Contents

Peter Wiebe

A small multiple-opening-closing net system is launched from *Atlantis II* for Warm Core Rings investigations.

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Cover Photographs: Open ocean zooplankton discussed by authors Harbison and Madin are featured on the front and back covers. A small *Leuckartiara octana* is shown on the front cover. It is a small hydromedusa about three centimeters high with tentacles extending 30 to 40 centimeters. The photo was taken in the California current by Laurence P. Madin (©). The back cover shows a solitary generation form of the salp *Pegea bicaudata* about 10 centimeters long. The spiral structure is a chain of baby salps produced by asexual budding. The salp was photographed in an aquarium by Laurence P. Madin (©).

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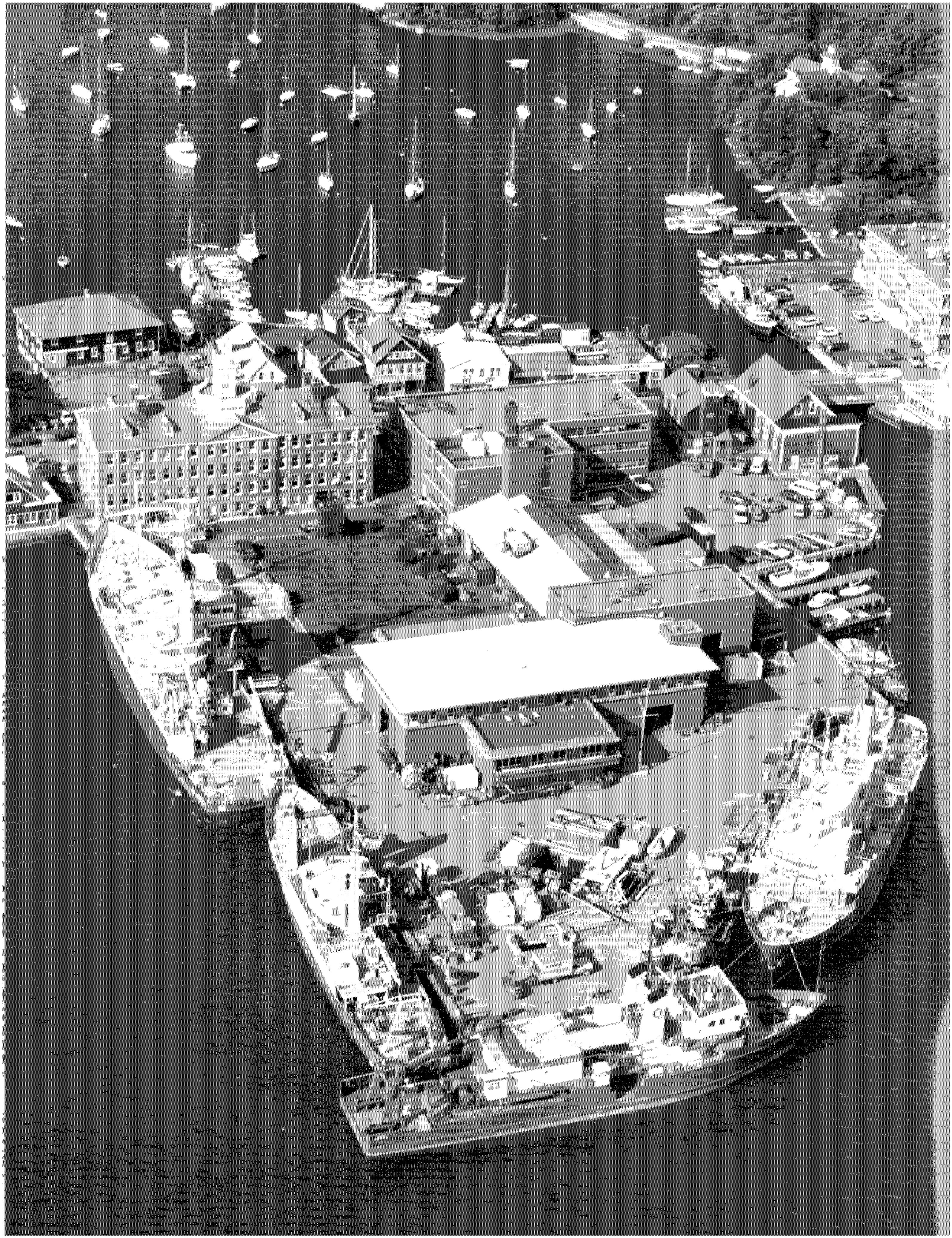


Director's Comments

New ideas, new technologies, and new facilities are at the heart of the advances in oceanography and in the leading role of this Institution. Can we continue to maintain our scientific creativity in a time when funding is tight in both the public and private sectors and when we must consider new sources for support of our work? I believe the basic health of the Institution is robust and there are many recent accomplishments we can point to with pride.

We have completed the experimental facilities for the Coastal Research Center, and they are now in use for experimental work on coastal dynamics. Some of the work done through this Center was the subject of an industrial seminar in 1983, presented at the Institution by members of our staff along with MIT colleagues.

The requirements of our organic geochemists for special advanced facilities are being met by a new chemistry building scheduled for dedication in mid-1983. These specially outfitted laboratories will greatly enhance the ability of our chemists to understand the ocean and man's influence on it as they explore the subtle changes in its chemical balance.

There are other specialized facilities which enable us to extend greatly the range of our research activities. For example, we have installed in the basement of McLean Laboratory a specially shielded chamber for measuring very low levels of radioactivity. This facility enables us to increase our understanding of the distribution of isotopes in the deep ocean and thus to enhance our knowledge of abyssal circulation in the ocean. At the other extreme we have obtained funding from the National Aeronautics and Space Administration for a satellite facility which will increase our ability to use new sources of data available through remote sensing. Our computer facilities have been considerably increased by the addition of another VAX that will link up with the satellite facility and provide a wide range of data analysis techniques. Institution staff members are also defining programs to combine the conventional techniques of moorings and deep floating drifters with remote sensing to give both horizontal and depth distributions of various properties. Taken together, these three technologies form the basis of an oceanographic observing system capable of sampling the full, four-dimensional structure of the ocean — a capability heretofore unavailable to the research community.

In recent months, there have been several very exciting oceanographic developments in which the Institution has played a major or a lead role. The technique of acoustic tomography which enables the mapping of the internal structure of the ocean from knowledge of the paths of acoustic signals over hundreds or thousands of kilometers has been tested successfully by a group of scientists, including members of our Ocean Engineering Department. The knowledge of warm core rings shed by the Gulf Stream along the margin of the North American continent has been explored as a chemical, biological, and physical phenomenon. This has required multi-ship operations with new equipment and special problems in organization. The Institution has played a leading role, both in the science and in the organization of these major expeditions. Problems concerning the transfer of organic matter from the near surface of the ocean to deep water are intimately related to a whole range of questions concerning, for example, carbon dioxide removal from the atmosphere and pollutant transfers from land to sea. We have developed programs using sediment traps to measure these organic transfers and to characterize their chemistry. These programs have been very successful in providing information that is leading us to reassess the whole process of organic production and transfer in the deep ocean.

As the mid-life refit of *Atlantis II* continued during 1982, funds were awarded by the National Science Foundation to convert the ship for handling of the submersible *Alvin*. This will greatly improve and extend the submersible's capability to operate in distant waters along with a full complement of scientific staff to work on material collected by the submersible. We are also looking to a new generation of vehicles for exploring the deep ocean. Such vehicles being developed may not contain human beings, but will enable the scientists on the surface to be in intimate, almost psychic, contact with the deep ocean.

At this present time we are conscious that the world of science may not grow in terms of numbers of people and possibly in quantity of funds. Yet, within these limitations, we must remain creative in our ideas and innovative in our methodologies. Many of these new concepts and techniques summarized here may not come to fruition for several years, but they will ensure continuity for advances at the Institution and for the expansion of our scientific horizons.

John H. Steele
Director

Frank Medeiros

Opposite: The WHOI pier in the summer of 1982 with, counterclockwise from upper left, R/V *Knorr,* R/V *Oceanus,* R/V *Gyre* (Texas A&M University), and R/V *Atlantis II* in port.

WHOI Board Chairman Charles F. Adams, left, and Director John H. Steele break ground for new chemistry laboratory.

Areas of Interest

Biology

The broad aim of biological oceanographers is to study the temporal and spatial distributions of populations of marine organisms and their interactions with each other and their environment. The work is predominantly ecological in nature and provides the basic information required to understand how the ocean works biologically. Among the research interests of Institution biologists are microbiology, planktonology, benthic biology, physiology, animal behavior, and aquaculture. Work on marine pollution includes research on the effects of drilling muds and hydrocarbons and the biochemical responses of animals to these pollutants. The "patchy" distribution of many marine animals is under investigation as are the physiological adaptations of deep sea organisms to sparseness of food, low temperatures, high pressures, and deep sea thermal vents. Answers to questions about the food supply in the oceans are sought in studies of particles falling from the surface waters through the water column to the bottom of the sea, in studies of upwelling areas, through investigations of sulfur oxidizing organisms in the deep sea and shallow coastal ponds, and in laboratory experiments that complement field investigations. The uses of sound by marine mammals, mechanisms of fish swimming and gill ventilation, and the behavior of large marine animals followed by tagging are being studied. Other work concentrates on salt marsh ecology and conservation, and there are research projects on aquaculture and waste water recycling and on the productivity of a salmon river in Canada.

Chemistry

Chemical oceanographers are concerned with the composition of the ocean environment. They seek to understand the processes that have brought seawater and sediments to their present composition and that contribute to the observed variability. They also seek understanding of the extent to which the environment may be changed by both natural and man-made phenomena operating on a variety of time scales. Input from rivers and reactions at the air-sea, seawater-sediment boundaries and seawater-volcanic rock interaction at spreading centers are under investigation as chemists consider the processes taking place at major ocean boundaries. Some critical questions in chemical oceanography revolve around the vertical transport and transformations in particles as they fall from the surface waters to the bottom of the water column. The photochemistry of the surface ocean and the marine atmosphere is critical to our understanding of the global sources and sinks for many gases. The genesis and composition of the oceanic crust and its interaction with seawater is important to a general understanding of the oceanic system. Studies concerning the interstitial water chemistry of deep sea sediments help us to better understand the diffusive flux of ions between sediments and the oceans. Work on the fluxes of organic carbon includes determination of the amount of organic carbon produced in surface waters, the distribution, nature, and biogeochemistry of specific organic compounds in the marine environment, and studies of processes responsible for formation and diagenesis of organic matter in sediments. While studying radioactive isotopes in the ocean, whether as a natural occurrence or as a form of pollution, chemists are also finding the known decay rates of the isotopes useful as indicators for studying rates of water circulation, the in situ rates of chemical processes in the sea, and rates of biological and chemical processes that change the composition of seawater. Stable isotopic studies in rocks can be used as geochemical and petrological indicators of large scale terrestrial mantle processes.

Geology and Geophysics

Marine geologists and geophysicists study the processes which form and affect the earth beneath the sea, as reflected in its underlying structure and composition. The sedimentary and volcanic material of the seabed is investigated by direct sampling and remote observation. Coring, dredging, or drilling techniques are commonly used to obtain samples, which are further classified in the laboratory by petrological descriptions, geochemical analyses, and measurement of physical properties. Geophysical methods include the fields of seismology, gravity, magnetism, and geothermics. The establishment of plate tectonics as the primary kinetic process creating and shaping ocean basins has focused attention at the boundaries where plates interact. At divergent plate boundaries, or mid-ocean ridges, the processes which bring up hot materials to create ocean crust and lithosphere are studied in detail. Investigations of rifted continental margins of different geological ages are important to understand how continental plates initially break apart. Finally, subduction of oceanic lithosphere beneath either continental or other oceanic lithosphere is a process which is intimately associated with the creation of deep sea trenches and back-arc basins, accompanied by the important geological phenomena of earthquake belts and volcanic island arcs. Research is actively pursued on processes of particulate flux in the ocean ('marine snow'), carbonate and silicate dissolution, and other phenomena relevant to the transport of biogenic material to the sea floor. The results are essential to a better understanding of the fossil record, which in combination with studies of its oxygen isotopic variation reveal changes in climate and ocean environment over periods of thousands to millions of years. The study of the dynamics of sediment distribution on the ocean floor is important to deciphering the fossil record and interpreting sea floor morphology. Marine geologists also study near-shore and shallower regions such as continental shelves and coasts where earth, ocean, and atmosphere dynamically interact to produce complex and rapidly-changing morphology.

Ocean Engineering

The increasing sophistication of ocean projects, especially within the last decade, has led to an unprecedented demand for special engineering knowlege and skills. The field of ocean engineering is a complex hybrid of many of the classical engineering disciplines such as electrical, mechanical, civil, chemical, and marine engineering. Its purview is broad and inter-disciplinary. Ocean engineers are conducting research and developing instrumentation in almost every field of oceanography. Mechanical, electrical, acoustical, chemical, optical, civil, marine, and ocean engineering talents are used to develop techniques for measuring oceanic processes and for answering basic scientific questions about the marine environment. Measurement programs span ocean time scales of years to milliseconds and ocean space scales of kilometers to millimeters. Electronic data handling and processing circuits using microprocessors and state-of-the-art devices are developed for these programs. Instrument housings and anchoring and mooring systems are designed, fabricated, and deployed at sea. Acoustic techniques are applied to measurement problems. Manned and unmanned deep submersible systems are engineered for search and discovery. Techniques for using the earth orbiting satellite as an observational tool are being developed together with image enhancement and image processing algorithms. Information processing, whether applied to acoustic systems, satellite images, geophysical time series or general data reduction is the primary concern of a large segment of the department. Research is conducted in hydrodynamics, signal processing theory, applied mathematics, acoustic tomography and propagation, deep submergence engineering, arctic acoustics, coastal processes and benthic currents, and instrumentation techniques. Programs in mooring materials and design, electronic and microprocessor applications, optical measurement, remote observation and sampling, and arctic instrumentation engineering support these and other scientific projects throughout the Institution. The technological sophistication of modern ocean science demands the application of special engineering knowledge and skills. The solution of challenging problems requires creative combinations of wide ranging ocean engineering principles.

Physical Oceanography

Physical oceanography is the study of the physics of the ocean. Its central goal is to describe and explain the complex motion of the ocean which occurs over a very wide range of scales. Variations of the temperature and salinity, the driving effects of the winds, the rotation of the earth, and the pull of the sun and the moon all contribute to these motions. There are both grand persistent currents like the Gulf Stream and transient waves and eddies of almost all sizes and speeds, from high frequency acoustic and surface gravity waves, to slower internal gravity waves hidden from the sea surface. Large regions of the oceans are dominated by the mesoscale eddylike vortical patterns of flow that display visual and dynamic similarity to atmospheric weather patterns. As in the atmosphere, relatively intense frontal systems exist. Important mixing and stirring across these fronts are accomplished by a variety of physical processes, some of great subtlety like the phenomenon of "salt fingers" whose sizes are on the centimeter scale. Important scientific questions also arise in considering the interaction of the ocean with the atmosphere. The ocean and the atmosphere drive each other in an as yet poorly understood way; exchanges of energy between the air and sea are important in determining the climate of both the atmosphere and the oceans. Physical processes in coastal regions are strongly affected by atmospheric forcing and bottom topography, and the current and wave systems in this complicated region are of vast importance to the local climate and ecology. Physical oceanography staff members are involved in experimental, theoretical, laboratory, and numerical investigations of many parts of the system of oceanic motions. Small programs and large international projects are underway, and multi-disciplinary efforts are increasing. All of these studies have the ultimate goal of understanding the structure and movement of the world's oceans, the interaction of the sea with its boundaries, and the physical role of the ocean in relation to other branches of oceanography.

Marine Policy & Ocean Management

The Marine Policy and Ocean Management Program is a multi-disciplinary effort that provides an opportunity for individual scholars to conduct research regarding the problems generated by man's increasing use of the ocean. The Policy Program maintains a staff of Policy Associates in addition to the Postdoctoral and Senior Research Fellows who are appointed for terms of one to two years. Fellowships are offered to individuals from such fields as anthropology, economics, international affairs, law, political science, and the marine sciences who are interested in applying their training and experience to marine policy and ocean management questions. The Program sponsors workshops, conferences, and seminars on important and timely marine policy issues. Present research themes in the Program include: coastal zone management and pollution problems; fisheries management issues; marine mineral management studies, especially on polymetallic sulfides; marine policy problems and opportunities in developing countries; implications of the Law of the Sea Treaty for U. S. ocean management and science; use of scientific information in decision making and policy planning; and U.S. and Canadian marine research and management issues, especially those in the Arctic.

Reports on Research

Right: Conductivity/temperature/depth array with water sample rosette is launched for Warm Core Rings research.

Large Oceanographic Programs

In recent years, certain oceanographic problems have been defined on scales that require the cooperative work of many investigators. A number of Institution scientists are involved in these multi-institutional, multi-disciplinary projects. The three large programs briefly discussed here are Transient Tracers in the Ocean, Gulf Stream Warm Core Rings, and the Coastal Ocean Dynamics Experiment.

R/V *Knorr* was engaged for seven months of 1981 in the North Atlantic Ocean on an extended voyage for the Transient Tracers in the Ocean (TTO) program. During an extensive sampling program, some stations she had made for the Geochemical Ocean Sections Study (GEOSECS) in 1972-73 were reoccupied. TTO is based on the premise that the oceans are important both in global climate and in the uptake of man-made substances, particularly the potential climate modifier carbon dioxide. Prediction of future changes requires quantitative understanding of the physico-chemical dynamics of the oceans, and the TTO researchers representing five American institutions as well as several foreign ones have recently proposed a 10-year program to continue to measure transient (man-made, time varying) tracers in the ocean as a basis for such prediction. The major thrust of the program is to obtain a series of "snapshots" of the distribution of several transient substances and use their differing natures, time histories, and boundary conditions to help unravel the complex oceanic processes responsible. Over the next ten years, the Transient Tracers scientists plan to expand a series of regional scale surveys already begun which will be combined to provide a tracer map of the entire world. A large scale prognostic model is the ultimate goal. In addition to the North Atlantic work in 1981, field work has been done in the equatorial Pacific, and in late 1982 R/V *Knorr* was again employed to begin work in the equatorial Atlantic. A South Atlantic study will follow.

The observations of bomb-test-produced tritium, helium-3, and carbon-14 made during the GEOSECS expeditions provided the first picture of the pathways by which these substances invade the oceans. The atmospheric bomb testing was carried out in the late 1950s and early 1960s, and its products could be seen in the early 1970s in the oceanic thermocline, the zone where the water temperature decreases very rapidly with depth, and, via the deep North Atlantic overflows, in the abyss of the North Atlantic. Further understanding of the response time of the deep ocean to surface events has come with initial analysis of TTO '81 cruise data that indicates reflection of atmospheric fluctuations in the North Atlantic and Norwegian and Greenland Seas by reduction in salinity and increase in temperature of deep North Atlantic water on a time scale of less than a decade.

