U. S. Commission on Ocean Policy
Northeast Regional Meeting
23 July, 2002

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In numerous reports and forums such as this one, the case has been made for the basic elements of observation and prediction needed for the Integrated and Sustained Ocean Observing System IOOS. A system is being developed to greatly increase the spatial and temporal resolution of observations and predictions of environmental change, and to explore patterns and processes of life in the ocean. The initial system is weighted in favor of variables readily and continuously measurable in time over vast areas and volumes of ocean. The resulting global perspective is an essential step in human understanding of the surroundings of individual species living in the ocean and in managing marine resources. It is also a prerequisite for the choice of temporal and spatial scales of sampling to understand biological and chemical processes.

Today, my main focus is on life in the oceans. There is an urgent need to learn more about the diverse assemblages of species in the ocean and understand how they make a living. There are several levels of biological understanding of the ocean, each implying a different spatial and temporal resolution of observations—the ecosystem level, habitat level, and species level. Fundamental ecosystem processes such as primary productivity, export of carbon from surface waters to the deep ocean, and the fate of excess nutrients entering the ocean are generally expressed in terms of integrated measurements over large areas. Pollutants bound to sediment particles, invasive species, and inappropriate fishing practices result in degradation of habitat, the characteristic environment of a particular assemblage of species. Population growth and reproduction, behavior, and biotic interactions such as predation, competition, or symbiosis can only be studied at the level of species. There needs to be more emphasis on the study of life in the oceans at the level of species and this is the goal of the Census of Marine Life (CoML) and the Ocean Biogeographic Information System (OBIS), a component of CoML. Small or rare animals may play a disproportionate role in ecosystem function. For example a small hydroid (a group best known for species that foul the ship bottoms) plays a completely unexpected important role in the functioning of the Georges Bank ecosystem, which supports major fisheries (Madin et al. 1996).

The design of an observing system to answer basic questions about the biology of the oceans will build on capabilities needed for safe and efficient coastal ocean operations of all kinds. Most of the observations required for practical purposes are also a prerequisite for more intensive biological observations. Information of immediate economic and strategic importance is similar to the information needed for understanding processes controlling the distribution and abundance of life in the ocean.

For example:

- Management of commercial and recreational operations in increasingly congested estuaries, embayments, and open coastal areas requires tracking systems and real-time, high-resolution information on ocean circulation. This information is also required to understand the behavior of marine organisms.
- Continuous monitoring and management of pollutants and pathogens from point and non-point sources is necessary to protect human health. The monitoring of responses of marine species to pollutants and pathogens also provides a measure of habitat quality.
- Rapid deployment of an observational and predictive capability to make unknown environments known has become an essential element for success of military operations. The "well-sampled ocean" (Glenn et al. 2000) is a product of such observation and prediction systems and a prerequisite for understanding movements of tagged animals, successful recruitment of fish, or plankton blooms.
- Forecasts of weather and ocean conditions affect peoples' daily lives as well as the viability of every coastal business—responses of fish, marine mammals, drifting gelatinous animals, clams, and crabs respond to atmospheric and ocean weather including hurricanes, downwelling events, and periods of low oxygen in ways that are poorly described. These events have been measured in the well-sampled ocean at LEO-15 and we are learning about the importance of such events to the survival and coexistence of marine species.

Satellites

The essential elements of ocean observing systems are instruments to measure winds, currents, salinity, temperature, and particle concentrations in a three-dimensional gridded space in near-real-time. The increased spatial and temporal coverage of an evolving international constellation of satellites describes patterns of environmental change at the surface of the ocean, and provides a context for sampling under the sea surface to determine the distribution and behavior of marine organisms. Satellites provide the global and long-term baseline needed to observe infrequent, potentially catastrophic events that affect the distribution and abundance of marine species. In addition, ocean color and hyperspectral satellites directly measure phytoplankton abundance and are used to estimate primary production and production exported to the deep ocean.

