undersampling the ocean is at least in part being rectified by access to various tools for remote sensing, some satellite-based, some deployed from aircraft, and others developed from low-frequency acoustic technology. Large-scale sampling programs are also adding to our base of knowledge of physics and ocean color.

A new view of the ocean is evolving from these improved sampling capabilities, especially those related to the mesoscale phenomena. This view is providing details required for an improvement in biological insight at the primary production level, but we also need a capability to sample the animal biota at comparable scales and with comparable densities as those now available for ocean color and some key physical oceanographic variables. In both the physical and the biological disciplines, extensions of improvements in sampling from the mesoscale into the fine- and micro-scale environments are needed.

The next generation of scientific issues to be addressed in both the near seabed (benthic) and water column (pelagic) environments demand the development of new sampling technology. In the benthic boundary layer, the details of water circulation may affect the distribution and availability of food and the dispersal of reproductive products. The validation, and to some degree, the development of advanced theory to describe the physics as well as the ecology of this critical habitat will be affected by our success in adapting existing high-technology sensors and new instruments to this special environment.

Pelagic ecology (life-history stages of benthic organisms are often found in the pelagic environment) differs in emphasis from much of the rest of ecology because the living space is three-dimensional. Pelagic organisms live in a fluid system. Distributions are continuously affected by fluid motion, modulated to varying degrees by organism motility.

Plankton are unicellular plants, bacteria, protozoa, and small animals with limited or no ability to control their movement. Hence, their distribution is dependent on motions of the water. Those called holoplankton spend their entire life cycles as plankton, and meroplankton spend part of their life cycles, usually the early stages, as plankton. Benthic organisms generally live on the bottom as adults but may in early life stages live pelagically in the water column as plankton. The plankton are in fact defined by limited ability to control their own distribution independent of fluid motions. Pelagic ecologists, especially those studying plankton, must be able to sample organisms on the several scales of motion of the water. Although fish are motile enough to control their distributions as adults, their eggs and larvae are planktonic, and many species depend on phytoplankton and zooplankton for food; therefore study on similar scales is required.

It would be convenient if fluid motion meant that plankton were evenly or randomly distributed by mixing, but we have excellent evidence that this is not the case. Plankton are "patchy" on every scale yet sampled. Consequently many samples are needed to describe the distribution on even one scale; yet the interrelations between events and distributions on different scales are critical and require advanced designs for intensive sampling.

Some recent advances in the understanding of ocean physics result from the development and deployment of instruments which, while sacrificing an order of magnitude in precision, have permitted either several orders of magnitude greater density of measurement (i.e., fine- or micro-scale resolution) or more nearly synoptic, large-scale coverage (e.g., acoustic tomography, satellite remote sensing). In the best studies these techniques will be used in concert, so that the relations among scales can be determined.

To meet GLOBEC objectives in plankton ecology, we need comparable advances in the application of various new, high-technology sensors to studies of the geographic and temporal distribution of plankton so we can relate distributions to physical processes on several scales from the same study. Major advances in technology applied to the sampling of plankton and related physical parameters are mandatory to unravel the complex relationships controlling plankton, and, ultimately, fisheries ecology in an era of global change in climate.

During the last decade progress has been made in developing and adapting technology for the determination of small-scale physics, nutrients and distributions of plankton and nekton (free-swimming animals). The next step involves both the adaptation of existing laboratory techniques from other disciplines and the development of entirely new technology. Existing technologies now in prototype configurations must be adapted to routine use at sea, and instrumentation developed for shipboard deployment must be adapted to drifting, moored, and expendable instruments.

Advances in the use of silhouette photography and image identification offers the potential to abate the tedious and costly processing of net and pump samples, allowing scientists to concentrate more effort on analysis and interpretation and less on the mechanics of sorting and classifying. High-speed photography now allows observation of individuals and their feeding and swimming behavior in detail in the laboratory. Extrapolation of this capability from the laboratory to the field is technically feasible and is a logical extension of current technology.

Acoustic techniques, used since the 1930s to study nekton, have more recently been applied to smaller and smaller zooplankton. Several international efforts are now under way in which scientists are determining the distributions of larval fish and even the naupliar (very early) stages of zooplankton. Some of these techniques, for example, the multifrequency approach, offer meter-scale resolutions as well as a capability of size discrimination over long periods.