Intitution scientists participating in the TTO program are William Jenkins and Peter Brewer, who is currently on leave as a program manager at the National Science Foundation, of the Chemistry Department, and Peter Rhines and Ray Schmitt of the Physical Oceanography Department.

The multidisciplinary program to study warm core Gulf Stream rings involves more than 25 principal investigators and 13 different institutions. Warm core rings are the dominant form of oceanographic variability in the Slope Water off the East Coast of the United States. A warm core ring is formed when a meander separates to the north of the Gulf Stream. The resulting ring typically has a diameter of 100 to 200 kilometers. Its central core usually has the physical, chemical, and biological properties of the Sargasso Sea, and a Gulf Stream remnant forms the high velocity region surrounding the core. These rings typically survive as independent phenomena for six months before coalescing with the Gulf Stream.

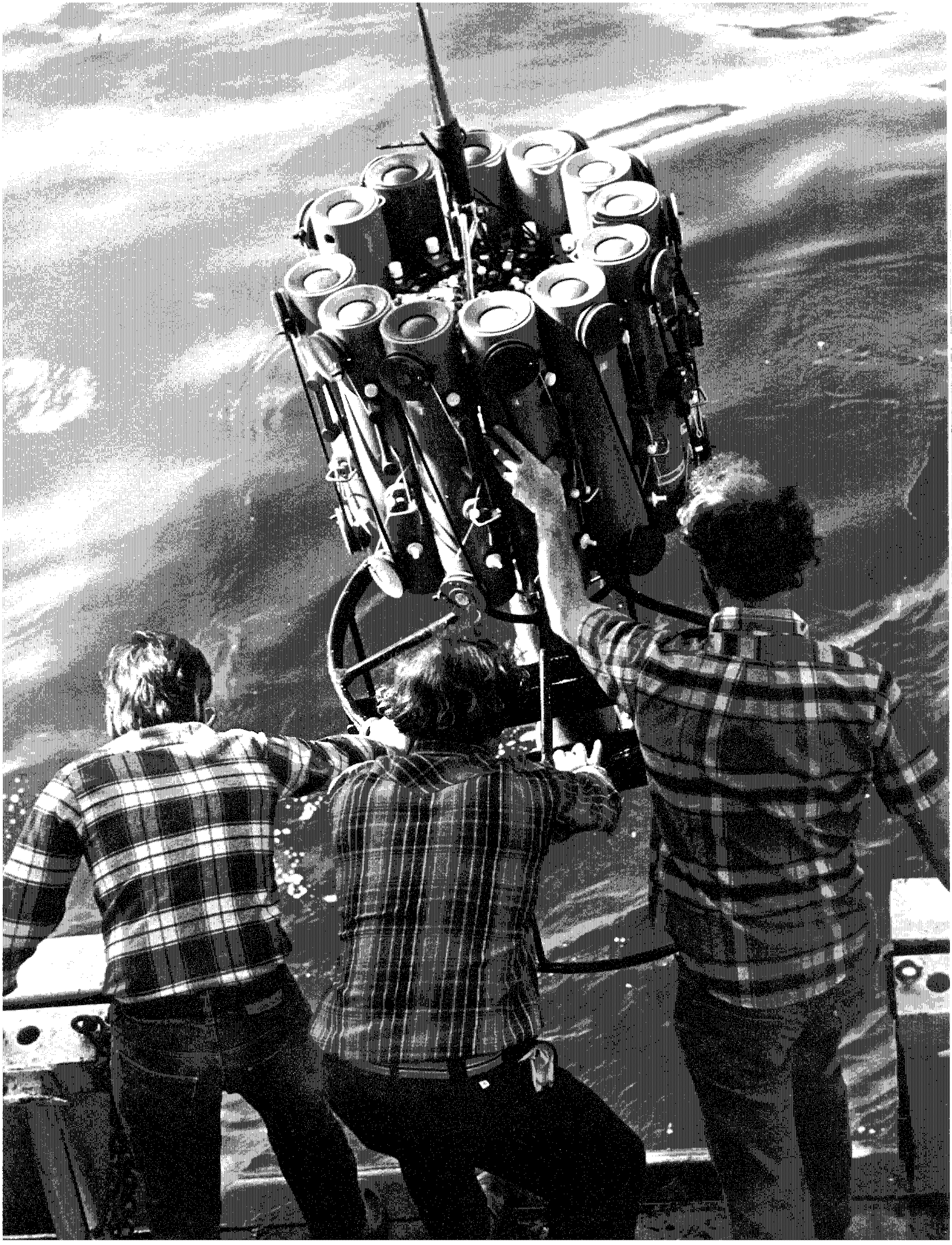
The objective of the Warm Core Rings program is to study the dynamics and evolution of warm core rings in order to understand fundamental oceanic processes in a semi-closed hydrographic regime and to contribute to the understanding of the role rings play in transport and exchange in the region between the shelf water and the Gulf Stream. There are seven main components to the program: 1) experimental and descriptive physical oceanography, 2) application of remote sensing to ocean studies, 3) chemical distributions and processes, 4) biological spatial patterns, 5) effect of entrainments on fish populations, 6) plankton physiology, and 7) analytical and numerical modeling.

WHOI Research Vessels *Knorr* and *Oceanus* were two of the four principal platforms used in a 1982 time series study of warm core rings. Four cruises were scheduled over a six-month period to investigate the structure and dynamics of a warm core ring over its life span. Information from research ships of opportunity, satellites, and aircraft overflights also contributed to the work. The birth of Ring 82-B, the second warm core ring to form in 1982, was observed by satellite in February just south of the central portion of Georges Bank. The ring was extensively sampled and studied until it coalesced with the Gulf Stream off Cape Hatteras in mid-September.

Since the ring had disappeared by the fourth scheduled cruise in late September/early October, 82-H was followed instead from the late meander stage through pinching off. After the ring formed, an intense gale passed through the area, and major transformations in the ring's surface structure could be seen as a result of the storm.

Among the findings of the Warm Core Rings work to date are: Satellite and aerial remote sensing provide quantitatively useful information on the temperature and chlorophyll structure and characteristics of warm core rings. The researchers have observed larger changes in the physics, chemistry, and biology of a ring in a week's time than they had expected would occur in several weeks to months. These rapid changes were caused by Gulf Stream interactions (a ring may come in contact with the Gulf Stream several times in its life span) and were evident in the increase in the populations of cold water zooplankton, whose physiological rates are high compared to their warm water counterparts. Large chemical fluxes have been seen in the center of the ring. The stratification in the water column and its variation with time have been monitored since it plays a very important role in chemical and biological processes in a ring.

WHOI physical oceanographers Terry Joyce and Ray Schmitt have been principal investigators for studies of the velocity structure and mass field (temperature and salinity distribution) in rings and the changes in these properties over time. They are also concerned with the effects of mixing versus advection. From the Biology Department, Dick Backus is investigating mid-water fish distribution in rings, Tim Cowles is studying macrozooplankton grazing and egg production, and Peter Wiebe's research centers on micro-zooplankton distribution and life history. Wiebe also serves as vice chairman of the program.



Reports on Research

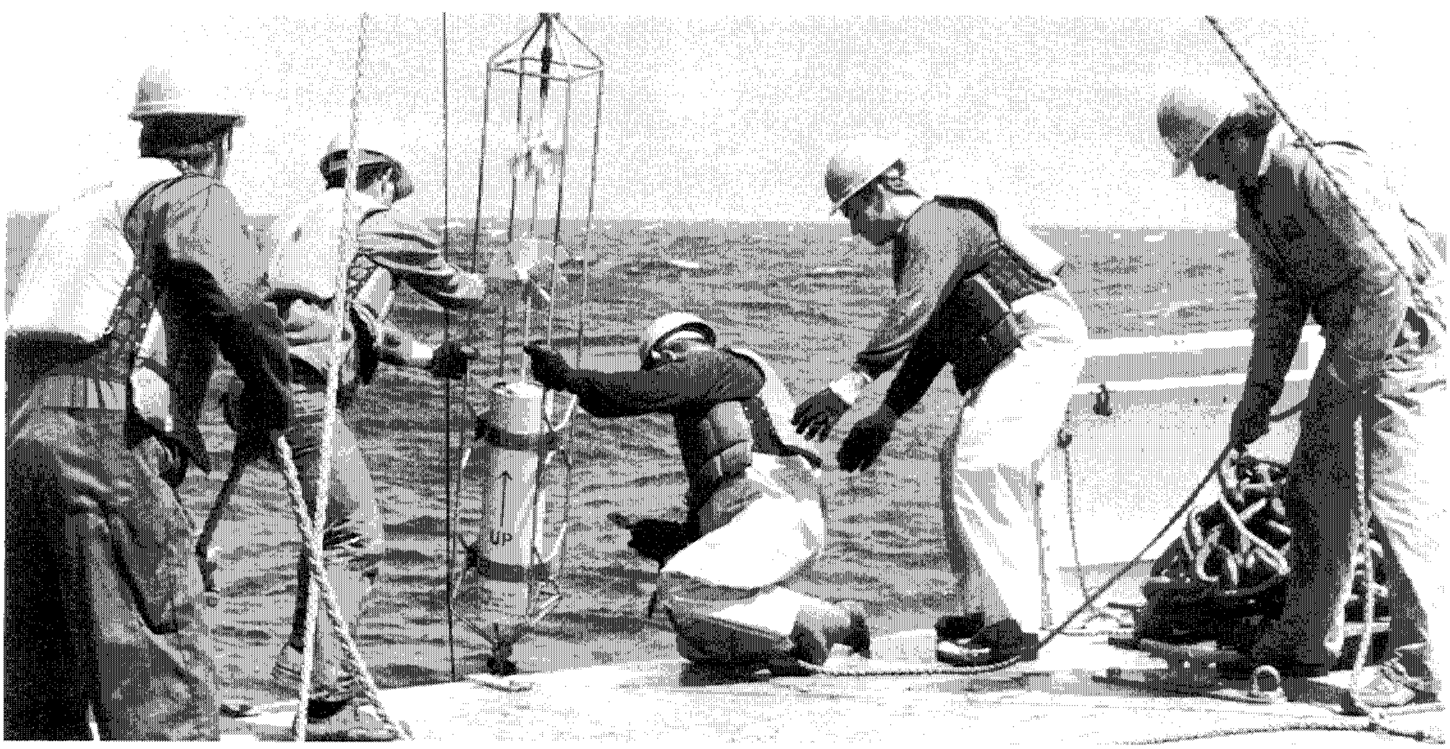
The general objective of the Coastal Ocean Dynamics Experiment (CODE) is to study the response of coastal water to wind stress in a simple geomorphological setting. Scientists from six institutions initiated a four-year project in 1980 to investigate the dominant physical processes governing wind-driven currents over the northern California continental shelf. A series of two four-month, densely-instrumented, small-scale field experiments were carried out in the spring and summer of 1981 and 1982 to obtain high quality measurements of relevant physical variables. These are being used to construct accurate kinematic and dynamic descriptions of the response of shelf water to strong wind forcing over time periods of two to ten days. Dense moored arrays of meteorological buoys, current meters, tide and bottom pressure sensors, and vertical temperature and temperature/conductivity chains were deployed, extensive hydrographic and Doppler acoustic current surveys were conducted by R/V *Wecoma* of Oregon State University, and a number of Lagrangian experiments were conducted using a new radio-tracked drifter. The heavily instrumented *Queen Aire* aircraft from the National Center for Atmospheric Research was used to obtain direct observations of wind, wind stress, and other meteorological variables in the marine boundary layer off the northern California coast.

A more lightly-instrumented, long-term, large-scale component of CODE is designed to help separate the local wind-driven response from motions generated either offshore by the California Current system or in some distant region along the coast. It is also intended to help determine the seasonal cycles of atmospheric forcing, water structure, and shelf circulation over the northern California shelf. William Grant and Albert Williams 3rd of the WHOI Ocean Engineering Department have been principal investigators concerned with bottom stress measurements as well as swell and wind-wave climate work in CODE. Robert Beardsley of the Physical Oceanography Department has served as overall program coordinator and principal investigator for the work on long-term current and temperature measurement as well as the buoy wind and current measurements in the two small-scale experiments.

Below: A vector measuring current meter is launched during field work for the Coastal Ocean Dynamics Experiment (CODE) aboard R/V *Wecoma* (Oregaon State University) in the Pacific.

Right: Mooring flotation is readied for placement for CODE.

David Simoneau



David Simoneau

Gelatinous Plankton

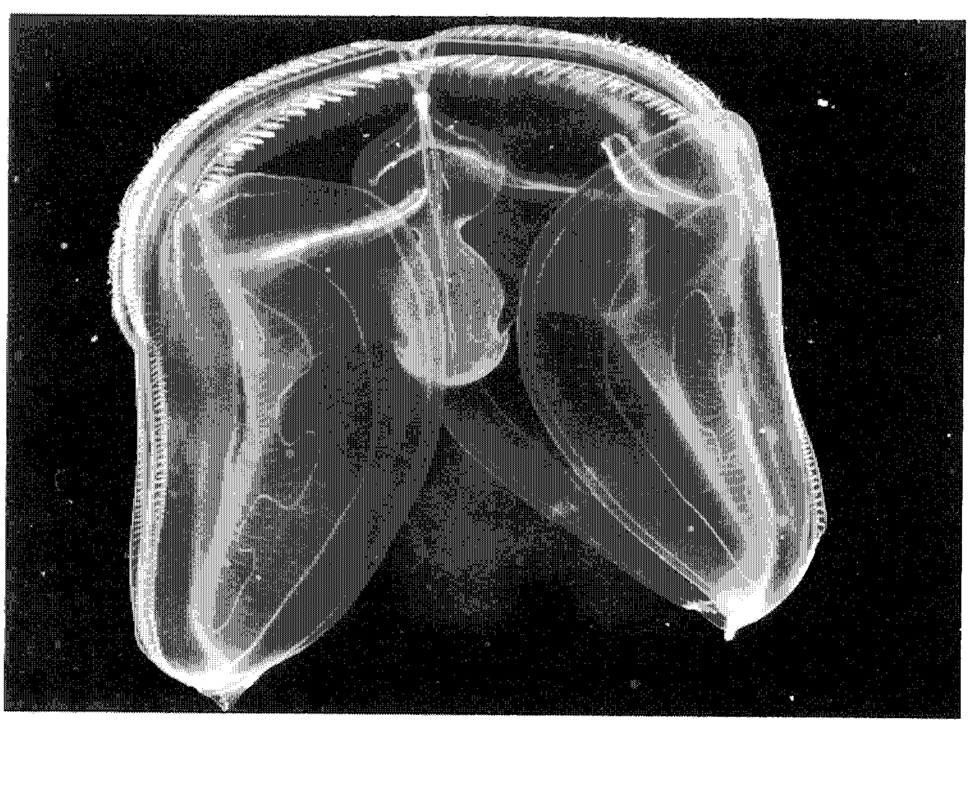
G. Richard Harbison

Gelatinous organisms are among the most prevalent animals in the open ocean. There are many reasons for gelatinous structure. Among them are the need to maximize body surfaces to capture widely-dispersed food; the decreased need for reinforced structures because there is little likelihood of colliding with anything in the middle of the ocean; ease in staying afloat; no demand for protection against the harmful effects of sunlight; and protection, to hide from predators. By studying their role in the open sea, we can obtain information about their environment through examination of their adaptations to it.

To this end, I have been studying two major groups of gelatinous zooplankton, salps and ctenophores, along with other planktonic organisms that live in association and interact with them. While both salps and ctenophores are unfamiliar creatures to most people, they are, in fact, widespread and abundant, and often important ecologically.

Salps are barrel-shaped animals, ranging in size from about half a centimeter to 30 centimeters in length. Filter feeders, they use a mucous net to strain microscopic particles from the water. While studying their rates of feeding and their responses to differing kinds and concentrations of food, I have found that they feed very well at concentrations of particles similar to those found in the open sea. At higher concentrations their feeding mechanism breaks down; a bolus of food is formed that blocks the esophagus, preventing the further ingestion of food. The concentrations of food at which the feeding mechanism is disrupted are so low that food concentration may be a major factor influencing the distribution of these salps, effectively serving to restrict them to the open ocean. It appears that too much, rather than too little, food is detrimental to their survival. At normal concentrations of particles found in the open sea, the filtering mechanism works perfectly, but at higher concentrations such as are usually found close to shore, the feeding mechanism ceases to function properly. Therefore, these salps may starve to death if food is too plentiful. This conclusion appears so paradoxical and contrary to what is generally believed to be the case for planktonic animals that I have experiments planned to see if elevated food concentrations actually result in decreased ingestion.

Whatever mechanisms may serve to exclude most salps from coastal waters, there can be no question that they are extremely good at removing particulate material from the water. In addition to processing large volumes of water, they are slow-moving and relatively large, so that they are attractive food sources to a considerable number of other oceanic animals. Crustaceans are often found in association with salps. Two groups, cyclopoid copepods and hyperiid amphipods, are major predators and parasites. Some of these crustaceans have such strong feeding preferences that they are only found on single species of salp. Lawrence Madin of WHOI, John Hanssen of Loyola University, and I are examining some of the factors that serve to establish and maintain this high degree of specificity. In addition to crustaceans, planktonic molluscs and fishes are also important salp predators. One genus of oceanic fish, *Tetragonurus*, appears to be very tightly associated with salps, at least in the early stages of its life, and highly selective in its feeding habits. These fish live in salps, eat the crustacean parasites, and also eat the stomachs of the salps, their teeth being specially modified for this purpose. We have examined *Tetragonurus* stomach contents and found nothing but the remains of salps and related tunicates along with remains of the crustacean parasites that live on them. When presented with a variety of gelatinous animals in the laboratory, these fish would eat only salps, refusing ctenophores, jellyfish, and siphonophores.



Martin Jones

Left: The ctenophore *Ocyropsis maculata* feeds on large crustaceans and larval fishes by grasping them with its large muscular oral lobes.