Ocean Observatories

At the most intensive coastal sites, such as the 30 km x 30 km area around LEO-15 (slide) and the Marthas Vineyard Coastal Observatory (MVCO), the platforms for sensors include instrument nodes serviced by underwater cables supplying power and internet connections from land. In the proposed MARS and Neptune projects, cabled observatories will be extended into the deep sea. LEO-15 includes profiling packages containing a variety of instruments to measure chemical properties of the water, temperature, light, and optical signatures of particles at depths throughout the water column. The nodes provide power and communications to pressure sensors to measure properties of surface waves, ADCP current meters to measure depth-stratified currents, chemical sensors, video cameras, hydrophones, a flow cytometer to study phytoplankton, and an array of bottom instruments to measure sediment transport. Because of accessibility by boats and divers, the nodes serve as a test bed for evaluating new instruments. The REMUS vehicle provides hydrographic surveys in an oscillating surface to bottom mode or bottom surveys either as single transects or as swath coverage for bathymetry and sidescan sonar imagery of the bottom. It has been adapted to measure optical properties of the water for studies of phytoplankton and fluorescence. It is also used with an optical plankton recorder or continuous net sampler for plankton. A similar suite of instrumentation can be carried by gliders that travel under their own power for weeks or months, operating on their own, communicating with shore stations every time they surface. All of these systems can be used in the open ocean serviced from relocatable buoys or the cabled observatories such as MARS and NEPTUNE.

A National System for Measuring Coastal Surface Currents

Perhaps the most important new technology for coastal research is high-frequency radar such as the long-range CODAR systems Rutgers has deployed in the New York Bight (Kohut et al. 2002--http://marine.rutgers.edu/cool/coolresults/papers/oi_london_kohut.pdf). It is possible to show hourly changes in surface currents on a grid scale of 6 km for the entire continental shelf out to and including the edge of the Gulf Stream. Systems such as this should be in place throughout the country.

Ocean Forecasts

Hourly, surface currents from high-frequency radar, satellite and aircraft data, weather information, and networks of subsurface measurements from observatories, buoys, autonomous vehicles, and ships of opportunity provide data that can be assimilated into numerical models to accurately forecast ocean conditions (Schofield et al. 2002b--http://marine.rutgers.edu/cool/coolresults/papers/oi_2002_oscar.pdf). Under these circumstances, observations from the well-sampled ocean are used to improve our understanding of errors associated with model assumptions.

IOOS

The development of IOOS requires linkages with import research efforts such as CoML-OBIS, GLOBEC, CoOP, and GODAE. These programs are both a means and an end for achieving the full potential of the global ocean observing system.

The Census of Marine Life (CoML) (http://www.coml.org)

CoML is a decade-long program to promote and fund research assessing and explaining the diversity, distribution, and abundance of species throughout the world's oceans. For the past two decades, the most intensive research effort in biological oceanography has been devoted to understanding biogeochemical and food web processes in marine ecosystems. Research on the diversity of ocean life and patterns of species movement and distribution has not kept pace with advancements in ocean observation and prediction. CoML is committed to developing advanced technology for observing marine life and to acquire meaningful data more efficiently and comprehensively. There are four major components of CoML:

- The History of Marine Animal Populations (HMAP). HMAP analyzes historical documents to determine what lived in the ocean over the past 500 years. Case study areas include: NW Atlantic, Caribbean Sea, SW African Shelf, Barents and White Seas, Norwegian North and

Baltic Seas, and SE Australian Shelf. Data from a variety of historical sources are being used to test hypotheses related to the ecological, environmental, and anthropogenic factors affecting the history of marine animal populations. This program will provide a unique new synthesis of historical and biological research documenting global marine biodiversity up to 500 years ago, before significant human impact. Data will be stored in formats compatible with modern data in OBIS.

- The Future of Marine Animal Populations (FMAP). FMAP will develop the capability for modeling and predicting changes in global biodiversity in response to fishing, pollution, and climate change.

- The Ocean Biogeographic Information System (OBIS). OBIS is an on-line, open-access, globally-distributed network of systematic, ecological, and environmental information systems. Collectively, these systems operate as a dynamic global digital atlas to communicate biological information about the ocean. Through use of Internet-enabled GIS and other Web-based analytical tools, biological data can readily be integrated with environmental data, maps, visualizations, and model outputs for a broad community of users. At present, OBIS contains the world's principal databases on fish, octopus, squid, anemones, corals, zooplankton, and seamount fauna integrated for the first time. All CoML field project data will be managed in and accessible through OBIS.

- Six Initial Field Projects. CoML Initial Field Projects develop and calibrate these technologies in selected regions to facilitate and accelerate global biodiversity research. As calibrated technologies and protocols are adopted in many regions, qualitative and quantitative biodiversity discoveries accumulate. Some the technology can become biological sensors for the IOOS.

CoML Projects include:

1. Natural Geography In Shore Areas (NaGISA) (led by Yoshihisa Shirayama, Seto Marine Biological Laboratory, Kyoto University, Japan) uses SCUBA divers to sample 0 m to 20 m depth transects along a latitudinal gradient in the Western Pacific from New Zealand to the West coast of Siberia and the coast of Alaska. Populations of species in bottom assemblages vary less in time and are easier to sample than species populations in the water column. For this reason, information on bottom assemblages is often used as reference for determining change in biogeographic patterns or environmental impacts. Theoretical generalizations have been made to explain species distribution patterns, but even simple correlations with latitude or depth generate more controversy than consensus, in part because of inadequate methods for measurement and very limited, readily- accessible databases on the distribution and abundance of marine life.