In one of the most exciting recent developments, many techniques are evolving from biotechnology with direct applicability in the marine environment. Genetic tools can play an important role in the identification and description of taxonomic units, including species, subspecies, populations, and demes. A few examples of these techniques include the use of mitochondrial DNA to identify the geographic origin of individual organisms and the use of RNA sequencing, immunochemical techniques, and polyclonal and monoclonal antibodies for the identification of different species. Additional techniques from this relatively new science can be adapted to study the physiological, nutritional, developmental, and reproductive status of marine organisms toward describing the mechanisms that drive recruitment processes in the sea.

Integrated combinations of new and old technologies, such as simultaneous use of optical and acoustic beams in both the forward and backscatter modes, are potentially synergistic. Likewise, the newly discovered principles of expert systems, artificial intelligence, and neural net computation can be combined with the great computing power now available.

Satellite-borne remote sensors allow placement of local survey areas in the context of broad-area sea surface temperature, ocean color (phytoplankton), wind stress, and general circulation patterns. With each new generation, these sensors provide improved data and increased resolution.

We believe we now have the equipment available to fortify existing theories, end undersampling of the marine environment, generate new theory, and forge new directions of research. What we lack is the general availability of equipment so that the best of several technologies can be focused on specific, complex problems.

Potential Areas of Investigation

Among the important and exciting areas of investigation in Global Ecosystem Dynamics are:

Linkage Among Scales

This problem is exquisitely complex because among populations mortality rates and organism sizes vary over many orders of magnitude. At the same time, individual populations interact with with each other and with spatial and temporal physical processes varying on time and space scales that themselves vary over many orders of magnitude. The spatial scales associated with important scientific issues in ocean sciences range from the sizes of individual plankters to global dimensions. Time scales of importance range from seconds to centuries. In many cases, the most important events, for example, those which have the most effect on society, are unpredictably episodic. Such episodes—a major storm or an El Niño—demand that observations be closely spaced and carried out continuously between, as well as during, transient phenomena in order not to miss events that are relatively rare but result in dramatic changes in productivity. To observe oceanographic phenomena on appropriate scales with adequate temporal and spatial resolution, at reasonable cost, continues to be one of the foremost challenges facing the modern oceanographer.

Dynamics of Individual Organisms

The dynamics of individual organisms reflects the population's capability to respond to environmental change, a factor evidently important in considering long-term population fluctuation. From a trophodynamic and short-term population dynamics point of view, the response of an organism to its immediate environment determines how it will move, feed, and reproduce.

The effects of turbulent motions in the water column and near the seabed are critical to understanding how animals adapt to their surroundings. Variations in turbulence and mixing, particularly due to extreme events such as storms, can produce large changes in distribution of the organisms and their food. The ability to integrate the consequences of such sporadic occurrences requires detailed study of this small-scale environment and of the theories that will relate the organism's response to the physical changes.

Understanding the microscale temporal and spatial physical interactions is a step toward understanding the behavior of the entire system. This might be thought of as a building block approach. The building block approach starting from the most fundamental properties may ameliorate inability to explain changes in population abundance or structure resulting from uncritical aggregation of phenomena and processes masking the nature of causality. Among other things, simple experiments and models that will more realistically incorporate the physical environment into study of predator-prey interaction will lend important insight into the dynamics of individual organisms.

Key Physical Processes

Recent advances in both remote and in situ sensing have improved our capacity to observe details of the physical environment. The advanced methods reveal ubiquitous features in the oceans characterized by pronounced spatial changes in temperature, salinity, and density. These features, known by such names as fronts, rings, squirts, and ice edge zones, arise from different dynamical causes, but many are persistent in their general location or exhibit relatively regular seasonal patterns. Satellite color imagery shows regions of considerable temporal and spatial variability in the distribution of chlorophyll. This variability is associated with physical processes, and an important next step for GLOBEC is to push forward the relation between chlorophyll and primary production to encompass the relations among chlorophyll, primary production, and secondary production. Key physical processes involving these linkages may be both large and small in comparison to the natural length and time scales of the biological population under consideration. The processes generally will be confined to the upper ocean, a region where physicists recently have made significant advances in understanding the dynamics of the ocean.

To focus attention, 4 testable hypotheses were advanced at the workshop:

- Anomalies of air-sea interaction are responsible for basin-scale anomalies in primary and secondary production.
- Productivity on continental margins is directly related to cross-shelf exchange.
- Secondary productivity is concentrated in frontal regions where physical events drive the variability of the secondary production.
- Submesoscale physical processes control plankton species patchiness and, consequently, primary and secondary production.