Below: Rich Harbison

Reports on Research

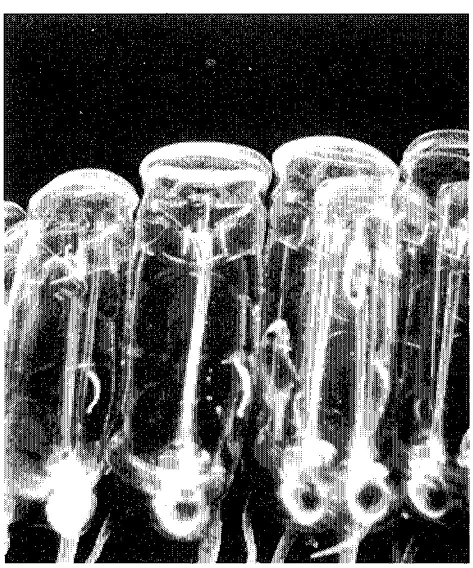
Less is known about oceanic ctenophores than about salps, largely because their delicate structure makes them difficult to collect. Ctenophores superficially resemble salps, being gelatinous and usually transparent, yet the two groups are not related. Most ctenophores use cilia to propel themselves through the water; in fact, they are the largest animals that employ cilia for this purpose. My past work with ctenophores has shown their ingenious and varied methods of capturing food, especially the use of tentacles covered with adhesive cells. Some of my present work is directed toward learning more about their roles in the open ocean, the rates at which they capture prey, and how food they capture is translated into growth and reproduction. Ctenophores can become quite large — some species grow up to six feet long — and a number of animals live on them as parasites and predators. Hyperiid amphipods are also found on ctenophores, but these are very different from the ones that parasitize salps. Other common parasites are hemiurid flatworms and alciopid worms. The latter are sometimes so large in comparison to their hosts that they are perhaps better thought of as predators. Trying to discover what kinds of animals prey on ctenophores is very difficult, as it is much harder to identify the remains of ctenophores in stomachs than the remains of salps.

Since a plankton net can tear the delicate ctenophores into unrecognizable fragments, they must be collected more gently. In the upper waters of the open sea, capturing them with jars while scuba diving works well, but at greater depths (and it must be remembered that the open ocean is over 4 kilometers deep, on average) special collecting devices operated from submersibles must be used. When these delicate deep-sea forms are collected, they usually are undescribed species. While diving in *Alvin* in the Panama Basin, I saw ctenophores as deep as 4,000 meters, and I recently collected a species in the Santa Barbara Basin off California, using the Wasp (a deep diving suit developed for the oil industry). The latter had been previously known only from Slope Water off the northeast coast where Laurence Madin and I collected it with *Alvin* in 1976. The ctenophore, *Bathyocyroe fosteri*, was very abundant in the Santa Barbara Basin below about 500 feet, yet its presence there had not previously been detected. I am convinced that many, if not most, species of ctenophores live in the deep ocean, but remain unknown and undescribed. Until we develop improved methods to count, collect, and study them, their importance in the open ocean ecosystem will also remain unknown.

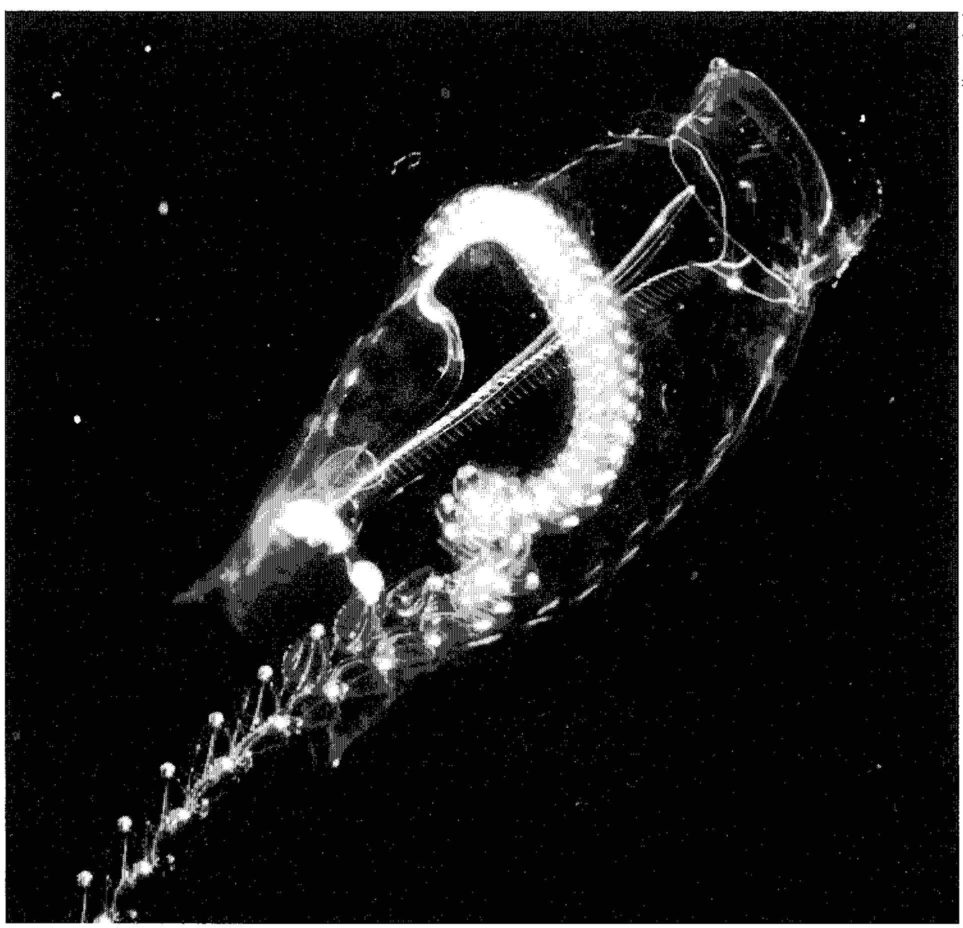
Most plankton ecologists have studied crustaceans, as these animals are relatively rugged, and many are easily collected with plankton nets. Now that improved techniques are being developed, it is possible to begin to study the more fragile forms. I believe these animals have much to tell us about the nature of the open ocean as an environment. As our ability to study the gelatinous forms increases, it is likely that our present conception of life in the open sea will be significantly altered.

Right: Salps have alternation of generations, and both generations of *Ritteriella amboiensis* are shown in this photo. The large solitary produces aggregates by asexual budding. The aggregates in this species are arranged so they look like a zipper.

Below: Two small fishes (*Tetragonurus cuvieri*) are living in these *Pegea confoederata* aggregates. These fish have specially modified teeth for cutting out the stomachs of salps.



Doug Biggs



Russell Reichelt

Assessing the Trophic Importance of Gelatinous Herbivores and Carnivores

Laurence P. Madin

During the last ten to twelve years, in situ zooplankton studies using scuba and submersibles have provided a wealth of new information on the biology of gelatinous animals and other organisms and structures which could not be sampled or detected with conventional approaches. The widespread distribution and periodic high abundances of pelagic tunicates, siphonophores, ctenophores, and others has been documented in various parts of the ocean, and laboratory-based studies of physiology and feeding behavior have made possible extrapolations of the potential impact of some of the gelatinous animals on their ecosystems.

It is also possible, with in situ methods to make more direct estimates of the effect of a population of gelatinous animals on the rest of the plankton community. Two categories of data are necessary: the abundance and size distribution of the gelatinous animals at the study site, and the rates of the processes of interest. Some processes of immediate interest are feeding, growth, and, in the case of salps, defecation. Whether herbivores or carnivores, animals have their most immediate impact by feeding. Over longer time scales, growth rates and fecundity of different species will influence how they respond to fluctuations in food levels and to predation or competition from other species. Herbivores like salps produce compact fecal pellets composed of the phytoplankton and other small particles they have collected and partially digested. The pellets sink much faster than do the small particles individually, and they can contribute significant amounts of nutrients and energy to deeper waters.

All of these rates can be measured in the laboratory, but often with some artificial constraints on the behavior of the animal. Measurement of feeding rates can be tricky in a lab experiment, especially for oceanic predators like ctenophores, because of the difficulty of mimicking the concentration, diversity, and patchiness of prey they would normally encounter in the ocean.

An alternative method for determining feeding rates is to collect organisms underwater, preserve them (or their stomachs) immediately, and then examine the numbers and kinds of organisms they have eaten. These data can be expressed as rates by dividing the number of prey found by the time required for the organism to fully digest the prey. These times are measured in the laboratory for prey of different sizes and kinds. Basically the same method is used in fisheries research to estimate feeding rates of fish. Feeding by gelatinous predators is easy to assess this way, since most of the prey are crustaceans which leave recognizable exo-skeletons behind after digestion. These remains also provide qualitative data on the kinds of prey eaten by different predators. In groups like siphonophores and ctenophores, it can be seen that different species display considerable selection of prey on the basis of size, morphology, or both. Ctenophores, for example, all use basically similar sticky cells for actually catching prey, but have evolved divergent mechanisms for arranging these cells, for concentrating prey items, and for transporting them once caught. Gut contents analysis shows, for example, that the largest ctenophore, *Cestum veneris*, which may be over a meter long, eats mostly copepods under 1 millimeter in length, while the relatively small *Hormiphora*, up to 20 millimeters long, eats larger crustaceans, some nearly half the size of the ctenophore. Yet a third genus, *Lampea*, specializes in salps as prey, most of them larger than the ctenophore itself.

A variation of this method can be used for herbivorous animals like salps. Instead of exoskeletons, pigments, which result from degradation of chlorophyll during digestion of phytoplankton cells, are measured and used as an index of gut fullness. Turnover time of the gut contents can be measured in the laboratory and expressed as a rate of gut filling or ingestion; by comparing the concentration of plant pigments in the water around the herbivore, ingestion can be expressed as filtration rate.

Salps are better suited to this method than crustacean herbivores. They are true filter feeders which continuously ingest a wide range of particulate food, and they are large enough that their guts can be excised and analyzed singly.

By collecting 20 to 30 individual salps underwater and determining their feeding rates in this way, we can extrapolate to the impact of all the salps in the area if the abundance and size distribution is known from a trawl sample. We are presently using this approach at stations within three characteristic areas of the North Atlantic — the Sargasso Sea, the Gulf Stream, and the Slope Water — to assess the importance of salps in these trophic regimes.

A biologically interesting complication to this method of estimating feeding is the fact that many ctenophores, siphonophores, and medusae do most of their feeding at night. While the same in situ methods can be used at night, the logistics and safety requirements are slightly different. We have built a set of specialized nighttime diving gear incorporating helmets with lights and two-way underwater

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Larry Madin in the laboratory of *Atlantis II*

Reports on Research

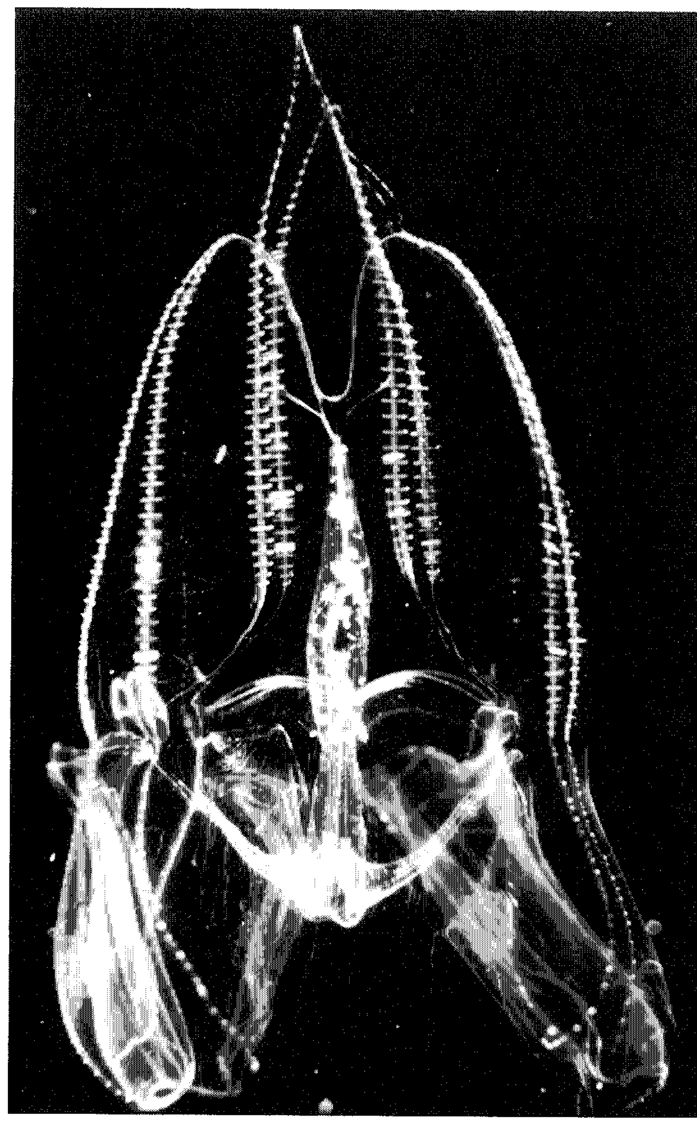
communication that allows all the divers to talk to one another even when they cannot see beyond their hands. At many of our stations in the last two years, the abundance, diversity, and activity of the nighttime fauna has been much greater than what we see during the day. One reason for this difference is, of course, the appearance at night of vertically migrating zooplankton, some of them destined to be prey of the gelatinous predators in surface waters, others predators themselves. The assessment of predation rates of many gelatinous carnivores must take day and night differences into account if it is to be anywhere near realistic.

Another difficulty with gelatinous predators is the estimation of their abundance. While salps are sturdy enough to be sampled in nets, the ctenophores and siphonophores are mostly destroyed. Counts of their numbers have to be made by divers. One approach we are currently developing is the use of a large illuminated frame which is pushed ahead of a swimming diver. It defines a known area and makes the transparent animals more visible, especially at night. As organisms appear in the frame, the diver visually counts and identifies them, recording the tallies on audio tape. Using a small flowmeter, the diver can also measure the distance the frame has moved through the water to calculate the volume searched.

Field studies like these can give us real-time and real-place information on the effects of various gelatinous plankters, particularly the rates and selectivity of their feeding. Laboratory experiments with many of the same or similar animals can provide more specific results on feeding capabilities under defined circumstances, as well as measurements of other energetic parameters like respiration and growth. The two approaches, telling us what animals can do, and what they do do at certain times and places, together give us much greater confidence in assigning levels of ecological impact to these organisms.

Below: During a night dive, Larry Madin injects fixative into a jar containing a collected ctenophore to preserve stomach contents.

This ctenophore, *Eurhamphaea vexilligera,* was photographed at night with a full stomach.



Planktonic Ciliates

Diane K. Stoecker

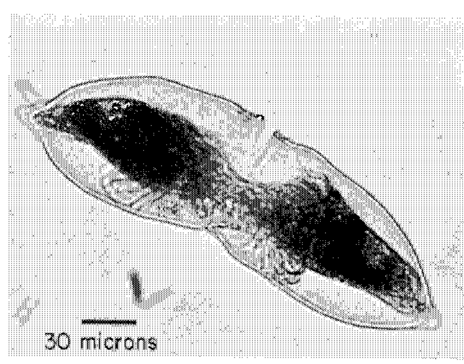
Ciliated planktonic protozoa (mostly tintinnids and oligotrichs) are an ubiquitous, microscopic component of the zooplankton; their importance, relative to larger zooplankters, in the pelagic food webs is a point of interest and controversy. Although the biomass of ciliates in the plankton is proportionately small compared to copepods and other macroplankters, their impact on phytoplankton dynamics may sometimes be comparable. This impact is due both to their high numbers, often thousands of ciliates per liter in coastal waters, and to their high feeding rates per unit biomass.

The smaller planktonic ciliates (less than 30 microns in size) may primarily eat nannophytoplankton (2 to 20 microns in size) and ultraphytoplankton (less than 2 microns in size) which are not efficiently grazed by crustacean zooplankton. However, these smaller ciliates are probably eaten by the larger zooplankton, and, therefore, smaller ciliates may be an important trophic link between the very small phytoplankton, which often account for the bulk of the primary productivity in the oceans, and the higher trophic levels. Also, many of the larger ciliates (up to a few hundred microns in size) consume phytoplankters of a size that is efficiently consumed by copepods and other macroplankton. Thus the planktonic ciliates may be both a trophic link to larger zooplankton and in competition with larger zooplankton for phytoplankton.

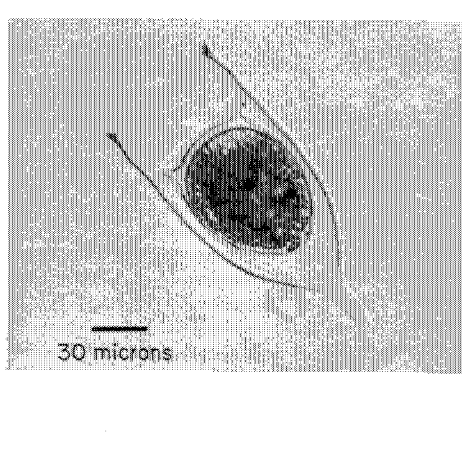
In my laboratory we are investigating the ecological roles of the larger, plankton-eating, planktonic ciliates. Our approach combines sampling and experimentation in the field with laboratory experiments, using phytoplankton and ciliates cultured in our laboratory. The field work has concentrated on the ciliates in local estuaries and ciliates in productive, coastal waters of the Gulf of Mexico. We are finding that some ciliates are associated with blooms of specific phytoplankters and that these ciliates can selectively feed on these species of phytoplankton: e.g., the tintinnid, *Favella* (see photographs), is a predator on dinoflagellates both in New England waters and in the Gulf of Mexico. This selective predation by ciliates may have an important influence on the species composition and the dynamics of algal blooms. In addition, we have found that some of the larger ciliates, i.e., *Favella*, are predators both on smaller ciliates and on the phytoplankton upon which these smaller ciliates feed. Such triangular trophic structure, in which one species is both a predator on and the competitor of another species, may be common among the ciliates since many can engulf particles of a size almost equal to their own. Our early investigations indicate that this phenomenon may be a critical factor in the regulation of ciliate grazing pressure, and we are studying this further. We have also found that common, omnivorous copepods prey on planktonic ciliates, perhaps preferring them to phytoplankton, and that macrozooplankton, particularly copepod, predation may exert a control on ciliate populations.