2. Biogeography of Chemosynthetic Ecosystems (ChEss) (led by Paul Tyler, Southampton Oceanography Centre, UK) studies biogeography, biodiversity, and the evolution of species living in hydrothermal vent ecosystems along the mid-ocean ridges and seep ecosystems on the continental margin in deep water. Standards and protocols for dedicated collecting by

submersibles will enable comparison of these systems and track change in these environments.

3. Patterns and Processes of Ecosystems in the Northern Mid Atlantic (MAR-ECO), (led by Odd Aksel Bergstad, Institute of Marine Research, Norway) maps the distribution and genetic structure of demersal and pelagic fish, zooplankton, and bottom-dwelling species on the Mid-Atlantic Ridge. Trophic interrelationships and life history strategies will be studied in the very deep water column over one of the largest physical features in the ocean. This project will combine state-of-the-art sampling gear with high-resolution bathymetric surveys to characterize the communities and bottom topography along selected areas of the Ridge. Animals, such as deep-sea squids known only from photographs (Vecchione et al. 2001), may be collected for the first time.

4. The Census of Marine Life in the Gulf of Maine (GoMAP) (led by Evan Richert, University of Sourthern Maine, USA) brings together teams of U.S. and Canadian scientists to develop an integrated view of marine life in an already well-studied marginal sea, taking advantage of advanced technologies and monitoring systems already operating there. A comprehensive web-based geographic information system for this area will be an important product of these studies.

5. Pacific Ocean Salmon Tracking (POST) (led by David Welch, Pacific Biological Station, Nanaimo, British Columbia, Canada) uses passive tags to track salmon in the ocean. Coded acoustic tags in fish as small as 25 grams send a numerical identification signal which is recorded each time the fish passes through an array of transponder lines crossing migration routes. Cumulative information records the life histories of individual fish.

6. Tagging of Pacific Pelagics (TOPP) (led by Barbara Block, Stanford University, USA) takes a multi-species approach. The TOPP project will use several electronic tags (archival, satellite-linked ARGOS, and GPS services) to examine the distribution and behavior of pelagic organisms relative to variations in the ocean environment of the North Pacific. Individual large fish such as tuna, marine mammals such as elephant seals, sea turtles, birds such as albatross, and large squid report on their movements and the rapidly changing environments in which they live. By identifying where large animals spend the most time, biological hot spots may be identified for further study by direct sampling.

   Census of Marine Life Programs are becoming established in Australia, Canada, Europe (EU), Japan, South America, Southeast Asia (IOC-WESTPAC), and the South Pacific. The committee to develop the plan for the U.S. CoML Program is being established by the Consortium on Ocean Research and Education.

CONCLUSIONS

- The Commission should urge Congress to fund the infrastructure required to observe the ocean and foster regional partnerships among industry, academia, and government to sustain observing systems. The elements of the IOOS have been defined and the recommendations of the Ocean.US Workshop should be implemented.

- IOOS should provide the rationale for a cross-cutting budgetary initiative to take advantage of the revolution in national undersea capability. Buoys, gliders, drifter floats, ships, and bottom observatories should all be equipped to service biological sensors and their deployment should consider questions important to understanding biological processes. The National Undersea Research Program is ideally suited to lead this technology development.

- The Census of Marine Life has its origins in the National Ocean Partnership Program and should continue to play a cross-cutting role on behalf of biological research in ocean programs. CoML provides a means for achieving many of the scientific goals of the global observing system. New approaches developed by CoML should be incorporated into IOOS and incorporated into individual agency budgets. For example, sensors integrated into fish tags, are similar to those on ARGO floats. Information from migratory marine animals in the CoML TOPP Project will provide important information on the environment that is not available from passive drifters. Lines of moorings to count tagged fish, as in the POST Project, would become an integral part of regional observing systems. The OBIS international approach to developing advanced information systems should be incorporated into the data systems developed for IOOS.

- Biological research programs such as those planned by CoML will benefit greatly from ship and submersible time devoted to interdisciplinary programs of exploration. Voyages to unexplored environments have an obligation to devote time to basic observations that will enhance our global view of the diversity of life and complexity of functions of underwater systems. NOAA's Office of Ocean Exploration must be equipped to provide regular access to suitable ships and submersibles to meet this challenge. A formal partnership with the NURP program can help provide access to these assets.

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