The efficient study of these critical hypotheses should involve concurrent modeling and field studies. The ecological organization of the models should probably be at the population level. Modeling will be required to parameterize important processes occurring at time and space scales both large and small compared to those of the population. Model complexity might productively be limited to the level of age structure to aid in understanding.

We believe there exists within the oceanographic community a sufficient store of disciplinary knowledge to address interdisciplinary questions of the interaction of the marine biosphere and its physical environment. Such an effort could make a great advance in our understanding of the marine ecosystem.

Continental Shelves

The continental shelf is a highly productive oceanic region exhibiting nearly all important oceanic processes from microscale phenomena, such as the effect of turbulence on zooplankton feeding, to macroscale recruitment variations on annual and longer time scales. There are specific questions concerning how the planktonic larvae of benthic animals are transported, how this affects recruitment, and how physical processes, such as frontal development, influence the feeding and predation environment of a species. An ambitious research program is proposed for this area encompassing laboratory, observational, and modeling efforts.

The core of the new approach involves a real-time physical model that would, in principal, give an accurate representation of the flow field, hence the position of drifting particles (plankton). This model should include biological submodels which could be used to predict the locations of vertically migrating organisms. The model would be an integral part of a field study to sample the plankton and evaluate their physiological state. Such a descriptive-predictive system for the continental shelf is as yet undeveloped and would represent a major effort on the part of physical and biological oceanographers. The new ability to predict the location of plankton would, however, be a major step forward and could ultimately lead to an ability to understand and predict recruitment of organisms. The shelves provide important sites where intensive pilot studies of biological and physical interactions could be undertaken with the objective of preparing the design for full global coverage to be compatible with WOCE (World Ocean Circulation Experiment) and GOFS (Global Ocean Flux Study).

Ecological Mechanisms for Population Persistence

The notion of population persistence has its roots in parts of ecological theory that describe in mathematical equations the trajectory of an individual or interacting populations. The properties of these equations are such that they might exhibit global or local stability as well as damped and undamped responses to perturbation. Although there is relatively little work on the problem, it is plausible that various physical features of the seas affect the dynamic behavior predicted by a particular equation (or set of equations), that is, the stability and instability and the fluctuation of populations. On the basis of both current technologies and theoretical understanding of the ocean, we believe that great strides in our understanding of the population dynamics of marine organisms can be made by integrated physical-biological studies of population dynamics at physical discontinuities in the ocean.

Theory and Modeling

Scientific progress is facilitated by a strong foundation in theory and modeling. Because GLOBEC involves integration and coordination of diverse fields, these activities become particularly important as ways to communicate ideas on the structure of the ecosystem and to organize priorities in field programs. Appropriate theoretical and modeling initiatives include:

- developing theory on the relations between organisms, populations, and communities in the context of physical forcing;
- constructing models that can be used to predict changes and fluctuations in ecosystems;
- simulating field-related programs so gaps in field-derived knowledge can be better identified; and
- designing sampling regimes and required technologies.

Of considerable importance from both theoretical and modeling points of view is the distinction between a taxonomic and taxonomic categorization of biomass. Approaches important to the GLOBEC mission include biophysical models of feeding behavior in turbulent environments, particle transport models related to the role of advection in recruitment studies, and the coupling of regional circulation models to biological models to explain or predict biological distribution and dynamics.

GLOBEC and Other International Initiatives

The status of international initiatives is changing continually so the current situation must always be taken into account. GLOBEC should begin as an international program taking advantage of multilateral and unilateral activities related to GLOBEC. Linkages should be made, for example, with the International Council for the Exploration of the Sea (ICES) and the Intergovernmental Oceanographic Commission (IOC) and with national programs such as those of Norway, Denmark, France, and Japan.

The October 1987 report of the U.S. Global Ocean Science Interagency Working Group identifies GLOBEC and GOFS (Global Ocean Flux Study) as the two components of the Global Ecosystems and Productivity Processes initiative. The programs complement each other and should be closely coordinated.

GLOBEC should also coordinate activities with other National Science Foundation (NSF)-led initiatives such as Land/Sea Interaction and WOCE. WOCE studies will provide a large-scale context in which GLOBEC efforts can be planned and implemented. Office of Naval Research (ONR), National Oceanic and Atmospheric Administration (NOAA), National Aeronautics and Space Administration (NASA), and Department of Energy (DOE) are planning programs relevant to GLOBEC objectives. These include an ONR focus on biological-physical interactions in a number of Oceanic Biology research initiatives and the NOAA fisheries research programs that provide biological and environmental data.