In local estuaries, we have carried out experiments to determine the in situ growth rates of planktonic ciliates. The data generated by these experiments indicate that in situ net growth rates are very variable, but they are often lower than the maximal rate which can be reached in culture. A comparison of laboratory and field results suggests that suboptimal food densities, predation among ciliates, and parasitism are all factors which reduce the net growth rate of ciliates. Also, during our long term culturing of planktonic ciliates, we have observed that life cycle events can influence both their feeding and growth rates. In *Favella*, conjugation appears to be necessary to maintain viability (first photo). We have also observed conjugation in field

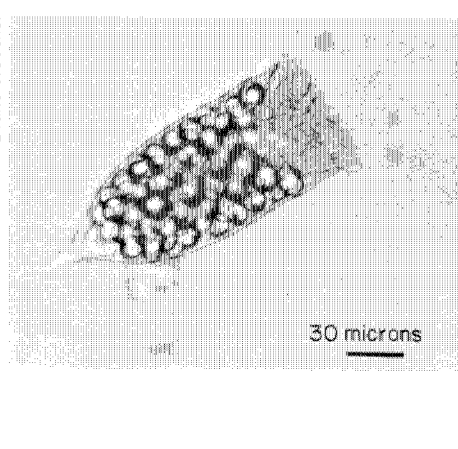

Vicky Cullen



Diane Stoecker



Diane Stoecker



Diane Stoecker

Far left: Diane Stoecker

Left above: Conjugating pair of tintinnid *Favella*.

Left below: *Favella* cyst.

Below: *Favella* parasitized by dinoflagellate *Dubosquella*.

samples which were collected as blooms were ending, leading us to suspect that conjugation often precedes cyst formation (second photo). It is believed that cyst formation may be an important mechanism by which ciliates can survive in a dormant state when conditions are unfavorable, and germination of cysts may synchronize the appearance of ciliates in the plankton with that of their prey. The feeding rates and growth rates of cilates are an integral part of much of our research, and we endeavor to glean any information relevant to the factors affecting them as we proceed in our investigations.

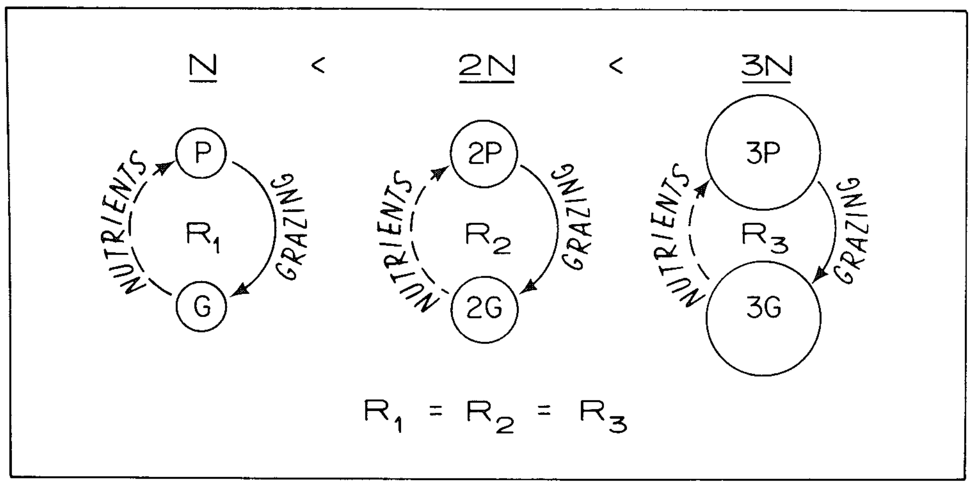
In the Gulf of Mexico our work has focused on the ciliates which may be important in food webs that support larval Gulf menhaden and spot. The first-feeding fish larvae have a very small oral diameter, and ciliates, which are very small animal food, may be important in their diet. We are investigating this by doing laboratory experiments to determine larval fish preference when ciliates, algae, and copepod nauplii (juvenile stages) are available as food.

We are currently expanding our research in the Gulf of Mexico and in local estuaries to determine the effects of natural and induced trace metal perturbations on ciliate/phytoplankton interactions. Trace metal regimes partly control the distribution and abundance of many phytoplankters. As ciliates are specialists on particular algal groups, they may be sensitive to changes in the species composition of the phytoplankton. Conversely, if some ciliates are more sensitive to trace metal perturbations than their algal food, changes in trace metal chemistry may reduce ciliate grazing on phytoplankton. Uncoupling of ciliate/phytoplankton trophic relationships could have an important impact on the dynamics of phytoplankton communities, and this is being investigated.

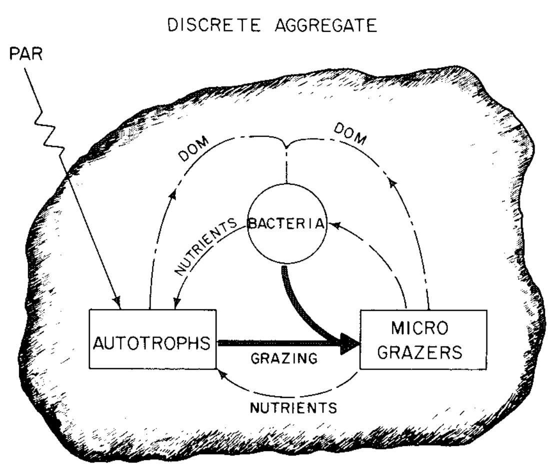
How nutrients are made available to phytoplankton, the primary producers, is yet another aspect to be considered in understanding the dynamics of plankton communities. In many planktonic communities, nutrient regeneration is thought to supply the bulk of nitrogen and phosphorous needed to sustain primary productivity. The role of ciliates in nutrient regeneration may be an important one. Ciliates directly restore nutrients by releasing nitrogen and phosphorus; they indirectly restore nutrients by producing fine suspended particulate matter which is remineralized in the upper part of the water column. We are now beginning to investigate this aspect of the ciliates' function in the plankton.

Below: Joel Goldman, left, in laboratory with Research Assistant Mark Dennett.

Right above: Diagram shows a conceptual scheme of how the total pool of nutrients (N) controls the combined biomass of phytoplankton (P) and grazers (G) in an enclosed portion of oceanic surface water, but not the rates (R) by which grazing and nutrient regeneration occur. Thus, even though there is a threefold increase in N and P+G in the food chains shown, the rates of phytoplankton growth, grazing, and nutrient regeneration would remain constant.



Shelley Lauzon



Left: This diagram shows a conceptual scheme of the spinning wheel-microbial food chain within a discrete organic aggregate. Growth of the autotrophs would be fueled by sunlight, or photosynthetically active radiation (PAR), whereas bacteria would rely on dissolved organic matter (DOM) released by the autotrophs and micrograzers for their energy source. Phagotrophic microflagellates would graze on both the autotrophs and bacteria and regenerate nutrients directly or through bacterial action.

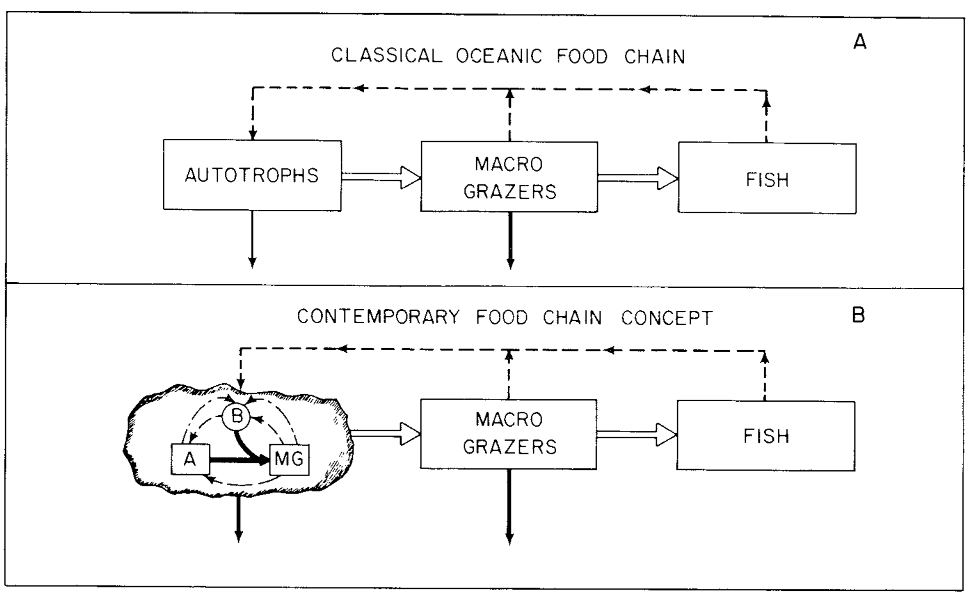
Oceanic Nutrient Cycles

Joel C. Goldman

Surface waters of oceanic regions characterized by permanent thermoclines have, in the past, been described as "biological deserts" because they contain very low concentrations of measurable biomass and are lacking in detectable nutrients. The physical features of such a system preclude any major mechanism by which nutrients from deeper, nutrient-rich waters can enter the euphotic zone. It is generally believed that both the growth rates of individual organisms and the total productivity of the community are severely nutrient-limited in such an enclosed environment. This perception of the open ocean has been based, to a large extent, on the choice of temporal and spatial scales upon which the pertinent biological and chemical measurements typically are made. For example, subsamples obtained from well-mixed, large volume samples (liters to tens of liters) commonly are used at sea both for a variety of analytical measurements and for long-term (tens of hours) bottle incubations to determine rates of primary production and nutrient turnover.

One of the major limitations in using discrete, large-volume samples to represent water-column biological activity is that the chosen temporal and spatial scales are based more on convenience than on the best representation of the real world of organisms. In waters seemingly void of nutrients and consistently low in biomass and in which up to 80 to 90 percent of the available nutrients are believed to be recycled within the euphotic zone, phytoplankton growth would have to be balanced both by herbivore grazing and by concomitant nutrient regeneration. Such a system is akin to a spinning wheel. As seen in the top figure at left, the rate at which this wheel spins is dependent not on the total nutrients and biomass of the system, but only on the tight coupling between phytoplankton and grazer components. The combined biomass of such a system is clearly a function of the total pool of available nutrients, however.

It is my view that this wheel may be spinning at rates approaching the maximum possible so that the growth rate of individual phytoplankton cells is not limited by nutrient availability, but only by how fast the fixed quantity of nutrients is processed and turned over by heterotrophic organisms. Several lines of reasoning have led me to this view. First, there appears to be a remarkable consistency in the gross chemical composition of particulate matter in oceanic surface waters, which frequently is characterized by the "Redfield proportions" of $C_{106}N_{16}P_1$ (that is, for every atom of phosphorus, there are 106 atoms of carbon and 16 atoms of nitrogen). In contrast, these proportions are found in laboratory cultures of phytoplankton only when nitrogen or phosphorus begins to become non-limiting and the growth rate approaches the maximum possible. Second, marine phytoplankton appear to have such a tremendous affinity for inorganic nutrients like ammonium, nitrate, and phosphate that they can grow under laboratory conditions at rates approaching the maximum possible when ambient concentrations of these nutrients are below detection limits. And third, during recent years some revolutionary insights have been made into the functioning of oceanic food chains. Among these new ideas is the notion that micro-heterotrophic processes involving protozoa and bacteria, rather than direct macro-zooplankton grazing, regulate the flow of energy and nutrients beyond the autotroph step. Pertinent to this argument is the growing realization that very small (about 10 microns) organisms, both autotrophic and heterotrophic, make up a very significant fraction of the plankton in oceanic waters and are responsible for the bulk of both primary productivity and nutrient regeneration. The major grazer of small phytoplankton in such a system would not be large zooplankton such as copepods, but, rather, small herbivorous protozoa such as microflagellates. Although we know virtually nothing of the predator-prey relationships between small autotrophs and equally small heterotrophic micro-flagellates, there is increasing evidence that these voracious protozoans are the main grazers of bacteria in the ocean.



Comparison of the classical oceanic food chain concept with a more contemporary concept. In the classical concept, phytoplankton (autotrophs) are the major food source for macrozooplankton, whereas the contemporary idea is that aggregations of organic matter upon which both small autotrophic and equally small heterotrophic organisms adhere are the major food source for the macrograzers. Nutrients (dashed lines) are regenerated both inside and outside of the aggregate, and organic matter is transported by sinking (solid arrows) to deeper waters both as aggregates and as the waste products (fecal pellets) of the macrograzers.

Reports on Research

If we accept the spinning wheel hypothesis as a reasonable description of oceanic food chain dynamics, then we must consider the possible environmental conditions under which such a rapid and continuous sequence of events could occur. At one end of the spectrum is the generally prevailing view of oceanic life that microbes are randomly dispersed and truly planktonic. In such a system autotrophs would be forced to depend on undetectably low nutrient concentrations that were homogenously distributed in time and space through molecular diffusion; similarly, microflagellates would rely on chance encounters with their prey (bacteria and phytoplankton). Intuitively, such a bleak, desertlike environment would not seem capable of supporting rapidly growing and nutritionally sufficient microbial populations, given the sparse numbers of microorganisms generally believed to be present in the euphotic zone of the open ocean.

Another view of oceanic microbial life, one consistent with the rapidly spinning wheel hypothesis, is that microbes are not distributed homogenously in the water column, but rather are intimately associated with microscopic organic aggregates which are unevenly distributed in surface waters and which are formed by complex physical-chemical processes. These minute flocculated masses of organic material, which small autotrophs, protozoa, and bacteria can adhere to and colonize, are ever present in marine waters, but in varying numbers. Conceptually, each aggregate can be thought of as a "floating oasis" in the biological desert, providing, as seen in the second figure, the necessary physical surface upon which attached organisms can concentrate nutrients from the surrounding seawater and then cycle them efficiently within a discrete, but enriched, microenvironment. From this perspective, the microenvironment surrounding individual microbes is the important determinant of how fast the wheel is capable of spinning.

The ability to adhere to a surface in an otherwise nutrient-poor environment may thus be an adaptive feature of successful oceanic organisms. In addition, it may not only represent an important way that primarily-fixed organic matter is packaged into large enough particles to be consumed readily by macrograzers (e.g., copepods) that otherwise could not graze on small individual organisms, but it also may be a mechanism by which transport of this material to deeper waters can be facilitated through rapid sinking (see figure page 17).

Thus the sparse "biological desert" of the open ocean may appear that way only because we have not, until now, made the right kinds of measurements. Improved techniques are needed for measuring very low concentrations of nutrients, for collecting and enumerating the small and fragile aggregates and associated organisms, and finally for making rate measurements of primary production and nutrient turnover on spatial and temporal scales that represent the "oases" rather than the averaged whole of the ocean desert.

The Role of Nitrogen in Phytoplankton Dynamics

Patricia M. Glibert

Though relatively sparse, phytoplankton play a central role in the oceans as primary producers and ultimately as food for all other members of the food web. Like all other plants, the rate of growth for phytoplankton in the sea depends upon the availability of sufficient nutrients and suitable light and temperature. It is generally assumed that the rate of phytoplankton growth in the sea is limited by the availability of nitrogen because the concentrations of all forms of nitrogen are so low as typically to be unmeasurable. These low nutrient concentrations, combined with the sparse nature of phytoplankton cells, have made it difficult to measure phytoplankton growth rates directly. It has long been thought that phytoplankton must indeed grow very slowly because they are starved for nutrients.

Recently, however, an alternative hypothesis was advanced by Joel Goldman of WHOI and James McCarthy of Harvard University. It suggests that phytoplankton may obtain sufficient nitrogen in waters seemingly devoid of this nutrient by utilizing ephemeral patches of nitrogen which may arise from the processes of zooplankton excretion and bacterial remineralization. By exploiting these patches, phytoplankton may perhaps grow at rates much faster than previously thought without increasing their abundance as long as they are eaten at the same rate as they are reproducing. My research has focused on understanding the potential role of these transient nutrient patches in phytoplankton nutrition, and ultimately phytoplankton growth.

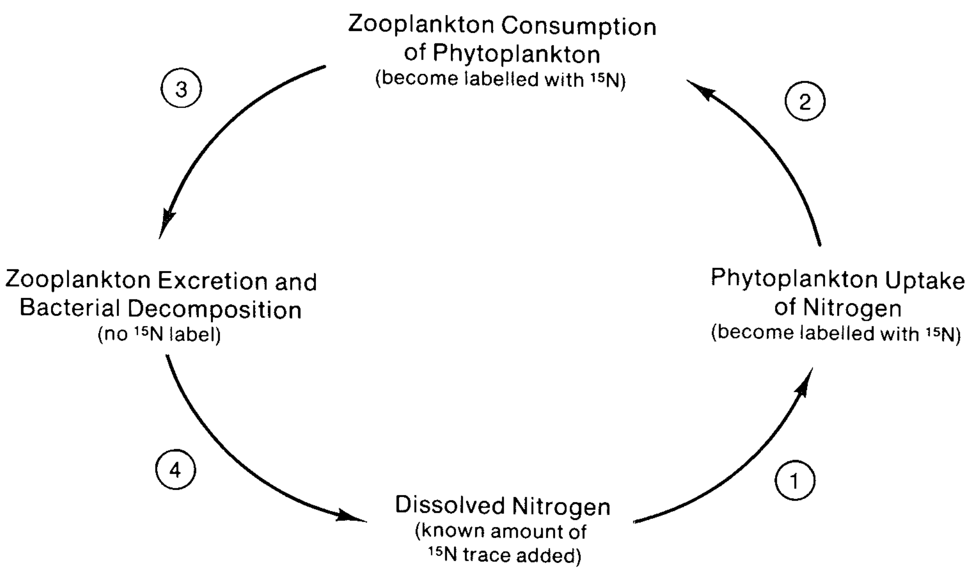
The most sensitive methodology for studying the nitrogen cycle is the use of the heavy isotope of nitrogen, ^{15}N, as a tracer. By exposing natural assemblages of phytoplankton, zooplankton, and bacteria in ocean water to a known concentration of an ^{15}N-labelled nutrient (such as ammonium or nitrate), one can simultaneously follow with time the rates of phytoplankton utilization and zooplankton and bacterial release. This is shown schematically in the upper figure at right. The analytical determination of the quantity of ^{15}N in the sample involves distilling the seawater, using specially designed apparatus, followed by analysis with a mass spectrometer. We have used this method in both coastal and oceanic waters, and our results have demonstrated that phytoplankton are indeed able to use the nitrogen released by zooplankton or bacteria at essentially the same rate that it is produced by excretion processes. Most recently, experiments of this type were conducted on R/V *Knorr* cruise 94 in conjunction with Laurence Madin in order to determine whether regional differences could be determined between Sargasso Sea, Gulf Stream, and Gulf Stream Ring waters. Samples from that cruise are still being processed, but, when finished, they will more than double the total available information on in situ rates of nitrogen cycling in the Atlantic.

The lower figure illustrates another aspect of our work on phytoplankton nutrition. Once nitrogen is taken up by a phytoplankton cell, it may have one of several fates: it may immediately be used to build structural material, such as protein, or it may be stored for future protein synthesis. By using ^{15}N tracer techniques, combined with chemical fractionation (e.g., separating protein from the cell), we can obtain an indication of the nutrient history of the cell. For example, cells which are essentially starved for nitrogen will use nearly all the available nitrogen for making cell protein, whereas cells which are growing under nutrient-rich conditions may store more nitrogen in non-growth-related compounds.

As stated earlier, nutrients are not the only factors influencing the growth of a phytoplankton cell. Light and temperature can also have a strong impact, particularly when conditions are extreme, such as in winter. Ultimately a complete understanding of phytoplankton dynamics will depend on consideration of all these factors.

An example of the interdependence of environmental effects comes from a collaborative study conducted this past year with Joel Goldman in Vineyard Sound, off the coast of Woods Hole. We showed that during the winter (water temperature −0.5°C) phytoplankton photosynthesis and nitrogen uptake occurred at the highest rates under very shaded light, whereas during the summer (water temperature 24.0°C) highest rates of photosynthesis and nitrogen uptake were observed under full sunlight. Ultimately a species which cannot adapt to seasonally varying light and temperature will be replaced by a species which can. Thus, these interactive effects may help to explain the succession of species observed throughout the year and why a particular species may demonstrate explosive growth at various times.

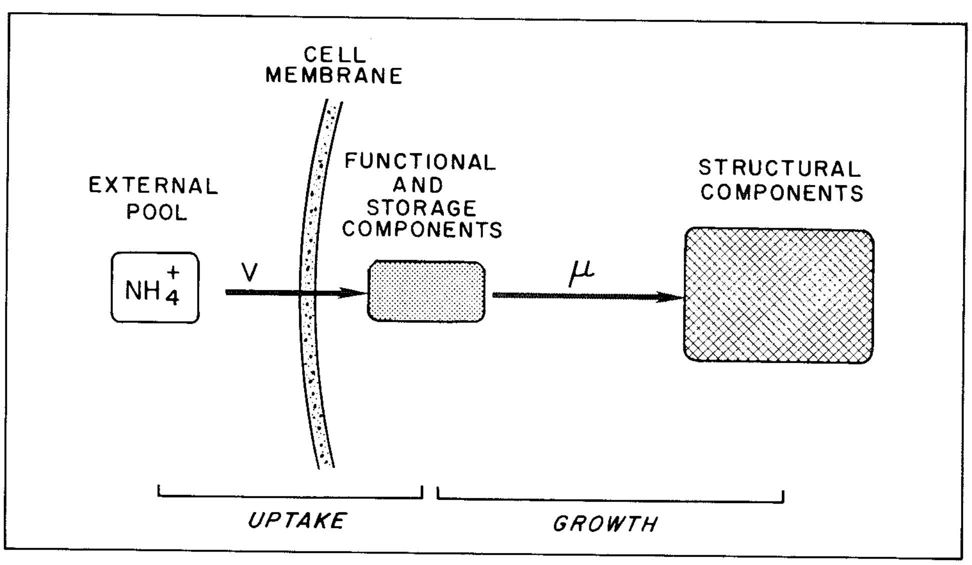
This spring we will be examining these factors in the context of growth of the "red-tide" dinoflagellate, *Gonyaulax tamarensis*, in collaboration with Donald Anderson. Additionally, over the next several years a project is planned (in collaboration with Joel Goldman, Laurence Madin, and several other WHOI scientists) to address the rates of nitrogen cycling in the Sargasso Sea and the temporal and spatial variability between coupled chemical and biological processes and availability of particulate material in deeper waters. At the same time we are pursuing newer, more sensitive techniques for analyzing the very small concentrations of nitrogen in the oceans.



Left above: Schematic diagram shows patterns of labelling with ^{15}N tracer. A ^{15}N labelled compound (such as ammonium) added to seawater will first be taken up by phytoplankton (1), then zooplankton will consume the phytoplankton (2). Simultaneously, the zooplankton and bacteria will be releasing nitrogen (3), but this will not be labelled in ^{15}N because it will reflect phytoplankton previously in the guts of the animals. The result is a decrease in the amount of dissolved ^{15}N (4).

Left below: Diagram represents the possible fates of nitrogen inside the cell as storage components or as growth-related structural components.

Below: Pat Glibert



Vicky Cullen

Reports on Research

Dinoflagellates: Strategies for Survival

Donald M. Anderson

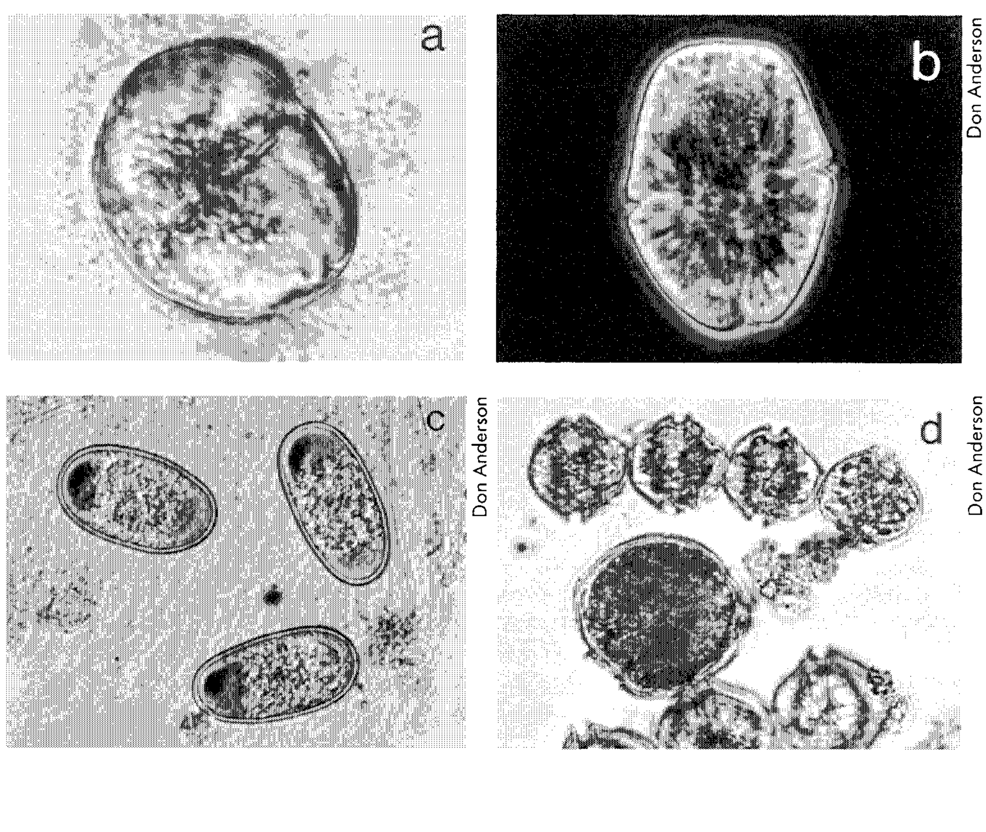
The dinoflagellates are one of the most important classes of phytoplankton within the diverse marine planktonic assemblage. Of more than 1,500 living species, approximately half are photosynthetic (autotrophic) and thus are capable of using the energy in sunlight to convert carbon dioxide and water into the organic carbon that constitutes the basis of the marine food chain. The remainder are heterotrophic — incapable of photosynthesis and instead fulfilling energy and nutritional needs through the consumption of dissolved or particulate organic matter.

In addition to their importance as carbon sources at the base of the marine food web, the dinoflagellates are noteworthy for the magnitude and impacts of their blooms. Many species tend to accumulate in concentrated populations, often resulting in discolored water or "red tides." Although many of these red tides are relatively harmless and may in fact represent a concentrated source of food for other marine organisms, in some cases they can be extremely dangerous. This is true along the coast of Florida, for example, where red tide blooms of the dinoflagellate *Ptychodiscus brevis* cause massive fish kills and extensive losses to recreation and tourist industries. In other parts of the United States and the world, species of the genus *Gonyaulax* bloom less spectacularly (i.e., often without red water), but their occurrence is nevertheless dangerous because of the associated outbreaks of paralytic shellfish poisoning (PSP). This results when shellfish ingest the dinoflagellates as food, retaining and accumulating a potent neurotoxin which can then be fatal to people.

The dinoflagellates are an extremely successful class of phytoplankton. This is evident not only in their widespread distribution and occasional dominance in marine waters, but also because they are one of the more primitive algal classes and thus have survived millions of years of natural selection. Much of the research in my laboratory is directed towards an understanding of the ecological strategies of several bloom-forming dinoflagellates. Due to the complex ways in which these organisms interact with their biological and physical environment, our studies span a wide range of disciplines.

One of the more important attributes of many of the organisms we study is that they include dormant cyst stages in their life cycles. The figure below gives an example of the cysts and associate motile stages of two dinoflagellates. Accumulations of cysts in sediments have been recognized as "seedbeds" from which these organisms can inoculate the overlying waters through germination. Cysts also facilitate geographic dispersal and ensure survival through environmental extremes. The existence of living dinoflagellate species whose cysts can be found in early Tertiary sediments is strong evidence of the effectiveness of this strategy in responding to short- and long-term environmental fluctuations.

For many years, scientists were unable to induce cyst formation in laboratory cultures of marine dinoflagellates and thus were forced to glean whatever information they could directly from sediment samples. Although this made certain physiological studies impractical, a great deal was learned about the distribution and diversity of cysts in various sedimentary environments. We have expanded the goals of such field studies and are presently using sediment samples to map the distribution of certain cysts and to correlate these patterns with measurements of relevant chemical and hydrographic parameters. In a collaborative project with scientists from the University of Delaware and The Johns

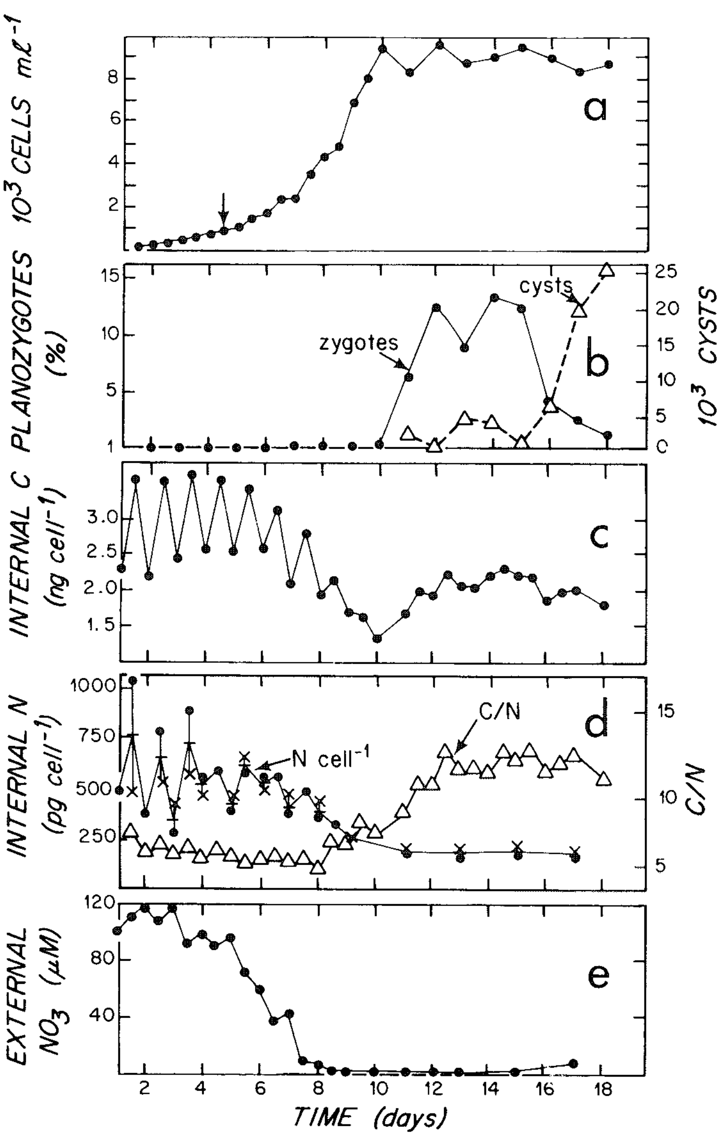


Photos show dinoflagellate resting cysts and their corresponding motile stages: (a) The cyst of *Gyrodinium uncatenum*, surrounded by mucilage and detritus. Diameter = 42 microns. (b) Swimming, vegetative cell following germination from cyst in (a). 50 by 40 microns. (c) Cysts of *Gonyaulax tamarensis*. Notice the central band containing lipid and starch reserves. Each cyst is approximately 50 x 25 microns. (d) Motile *G. tamarensis* cells. Note the chain of four cells following division. Also note the large, dark cell which is also *G. tamarensis* but is a zygote immediately prior to its transformation into a cyst. This large cell is the result of the sexual fusion of two smaller cells.

Hopkins University, we demonstrated that the dense accumulations of the dinoflagellate *Gyrodinium uncatenum* in the Potomac River were the result of persistent estuarine frontal features that retained and recirculated the *Gyrodinium* populations. Cysts formed by this species settled to the sediments in areas determined by the water circulation near the frontal convergences, creating a concentrated "seedbed" for future blooms. Thus the locations of the initial inoculum and the subsequent blooms could be predicted from a knowledge of estuarine circulation patterns.

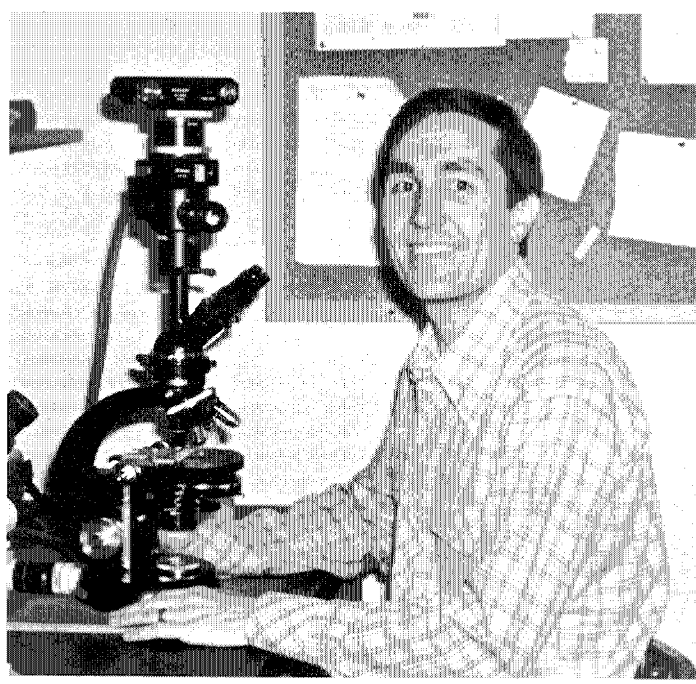
Studies like these require quantitative assessment of the cyst distribution. To this end, we developed sampling and processing techniques that preserve the vertical and horizontal structure of cyst distributions. Where most previous sampling efforts concentrated on the flocculent surface layer of sediments (under the assumption that cysts are relatively light and would thus accumulate above the more dense sands and clays), we found a variety of vertical cyst profiles, many with peak abundances five or six centimeters below the surface. The fate of cysts at these depths and their role in seeding blooms are topics for continuing study.

One important aspect of our field research program is that we take advantage of the unique characteristics of nearby Cape Cod salt ponds. These small embayments provide ideal growth conditions for dinoflagellates and they also have restricted tidal flushing and thus permit a population to be studied from initiation through cyst formation and decline. Thus we can monitor not only the vegetative, dividing cells of a species but the stages that are precursors to cyst formation or the product of cyst germination as well. Part d of the first figure shows how morphologically distinct some of these stages are. One of our objectives has been to test the widely-held assumption that cyst formation is a response to adverse conditions. By following one *Gonyaulax* population throughout a bloom sequence, we found that zygotes (precursors to cysts) appeared when nutrient concentrations were relatively high and when temperature and other growth factors were near optimal. It now appears that the cells anticipate "hard times" ahead and thus initiate encystment sufficiently early to accumulate nutrient



Left: Plots show time course of cyst formation in *Gonyaulax tamarensis.* (a) Total motile cells through time. Note that the cell number increases exponentially through day 10 and remains constant thereafter. (b) Life cycle stages. Zygotes appear in large numbers on day 11, followed six days later by cysts. (c) Internal carbon pool showing early diel fluctuations and general decrease as exponential growth ceases. (d) Internal nitrogen pool and C/N ratio. (e) External nitrogen concentration. This sequence demonstrates that zygotes have appeared just as internal nitrogen pools reach subsistence levels, several days after external supplies were exhausted. Knowing that the gametes that fused to make each zygote were present 2 to 3 days earlier, we see that the induction of sexuality occurred when the nitrogen per cell was twice the subsistence level (i.e., where no growth occurs) and external nutrients were well above detection limits. Thus these cells appear to be going into cyst formation well before any nutrient starvation occurs.

Below: Don Anderson



Vicky Cullen

reserves to sustain a prolonged resting period in the sediments.

Despite the obvious value of field measurements in addressing these issues, the inability to conduct laboratory studies on encystment remained a serious constraint to our understanding. After extensive effort, we can now manipulate certain dinoflagellates through their entire life cycle. This has opened up a wealth of experimental opportunities that we are only beginning to tap.

The figure on page 21 demonstrates the results of our first encystment studies in culture. In this case we wanted to monitor the life cycle stages over very small time intervals to see how the transformations correlated with both external and internal cues (e.g., changes in ambient nutrient concentrations or internal nutrient pools). Our preliminary data tend to confirm the field observations, in that cyst formation began when external nutrients were well above detection limits and internal pools were more than double the subsistence levels that are indicative of nutrient starvation. Our next efforts will be directed towards the development of quantitative cytological techniques that will permit us to use DNA per cell or some other physiological parameter to pinpoint the onset of the cyst formation process. Our present reliance on external morphology is not sufficiently precise.

These are but a few examples of the ongoing studies directed at an understanding of the factors regulating dinoflagellate dynamics in natural waters. Our efforts necessarily span several scientific disciplines and take us from the planktonic to the benthic environment. Our hope is that this comprehensive approach will lead to an understanding of the subtle factors that regulate the growth and distribution of this important algal class in the oceans.