Why a Program is Necessary and Why It Should Begin Immediately

The need for global environmental policies is outstripping society's capability to make decisions that shape human activity or set in motion policies that prepare for environmental or resource change. One reason for the sluggishness in policy development is that scenarios for global change are uncertain and it is difficult to separate natural components of change from those that are anthropogenic. If a particular dynamic was naturally induced, then policies could be developed to prepare for the consequences. On the other hand, if a particular dynamic has its roots in human activity, then that activity could be altered, at least in principle.

The GLOBEC workshop at Wintergreen focused upon these issues. By developing a materially improved understanding of natural variation in the sea, the way will be paved not only to better understanding of a significant portion of the Earth system but also to developing a policy-relevant understanding of the fate and effect of pollutants, the sources and sinks and variability in carbon dioxide in the sea, the effects of sea-level rise on coastal fish and shellfish resources, and future forecasts useful for resource management in both the developed and developing world. GLOBEC should be quickly implemented; an understanding of the marine ecosystem that is scientifically and societally relevant and a capability to link with other international and national coherent programs are at stake.

Acknowledgments

The Wintergreen workshop was supported by NSF jointly with ONR, NASA, and NOAA under NSF Grant #OCE 87–19593 to the Joint Oceanographic Institution, Inc. Vicky Cullen, Woods Hole Oceanographic Institution, served as editor.

Editorial Committee

Brian J. Rothschild (Chair), University of Maryland, Solomons; Kenneth H. Brink, Woods Hole Oceanographic Institution, Mass,; Tommy D. Dickey, University of Southern California, Los Angeles; David M. Farmer, Institute of Ocean Sciences, Sidney, British Columbia; D. Van Holliday, Tracor, San Diego, Calif.; Peter A. Jumars, University of Washington, Seattle; Michael M. Mullin, Scripps Institution of Oceanography, La Jolla, Calif; Peter B. Ortner, NOAA, Atlantic Oceanographic and Meteorological Laboratories, Miami, Fla.; Thomas R. Osborn, Chesapeake Bay Institute, Johns Hopkins University, Baltimore, Md.; Charles H. Peterson, University of North Carolina at Morehead City; Dennis A. Powers, Johns Hopkins University, Baltimore, Md.; Michael R. Roman, University of Maryland, Cambridge.

News & Announcements

Oceanographers Form New Scientific Society

PAGE 85

1988 saw the formation of a new scientific society for oceanographers, The Oceanography Society. Modeled on other disciplinary societies like the American Meteorological Society and the American Astronomical Society, the goals of the Oceanography Society are to strengthen communication among oceanographers, to develop and disseminate knowledge of oceanography, and to provide recognition of the achievements of oceanographers. Aimed at serving all disciplines of ocean sciences including applications and technology, the new society had more than 1800 members by the end of the past year.

The Oceanography Society has come about because of the recognition by oceanographers of the need for a body to focus on oceanographic issues, which are becoming more and more important for our nation. Oceanography as a field of science has been immensely helped by publications, meetings and other efforts by supporting societies such as the Ocean Sciences Section of the American Geophysical Union, the American Society of Limnology and Oceanography, the Marine Technology Society, and the American Meteorological Society. At the same time, there is recognition that oceanography needs a voice of its own, and that a society of ocean scientists can fruitfully exist alongside a national union representing the broader interests of all of the geophysical sciences.

The Oceanography Society plans to work closely with existing societies. The society will participate in the AGU initiative to build consensus among scientific societies with interest in Earth sciences in general. This joint effort by all groups will be essential if the Earth sciences community is to take advantage of the general public interest in global environmental change on planet Earth.

The Oceanography Society will be international in scope and will work closely with existing societies focused on oceanography, such as the Challenger Society in the United Kingdom. The establishment of national chapters of the society in those countries that have no such structure in place already is under consideration. Interim officers D. James Baker (Joint Oceanographic Institute, Washington, D.C.), president; Neil Andersen (National Science Foundation, Washington, D.C.), treasurer; Mel Briscoe (Office of Naval Research, Arlington, Va.), secretary; and David Brooks (Texas A&M University, College Station, Tex.), publications editor, and an interim council consisting of the officers and Leonard Johnson (Office of Naval Research, Arlington), Christopher N.K. Mooers (Institute for Naval Oceanography, Stennis Space Center, Miss.), David Schink (Texas A&M University, College Station), and W. Stanley Wilson (National Aeronautics and Space Administration, Washington, D.C.) are guiding society activities until elections are held in spring 1989.