Dormant Eggs of Marine Copepods

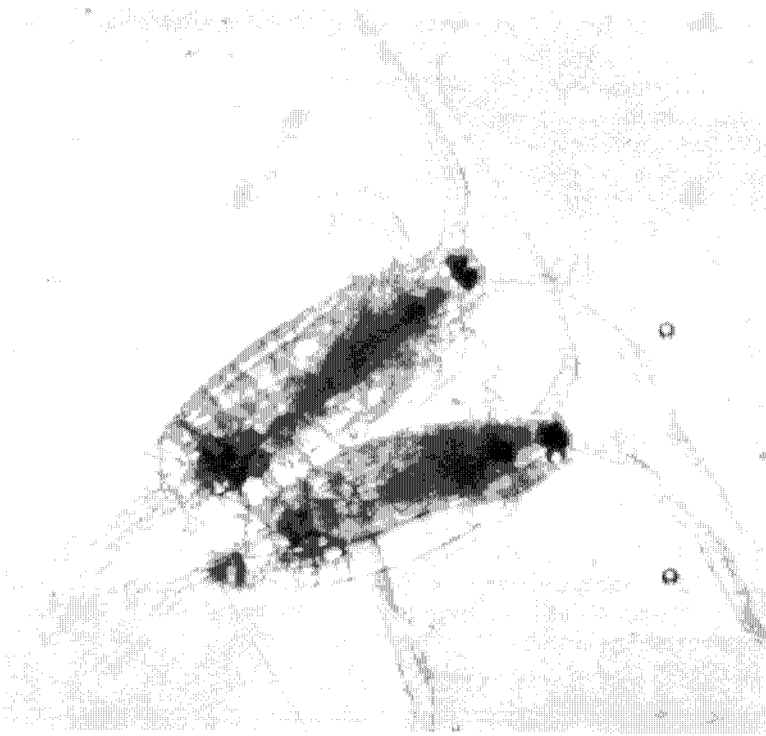
Nancy H. Marcus

The elucidation of factors that control the temporal and spatial patterning of marine species is a fundamental problem in biological oceanography. Copepods are important members of the zooplankton community in most areas of the marine system. Many species have broad spatial distributions that often encompass an extensive latitudinal gradient. Along such a gradient, as well as within any one region, environmental factors vary, often on a seasonal basis, so that periods of active growth, development, and reproduction are timed to coincide with the occurrence of favorable conditions, and periods of inactivity, migration, and dispersal are synchronized to unfavorable conditions. This pattern is most typical of temperate-boreal coastal waters in which environmental fluctuations are typically greater than in tropical or open ocean regions. During periods of extreme temperatures or salinities, food scarcity, or predator abundance, some copepod species disappear entirely from the plankton. For many of these species, their perpetuation in a region year after year is due to an influx of individuals from offshore or other geographic populations. An alternative mechanism, which until recently has largely been ignored, is the renewed development of dormant benthic stages following the resumption of favorable conditions.

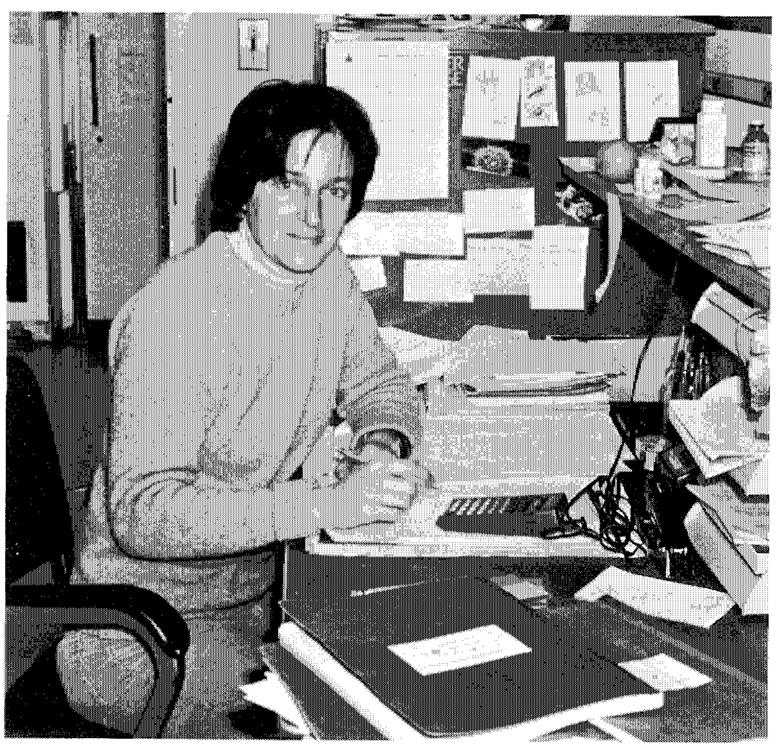
The production of dormant benthic eggs by planktonic marine copepods was first postulated 45 years ago, but only within the last ten years have investigators demonstrated their existence. At the Woods Hole Oceanographic Institution this problem first received attention in the mid-seventies by George Grice, Victoria Gibson, and Thomas Lawson. They showed for two local species, *Labidocera aestiva* and *Pontella meadi*, that two types of eggs are produced, a subitaneous egg that hatches within a few days at optimal temperatures (e.g., 15 to 20°C), and a dormant egg which hatches only after a delay period of several weeks or months. It is now evident that the eggs or cysts of many marine planktonic organisms (e.g., copepods, cladocerans, tintinnids, dinoflagellates) exist in the bottom sediments of coastal waters.

For the past five years we have been studying the dormancy response of *L. aestiva* collected from several locations along the East Coast of the United States. The range of this species extends from Woods Hole, MA, south to Florida. By rearing individuals in the laboratory, we have shown that the type of egg produced by a female is determined by a temperature-compensated photoperiodic response. Short daylength periods (of less than 12 hours of light) induce the production of dormant eggs, whereas longer daylengths induce subitaneous egg production. For a given photoperiod, colder temperatures induce production of a higher proportion of dormant eggs. The specific temperature and photoperiodic conditions that induce dormant egg production varies among females both within and between populations. The results suggest that adaptation to seasonal fluctuations and local environmental patterns leads to genetic differentiation of these organisms that spend their entire life cycle as plankton. In Woods Hole, where seasonal fluctuation of environmental factors is considerable, production of dormant eggs occurs in the fall. This response is critical for perpetuation of the species, since individuals disappear entirely from the plankton during the winter. The dormant eggs remain viable in the bottom sediments and hatch the following spring as water temperatures increase. Dormant eggs can be induced to hatch in the laboratory by chilling them at 5°C for 2 to 4 weeks, followed by warming at 19°C. After such treatments the eggs hatch within 2 to 3 days. In Florida, on the other hand, seasonal variation is moderated and *L. aestiva* exists year-round in the plankton. Females do not produce dormant eggs in the field, nor do they produce them in the laboratory under conditions that are effective for individuals from Woods Hole. Intense selection for an optimal life history pattern in these ecologically different geographic areas apparently overrides the homogenizing effects of any interbreeding that may occur between the populations. Through evolutionary time such selection may ultimately lead to the formation of distinct species.

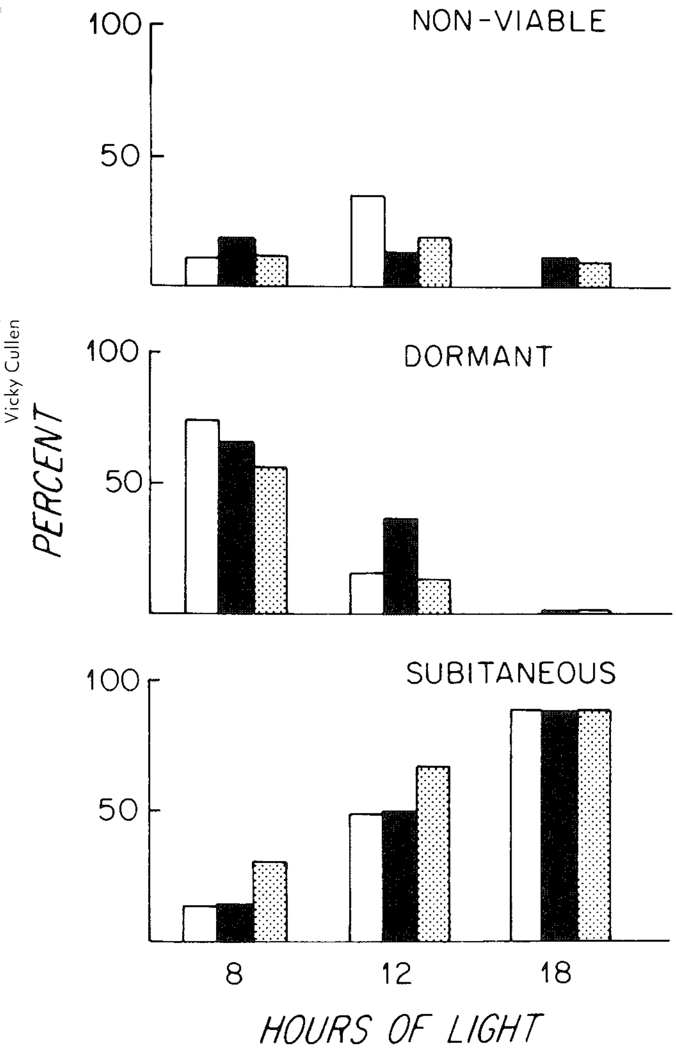
Research to date has demonstrated that the highest densities of copepod eggs (ca. $10^6/m^2$) occur in sediments with a high percentage of silt and clay sized particles less than 63 microns in diameter. These results suggest that eggs produced at different times and places gradually accumulate in specific areas on the sea bottom. For *L. aestiva* and other species with similar life history cycles, accumulations of eggs at such high densities on the sea-bottom must provide an important source for recruitment of nauplii (juvenile stages) into the planktonic population. Over the next few years our research will be focused on elucidating the distribution, abundance, and viability of copepod eggs on the sea bottom, and evaluating the influence of physical, biological, and chemical factors on these parameters. For the eggs that reside in the sediments the temporal and spatial patterns of their hatching should directly influence the population dynamics, genetic structure, and species diversity of planktonic communities.



Nancy Marcus



Vicky Cullen



Left: *Labidocera aestiva* adults, female above, male below.

Below: Subitaneous, dormant, and non-viable egg production (percent) by females reared under different light conditions at 13.5 to 15.5°C (white), 17.0 to 19.0°C (black), and 23.0 to 25.0°C (dots). At 13.5 to 15.5°C and 18 hours of light only subitaneous egg production was determined.

Below left: Nancy Marcus

Reports on Research

Crustacean Development and Metamorphosis

Judith M. Capuzzo

Early development in marine crustaceans is characterized by a sequence of distinct morphological stages, increasing in complexity in both internal and external form from the time of hatching of the egg to metamorphosis of the postlarval or juvenile stage. Although development in the crustaceans is extremely complex and diverse among various groups, several trends are apparent in crustacean development and are illustrated in the figure below. The nauplius larva is the basic developmental form that may be transformed to a more complex developmental stage after molting. During early periods of development in more primitive groups, such as barnacles and copepods, developmental stages are primarily free-swimming planktonic forms, whereas in more advanced forms, such as lobsters and crabs, early developmental stages are embryonic and the larvae hatch at a more advanced morphological form. In addition larval stages of more advanced forms are reminiscent of adult stages of more primitive forms and reflect evolutionary relationships of the various groups.

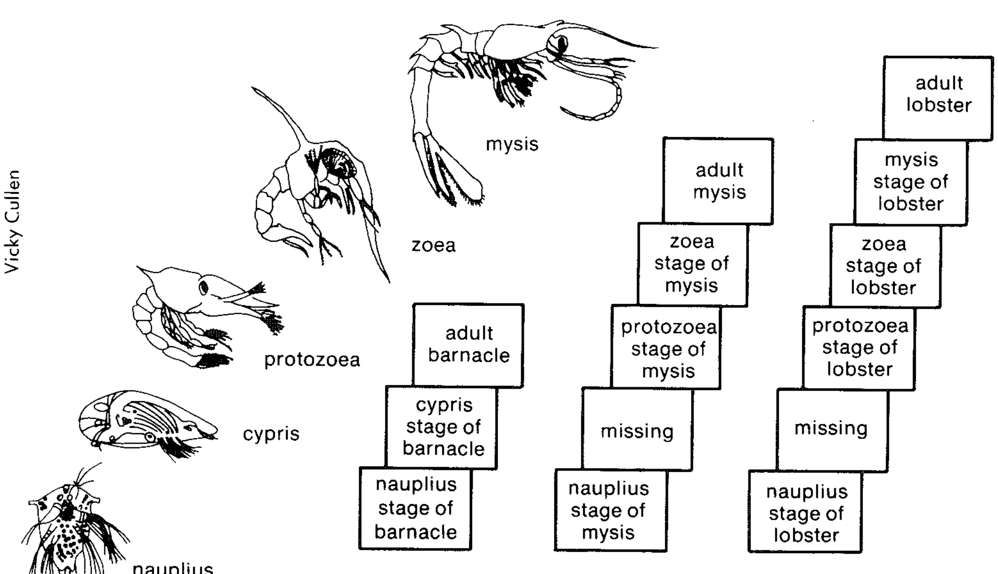
Research on larval development in marine crustaceans has traditionally focused on the morphological and behavioral aspects of development and metamorphosis. More recently, attention has been directed to the physiological and biochemical aspects of crustacean development. In our laboratory we have focused our studies on the early development of the American lobster, *Homarus americanus*, with particular emphasis given to the physiological and biochemical changes associated with the transition from the egg to larval development and metamorphosis to the postlarval form. Larval development in the lobster was described by Herrick as early as 1896 and is illustrated in the figure on the next page. In the first three larval stages there is a gradual development of the swimmerets and a forward movement of the maxillae, maxillipeds and pereiopods. These mysid stages swim using the thoracic legs and flexions of the tail and with the head pointed in a downward position. In the last larval stage (stage 4) the swimmerets become operable, the other appendages are positioned similar to the adult, and the body is in a straight position during swimming with the claws extended in front of the head. The morphological and behavioral changes in stage 4 larvae are correlated with the onset of a bottom-dwelling existence; stage 4 lobsters are active swimmers but may continue to be found among the plankton for several days before seeking a suitable benthic habitat. With the molt to stage 5 (the first postlarval stage) there is a complete shift from a pelagic to benthic habitat.

In our studies of the metabolic changes associated with this developmental sequence, we established that changes in metabolic activity during larval development of the lobster do not vary as a function of body size alone. Changes in metabolic rates indicate an increased energy demand of successive larval stages that reflects the physiological compensation for the rapid morphological and behavioral changes taking place. Successful development and metamorphosis of larval lobsters are dependent on the balance and efficient utilization of energy reserves, with the catabolism of lipid and protein being of primary importance. Glenn Sasaki, a WHOI/MIT Joint Program student working in my laboratory, is currently investigating the changes in lipid composition and lipid utilization of successive developmental stages of the lobster to elucidate the transition in energy utilization and storage patterns from embryonic to postlarval development. Using both light microscopy and electron microscopy, Patricia Biesiot,

Right: Trends in crustacean development.

Below: Judy Capuzzo

Vicky Cullen



another WHOI/MIT student, is studying the morphological aspects of lipid storage in the developing hepatopancreas of larval lobsters. It is apparent from our investigations that cyclical changes in physiological, biochemical, and morphological parameters are evident within the molt cycle of each developmental stage and strongly suggest that these developmental processes are under endogenous hormonal control. We are currently initiating studies to address the structural and physiological aspects of ecdysone (the molting hormone) synthesis in early larval stages and the role it plays in controlling developmental processes.

In an additional aspect of our work, we are evaluating how exposure to environmental pollutants may affect developmental processes in marine crustaceans. Exposure of larval lobsters to petroleum hydrocarbons results in decreased rates of lipid synthesis and utilization and inhibition of the molting process, possibly due to a deficiency in ecdysone synthesis. Our studies will continue to attempt to identify the toxicological mechanisms responsible for the disruption in energetics and development of larval crustaceans associated with pollutant exposure.

Bioenergetics of Marine Bivalve Molluscs

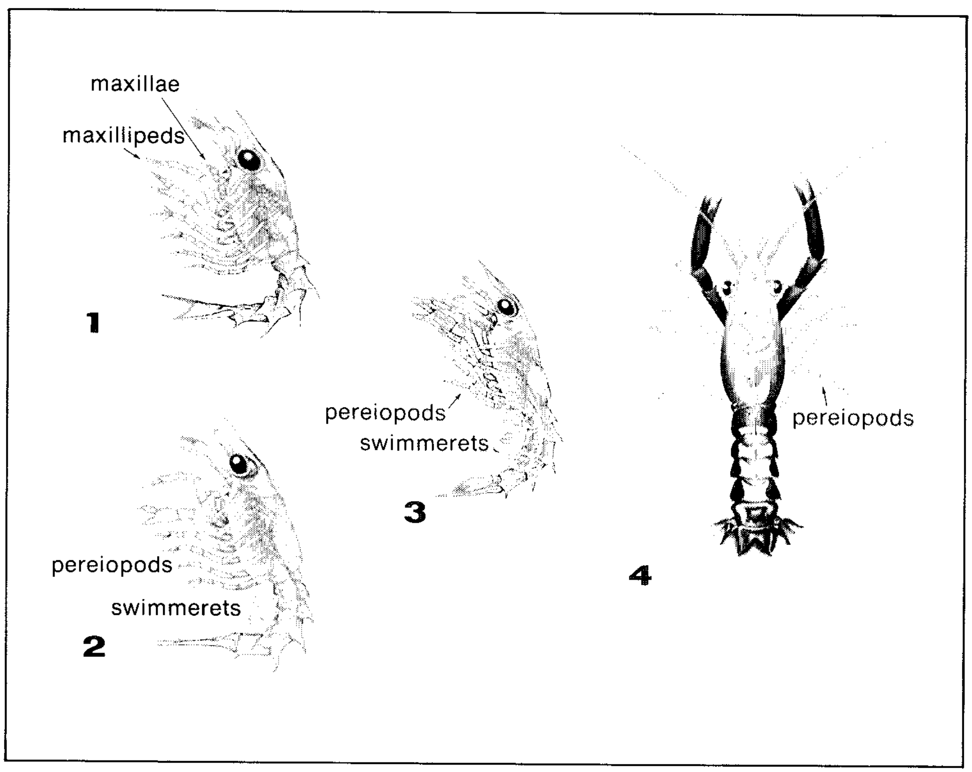
Roger Mann and Scott M. Gallager

Bivalve molluscs are important members of the benthic community from the intertidal zone to the deep ocean bottom and from polar to equatorial latitudes. They support commercial fisheries, are the focus of many aquaculture ventures, and are commonly found in marine fouling communities. There is, therefore, both academic and practical interest in examining the quantitative bioenergetics of marine bivalve molluscs.

The adult bivalve is characterized as a sedentary animal living on or just below the water/substrate interface. By contrast, the larval forms are usually planktonic for all or part of their development from egg to metamorphosis. During their planktonic development bivalve larvae meet their energy requirements from reserves of lipid and, to a lesser extent, protein (figure next page).

These reserves are either furnished directly from the adult with the egg (lecithotrophic development) or maintained by feeding on phytoplankton (planktotrophic development). Analytical procedures to measure lipid and protein contents of developing larvae are relatively slow and complex. Recently, we have developed a simple, rapid technique to qualitatively examine lipid content visually using a lipid specific stain. In laboratory experiments we have found the technique to be sensitive to changes of only a few nanograms of lipid per larvae. In conjunction with measurements of feeding rate and energy expenditure through respiration and growth, we believe that this technique can be used as a valuable tool to assess the "health" of bivalve larvae. We have introduced the technique to the commercial bivalve culture industry where it is now being used on a regular basis. In the near future we hope to use the technique in the field where we feel it has application in both the study of natural variability of nutritional status of zooplankton and in examining the influence of man's activity on those zooplankton through pollution.

The transition from planktonic to benthic existence at metamorphosis is accompanied by a change from a lipid-protein to a carbohydrate based energy metabolism. This facilitates respiration in the low oxygen environments where many adult bivalves live. Adult bivalves usually obtain their energy from phytoplankton, which are retained during filter feeding, or from



Drawings from Herrick

Left: Illustration of larval development of the American lobster, *Homarus americanus*.

Reports on Research

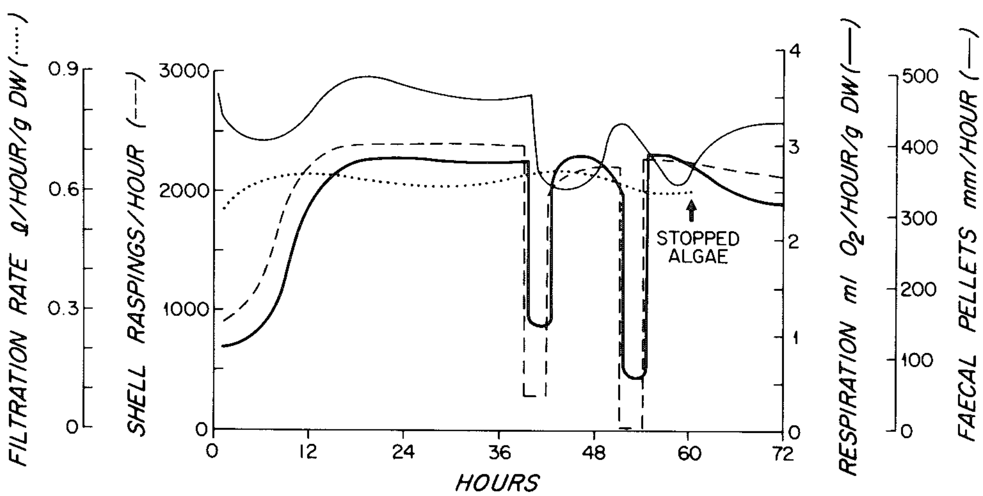
detritus during deposit feeding. The role of dissolved organic material (DOM) in the nutrition of soft bodied marine invertebrates has long been a subject of active debate. Recent advances in analytical instrumentation, notably high performance liquid chromatography, has opened the door to critical experimentation in this subject area. Initial results suggest that DOM may indeed be important to adult bivalves, but more work is needed before generalizations can be made. A number of adult bivalves also appear to obtain at least part of their energy requirements from symbiotic relationships with microorganisms. The best known of these is the giant clam *Tridacna* from the Southwest Pacific which harbors photosynthetic zoo-xanthellae in its exposed siphonal tissue. There is strong evidence to suggest that giant clams of the genus *Calyptogena* from the deep ocean "hot" vents have a symbiosis with chemosynthetic sulfur oxidizing bacteria. We have examined a third group of bivalves which have bacterial symbionts. These are the wood boring clams of the family Teredinidae, more commonly known as shipworms (an unfortunate misnomer, although it is not difficult to understand why early observers failed to detect or note the significance of the much reduced valves in the shipworms).

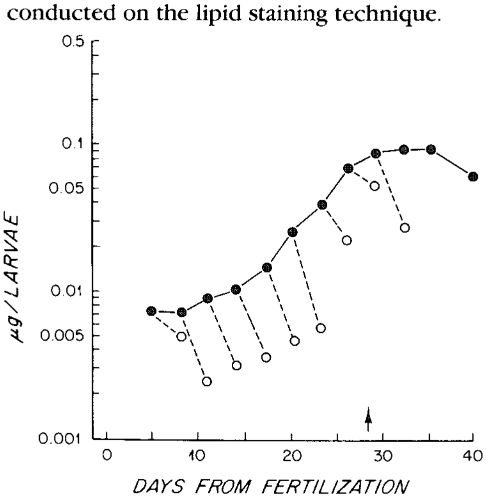
The shipworms bore into, ingest, and digest wood in the marine environment. Not only are they a significant fouling problem but they are also important in the degradation and recycling of large woody debris that enters the oceans from terrestrial systems. In laboratory systems we were surprised to find that growth rate of adult shipworms maintained in wooden blocks in seawater was not influenced by the addition of phytoplankton to that seawater, even though the added phytoplankton was filtered by the shipworms. Long term measurements of physiological activity of adult shipworms indicated that a large portion of the energy expended by actively boring shipworms is devoted to the boring process per se rather than pumping of water across the gills or maintenance metabolism (figure below). Two questions were evident. How did the shipworm break down the cellulose content of the wood to assimilable simple sugar which could be used to offset the tremendous energy cost associated with boring, and how did the shipworm in the system without added phytoplankton satisfy its dietary nitrogen requirements? The latter

Below: Increase in lipid content of cultured larvae of the shipworm *Teredo navalis* during larval development (solid line). The broken lines describe periods during which larvae were removed from the culture and starved for periods of three days. Note the depletion of the lipid energy reserve on starvation. The arrow indicates that 50 percent of the population have begun the metamorphosis to the adult stage.

Upper right: A continuous recording of oxygen consumption, boring, and filtration activity by an adult shipworm. Note that filtration and boring can function independently and that oxygen consumption decreases markedly on cessation of boring.

Lower right: Scott Gallager, left, and Roger Mann, second from left, talk with participants in a workshop they conducted on the lipid staining technique.





Shelley Lauzon

question is particularly relevant in that nitrogen is a basic building block of protein, yet wood is very low in nitrogen content. The answer came when Ruth Turner and Bradford Calloway of Harvard University and John Waterbury of the Department of Biology at WHOI isolated a bacterium from the gills of the shipworm. This unique bacterium, still to be formally named and described, can both fix nitrogen and degrade cellulose to simple sugars. Very large numbers of these bacteria have now been found in the gills of several shipworm species. The shipworm provides an environment conducive to the growth and survival of the bacteria while the bacteria aid the shipworm in wood digestion and provision of dietary nitrogen. Future collaborative work with Turner, Calloway, and Waterbury is focused on a better understanding of the quantitative importance of this symbiosis to the energy requirement of the adult shipworm and describing the means by which the symbiosis is maintained from generation to generation of shipworm.

The life styles of the larval and adult bivalve mollusc offer many contrasts. Bioenergetics studies offer a means by which these life styles can be compared quantitatively both to one another and to other components in marine ecosystems.

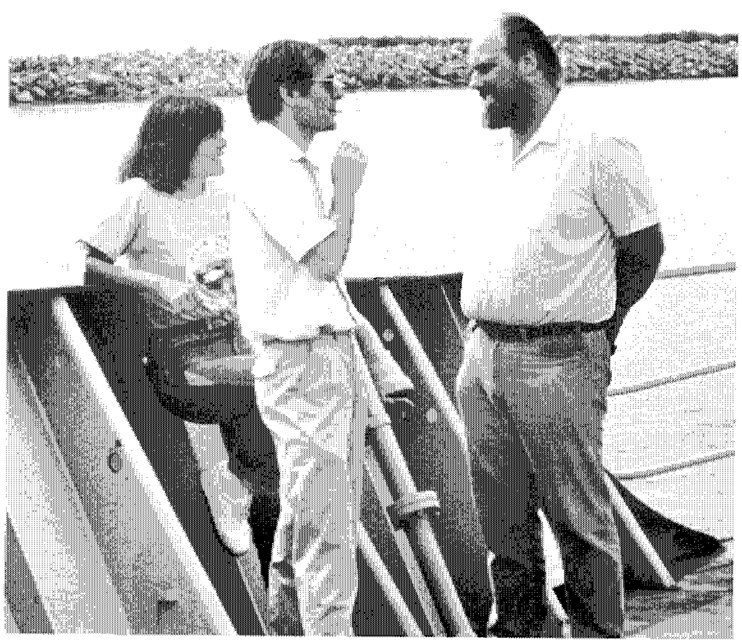
The Dynamics of Deep-Sea Benthic Communities

J. Frederick Grassle and Howard L. Sanders

The qualitative description of deep-sea benthic communities was not possible until the development of new trawling techniques in the mid-60's, and even now there are only a handful of quantitative descriptions of deep-sea bottom communities. The taxonomic work that is the basis of future deep-sea studies is nearing completion for many of the major taxa collected over the last two decades by Woods Hole ships from the major Atlantic Ocean basins.

With good taxonomy as the key, we are now studying the dynamics of deep-sea communities. The deep-diving submersible has been used to establish bottom stations marked with long-term transponders so that we can conduct experiments on the bottom lasting from several weeks to several years. During the Galapagos Rift expedition, individual mussels were marked in situ and picked up 11 months later. The increase in size of the animals during this time interval provided one measure of growth. After 5 years on the deep-sea floor off New England we have brought back trays of sediment used to study rates of colonization, and we have sampled around concentrations of wood over even longer time intervals. The deep sea is a good place to conduct ecological experiments for two reasons: 1) the fauna does not change radically with distance and 2) large-scale physical disturbance is very uncommon. It is therefore possible to see similar population responses despite different times of placement and slightly different locations on the bottom, and to draw general conclusions about recolonization rates in the deep sea.

Rates of colonization of new substrata are low in the deep-sea when compared with shallow-water benthic communities. The most rapid response occurs when there are concentrations of potential food. The richest sources of food coming into the community, such as dead carcasses of fish, are rapidly consumed by large scavenging fish and invertebrates. Longer-lasting sources of food such as wood and algae result in population increases of relatively opportunistic species of invertebrates. Most of the deep-sea community, however, is dependent on a more steady rain of particles, often in the form of zooplankton fecal pellets, that settle out of the



Vicky Cullen

Left: Fred Grassle, right, chats with French colleagues aboard R/V *Melville* (Scripps Institution of Oceanography) at the end of an April 1982 research voyage to a hot vent area on the East Pacific Rise.

Below: Howard Sanders, second from left, joins a group examining fresh samples from East Pacific Rise hot vents aboard *Melville*.

Vicky Cullen

Reports on Research

overlying water column onto the bottom.

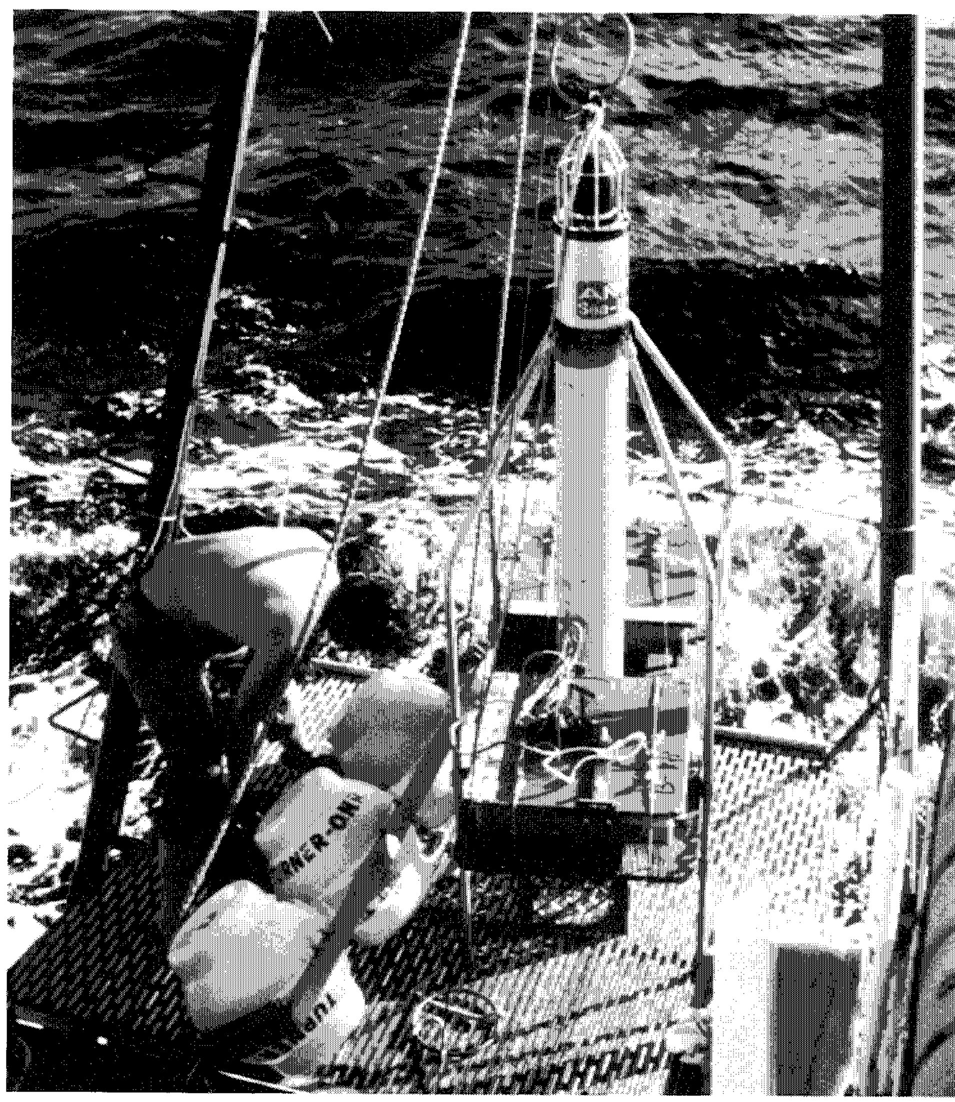
The arrival of large lumps of food on the bottom and the subsequent activities of big animals result in disturbance of the surrounding community. Each local patch recovers slowly, resulting in patchy distribution of the fauna. Other disturbances are produced by the activities of fish and invertebrate predators. In contrast to other environments each source of disturbance affects only one small spot at a time and, for any given place on the bottom, is infrequent. The elevated diversity of deep-sea species at the larger, apparently more homogeneous, spatial scales (such as the areas sampled by trawls) may, in part, be maintained by this mosaic of small-scale disturbances. Species that specialize on occasional windfalls from the surface grow rapidly to maturity and produce many offspring, whereas species from the greater part of the seafloor, that may be undisturbed for a hundred years or more, grow slowly and produce few offspring at a time.

The discovery of the unusual hydrothermal vent communities living around hot springs on the Galapagos and East Pacific Rise rifts provides a test of these ideas. Here there is a rich food supply of microorganisms living indirectly on energy from deep within the earth. Hydrothermal vents support as rich a concentration of animal mass as has been observed in any environment. The animals are unusual and cannot live away from the chemical environment provided by hydrothermal circulation. Since the hydrothermal circulation does not persist for more than a few decades at any one site, we would expect rapid growth to maturity and the production of large numbers of offspring. This was confirmed in the two large bivalve species (clam and mussel) which live little more than a decade, growing as much as an inch a year. As in most ephemeral environments the diversity of species is low. The relatively few species that have adapted to the vent environment are spectacularly different from other known species. The most difficult unanswered question concerning vent communities concerns the distances traveled and behavior of the larval forms that must colonize each new vent. Rates of larval dispersal and the genetic connectedness of communities and populations across the broad expanse of seafloor remains unknown for any of the deep-sea environments.

Right: An elevator platform carrying two boxes of fauna-free sediment is prepared for launch from R/V *Lulu*. The submersible *Alvin* is used to locate the platform once it is on the bottom by ranging on the cylindrical transponder's signals, and the boxes are opened with the sub's mechanical arm. The boxes are retrieved after periods ranging from two months to several years for population counts.

Below: One of the colonization boxes was photographed near a sea urchin from *Alvin* with lid in open position.

Fred Grassle



Fred Grassle

1982 Degree Recipients

Massachusetts Institute of Technology/ Woods Hole Oceanographic Institution Joint Program in Oceanography/ Oceanographic Engineering

Doctor of Philosophy

MARY L. BREMER
B.A., Chico State University
M.S., University of Cincinnati
Special Field: Marine Geology
Dissertation: *Abyssal Benthonic Foraminifera and the Carbonate Saturation of Sea Water and A Benthonic Foraminiferal Carbonate Saturation History for the Cape Verde Basin for the Last 550,000 Years*

ROGER W. BURKE
B.A., B.S.,University of Pennsylvania
Special Field: Oceanographic Engineering
Dissertation: *Free Surface Flow Through Salt Marsh Grass*

JERRY CHENEY
B.S., Lamar University
Special Field: Biological Oceanography
Dissertation: *The Spatial and Temporal Abundance Patterns of Chaetognaths in the Western North Atlantic Ocean and Associated Sampling Problems*

TERESA K. CHERESKIN
B.S., University of Wisconsin
Special Field: Physical Oceanography
Dissertation: *The Development of Non-Linear Surface and Internal Wave Groups*

FRANCES L. S. HOTCHKISS
A.B., Oberlin College
Special Field: Physical Oceanography
Dissertation: *Observed Circulation and Inferred Sediment Transport in Hudson Submarine Canyon*

MARK D. KURZ
B.S., University of Wisconsin, Madison
Special Field: Chemical Oceanography
Dissertation: *Helium Isotope Geochemistry of Oceanic Volcanic Rocks: Implications for Mantle Heterogeneity and Degassing*

LAWRENCE J. PRATT
B.S. & M.S., University of Wisconsin, Madison
Special Field: Physical Oceanography
Dissertation: *The Dynamics of Unsteady Strait and Sill Flow*

DANIEL J. REPETA
B.S., University of Rhode Island
Special Field: Chemical Oceanography
Dissertation: *Carotenoid Transformations in the Oceanic Water Column*

PING-TUNG P. SHAW
B.S., National Taiwan University
M.S., University of Rhode Island
Special Field: Physical Oceanography
Dissertation: *The Dynamics of Mean Circulation on the Continental Shelf*

KOZO TAKAHASHI
B.S., Hokkaido University
B.Sc. & M.S., University of Washington
Special Field: Marine Geology
Dissertation: *Vertical Flux, Ecology and Dissolution of Radiolaria in Tropical Oceans: Implications for the Silica Cycle*

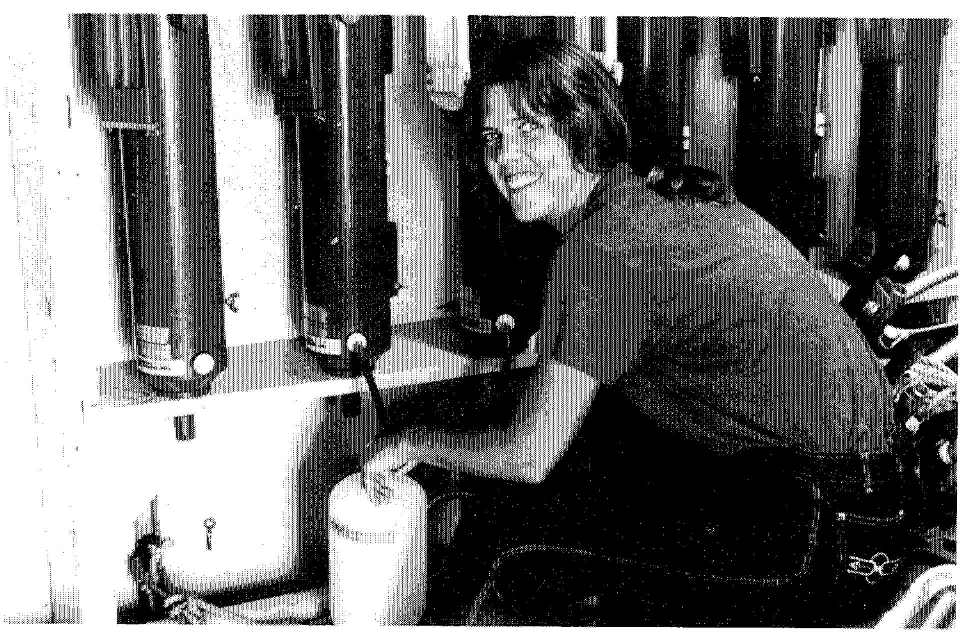
LYNNE D. TALLEY
B.A., Oberlin College
Special Field: Physical Oceanography
Dissertation: *Instabilities of Thin, Baroclinic Jets*

ANNE M. TREHU
B.A., Princeton University
Maitrise, University of Paris VII
Special Field: Marine Geophysics
Dissertation: *Seismicity and Structure of the Orozco Transform Fault from Ocean Bottom Seismic Observations*

Ocean Engineer

MICHAEL F. COOK
B.S., Texas A. & M. University
Special Field: Oceanographic Engineering
Dissertation: *Damping Estimation, Response Prediction, and Fatigue Calculation of an Operational Single Pile Platform*

EDWARD K. SCHEER
B.S., Massachusetts Institute of Technology
Special Field: Oceanographic Engineering
Dissertation: *Estimates of Crustal Transmission Losses Using MLM Array Processing*



Frederica Valois

Joint Program Student Beth Snowberger is at work on a microbiological cruise aboard R/V *Cape Florida* (University of Miami).

Dean's Comments

Enrollment of Women

Women comprised 46 percent of our 1982 entering class of graduate students, as compared to 29 percent in 1981. Increased percentages of women in our other education programs reveal a similar trend: oceanography is growing in popularity among women, both at WHOI and nationwide. A recent survey done by the National Science Foundation showed that the 1982 to 1981 percentage increase for women oceanographers at the professional level was the highest (27 percent) of all fields of science. The second highest gain for women was 22 percent in computer science. Likewise, in our undergraduate Summer Student Fellowship Program more than half (51 percent) of the 1982 applicants were women.

There is a less pronounced upward trend in women applicants to our Postdoctoral Scholarship Program. Between 1961, the first year of the Program, and 1974, only three of the 63 successful candidates were women; however, since 1975 we have accepted an average of 23 percent women, which is considerably higher than the percentage of women in the applicant pool (13 percent). From our overall total of 12 women Postdoctoral Scholars (90 percent accept our offers), four are now on our resident scientific staff: Drs. Judith Capuzzo, Nancy Marcus, Diane Stoecker, and Patricia Glibert, all in the Biology Department.

All three programs show a steady increase in women applicants, but the rate of increase at the postdoctoral level is slower than at the other two levels, indicating a much greater drop-out rate for women than for men in the field of oceanography. What is most encouraging overall is the general upward trend of women applicants at all three levels, and especially the consistency of the trend at the graduate and postdoctoral levels.

Steinbach Remembered

Friends and employees of the Woods Hole Oceanographic Institution were saddened to learn of the passing of H. Burr Steinbach late last year. As a fitting culmination to his distinguished accomplishments, he served as the principal architect and founding dean of the MIT/WHOI Joint Program. After a great deal of thought and with the approval of the Steinbach family, we are paying tribute to Dr. Steinbach's dedication to students by naming our Visiting Scholars program in his honor. This program, which was created by Burr at the outset of his tenure as the Joint Program's first dean, allows students to invite leading international scientists to spend time at the Institution. The Visiting Scholars hold informal discussions with students, give lectures, and provide opportunities for students to seek scientific and career advice from practicing professionals. The gratifying response we have had to this announcement shows the high esteem in which Burr was held by his many friends, colleagues, and students of the Joint Program.

Dean's Retreat

In January 1982 the University of Hawaii was host to the second meeting of the major academic officers in charge of doctoral programs in oceanography. This Deans' Retreat was attended by the deans or their representatives of the following schools: Dalhousie University, University of Delaware, University of Hawaii, Lamont-Doherty Geological Observatory, MIT/WHOI, Oregon State University, Scripps Institution of Oceanography, Texas A&M, and University of Washington.

The principal findings of the meeting include: 1) There is a nationwide shortage of qualified applicants to the physical, geophysical, and engineering subdisciplines of oceanography. 2) There is a nationwide downward trend in the number of applications to all fields of oceanography that is especially noticeable in the field of biological oceanography. 3) There is a noticeable increase in the quality of undergraduates applying to oceanography graduate programs. This appears to be due in part to an increased awareness of the need for a strong basic science background in order for a student to be competitive in the very selective admissions process for graduate school. 4) All graduate programs represented provide the successful applicant with financial support equivalent to tuition waiver as well as a stipend. Rates of support vary considerably, depending on the area, with none considered a living wage; however, there are an increasing number of generous fellowships being provided in very specific areas of interests (physics, dynamics, acoustics, robotics, etc.) by the Department of Defense. 5) There was a strong concensus that oceanography schools may have to recruit more vigorously if the number of applicants continues to fall. A booklet describing career opportunities in oceanography was felt to be the most cost-efficient way of doing this, and I have just finished a draft of such a booklet, which the American Geophysical Union has agreed to publish in 1983.

The 67 percent acceptance rate in the Joint Program is still the highest among the major oceanographic institutions, and we are very proud of this. The 95 percent acceptance rate of Postdoctoral Scholars, and the 90 percent rate for Summer Student Fellows suggests that placement in all of our education programs is sought. This is an encouraging sign when there is a nationwide decrease in enrollment in most science programs.

The MIT/WHOI Joint Program now has 138 graduates who continue to enjoy fine job opportunities in their choice of career options. Twenty-three percent have chosen industry, 12 percent are employed in government research laboratories, and the majority (56 percent) hold positions in educational and/or nonprofit research institutions. The remainder (10 percent) are either working out of the field or are in the military service.

Vicky Cullen

Joint Program Student Steve McCormick checks tanks of fishes he maintains for work on survival and growth of young brook trout in seawater.

Ashore & Afloat

Trends in National Science Foundation oceanographic funding were outlined by Director John H. Steele at the winter meeting of the Corporation 14 January at Boston's Copley Plaza Hotel. Senior Scientist L. Valentine Worthington of the Physical Oceanography Department spoke of his 41 years of research on circulation in the North Atlantic.

The new year saw the helm of *Oceanus* magazine change hands as Editor William H. MacLeish stepped down after nine years to devote more time to writing about the oceans. MacLeish will remain a consultant and was succeeded by Managing Editor Paul R. Ryan.

Associate Director for Research Derek W. Spencer chaired a series of Institution staff meetings in February exploring the implications of closer relations with industry and with more applied government agencies. The committee's report recommended the Institution proceed actively to solicit industry-sponsored research.

On 1 February Senior Scientist John M. Teal succeeded Senior Scientist Ralph F. Vaccaro as chairman of the Biology Department. Vaccaro had been acting chairman since October 1981, when George D. Grice left the post to become Associate Director for Scientific Operations.

Some 140 Associates and guests attended the annual spring dinner 30 March at the Museum of Science in Boston. Four poster sessions were presented and a short film of early *Atlantis* cruises was narrated by Associates Program Executive Secretary L. Hoyt Watson. The New York dinner scheduled for early April was cancelled due to inclement weather.

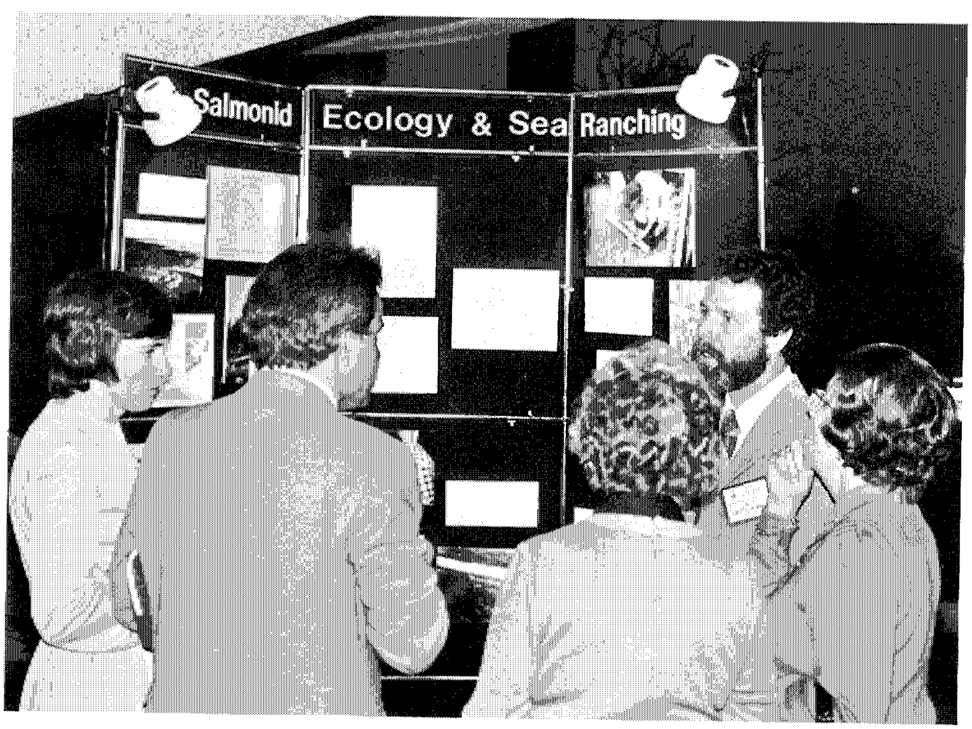
Roger Hayward, a Falmouth High School sophomore and son of Chemistry Department Research Assistant Nancy A. Hayward, received the Institution's $750 college scholarship for an aerodynamics project he entered in the Falmouth Science Fair 27 March.

Departmental visiting committees began a series of meetings in Woods Hole in April to evaluate the Institution's work for the Trustees. Visiting committees for the Chemistry Department met in April, Ocean Engineering in May, and for Geology and Geophysics, Physical Oceanography, and Biology in June.

Former CBS anchorman Walter Cronkite made a dive in *Alvin* 17 April during the "Oasis" expedition to the East Pacific Rise. The dive, along with an interview with Geologist Robert D. Ballard conducted in Woods Hole in May, was aired on the CBS news program "Universe" in July.

The site was cleared in the spring for the Institution's $2.1 million Advanced Chemistry Laboratory on the Quissett Campus. Ground was officially broken 18 June and work progressed on schedule through the summer and fall. Construction should be completed in late spring 1983.

Annual meeting activities got under way 17 June when a group of Trustees assembled in Woods Hole to discuss the role of Trustees in the Institution and to consider closer involvement of Trustees and Corporation Members in Institution activities. The following day, 67 Trustees and Corporation Members attended the Annual Meeting of the Corporation; Assistant Scientist Henry J. B. Dick gave the science presentation on "Exploring the Oceanic Mantle by Dredge, or Just What Do You Do With Four Tons of Rock Once You Have It?" Special exhibits open during the afternoon were the new radiocarbon facility in McLean Laboratory, the VAX computer center in Clark Laboratory, and *Argo/Jason* instrumentation on the pier. Associates joined the group to hear Associate Scientist Roger L. Mann speak on "Aquaculture: Past, Present and Future" later in the afternoon. Ground was then broken for the Advanced Chemistry Laboratory between Clark Laboratory and Fenno House. Approximately 380 attended the combined Trustees, Corporation Members, and Associates dinner that evening under a tent on the Fenno House grounds. Retiring Associates President Townsend Hornor was honored for his 14 years of service to the Institution; he was



Left: Associate Scientist Bob Naiman talks with Associates at the annual Boston dinner about work at the Matamek Research Station.

Right: Townsend Hornor, Associates president for 14 years, took the microphone at the 1982 Boston dinner.

Ashore & Afloat

succeeded by Corporation Member James S. "Spike" Coles.

A handsome addition to the Institution's summer Exhibit Center was a two-piece plate tectonics display from Chevron, U.S.A., a division of Standard Oil Company of California. The pieces had been part of a traveling exhibit celebrating Chevron's 100th birthday. Nearly 10,000 persons visited the Exhibit Center between 16 June and 4 September.

Among the many groups and individuals to visit the Institution during 1982 were five delegations of scientists from the People's Republic of China. Ambassador Huan Jayewardene, leader of the Sri Lanka delegation to the Third United Nations Conference on the Law of the Sea, met with several WHOI staff members in March to explore the prospects of establishing relations with Sri Lanka's National Aquatic Resources Research and Development Agency. Five scientists/engineers from the National Taiwan University visited in March to look at R/V *Oceanus* and similar vessels their government may build. Dr. C. Barry Raleigh, director of Lamont-Doherty Geological Observatory, addressed 60 staff members on plate tectonics research in April. Eighty members of the Harvard Club of Cape Cod held their monthly meeting at WHOI in April and heard Senior Scientist John M. Teal speak on salt marshes. Some 35 representatives from the U. S. and abroad attended a Cooperative Marine Policy Workshop in the spring sponsored by the Marine Policy Program. Representatives from 13 oil companies attended a May meeting hosted by Senior Scientist William A. Berggren to discuss the five-year study of benthic foraminifera they are funding being conducted by Institution micropaleontologists. Global habitability was the topic of a two-week workshop in Woods Hole in June sponsored by NASA which resulted in a report on "Global Change: Impacts of Habitability, Scientific Basis for Assessment;" Director John H. Steele and Research Specialist Robert R. P. Chase were members of the workshop executive committee. The Chief of Naval Research, Rear Admiral Leland S. Kollmorgen, met with the Director and members of the scientific staff 16 June; Oceanographer of the Navy Rear Admiral John B. Mooney paid a visit in July. Another Navy visitor during the summer was Herbert Rabin, Deputy Assistant Secretary of the Navy for Research, Applied and Space Technology, who reviewed Navy-supported programs at the Institution. Semi-annual presentations were organized for the Institution's Ocean Industry Program and the Naval War College's Naval Staff Course for Foreign Officers.

The Marine Policy Reading Room in Crowell House was dedicated 24 August to Marine Policy Executive Assistant Kaleroy L. Hatzikon, who passed away in March.

A number of personnel and office moves took place during the year to provide more laboratory and office space for science programs and to improve facilities for supporting operations. Two of the major moves were the relocation from the Blake Building of the Purchasing and Property Offices to the GEOSECS Warehouse and Shipping & Receiving to the Quissett Warehouse on the Quissett Campus, and the relocation of the Personnel Office to the Blake Building.

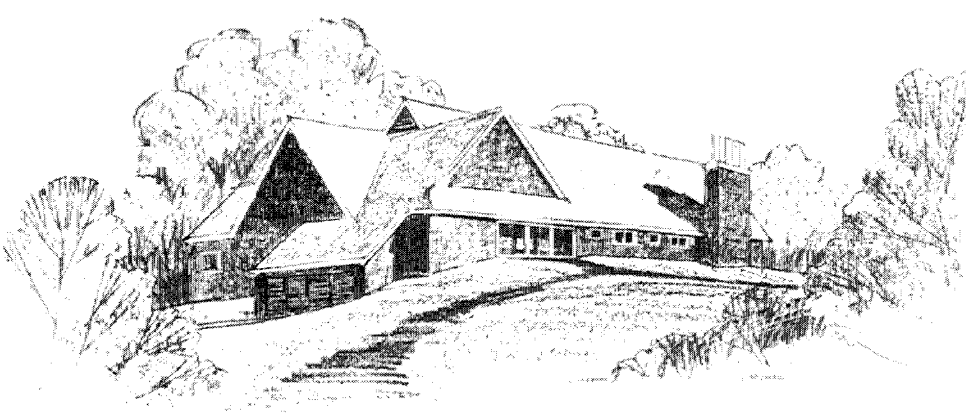
The second installment of a $150,000 grant from the Mobil Foundation in support of the Institution's Center for Analysis of Marine Systems was received during the summer. The grant is appropriated in equal sums of $50,000 per year for three years.

The third annual "Anything But a Boat Regatta" attracted more than 1,000 spectators and 18 contestants 29 August to Great Harbor. Fourteen paddling people aboard "Ocean Craps" from MacDougall's Boatyard easily brought their craft to victory, but not without joining the rest for a drenching with water ballons and a pump-powered fire hose aboard the unexpected obstacle "Death Star."

Caribbean Carnival was the theme of the annual Employee Picnic following the boat

Below: Construction of a new advanced chemistry facility began in 1982.

Right: More than 10,000 visitors viewed the Institution's summer exhibit center.



Shelley Lauzon

race 29 August. More than 500, many in costume, danced to the music of a steel band and enjoyed limbo and other games on the Fenno House grounds.

R/V *Lulu* with *Alvin* aboard arrived in Woods Hole 19 August to a gala welcome after 390 days, most of them spent in the Pacific. *Lulu* departed Woods Hole 25 July 1981 and steamed 20,878 miles in the interim, while *Alvin* completed a record 133 dives in 1982. The previous record was 117 dives in 1979.

R/V *Atlantis II* spent the year at the Institution pier undergoing maintenance and repair as part of the ship's mid-life refit and overhaul begun in 1980. A $1.7 million proposal for conversion of *Atlantis II* for *Alvin* operations was approved by the National Science Foundation, Office of Naval Research, and the National Oceanic and Atmospheric Administration in October. An over-the-stern handling system, a fantail hangar for *Alvin*, and an upgraded bow thruster to improve *Atlantis II*'s maneuverability will be installed on the ship, and the sub will be adapted to a single point hoist during its annual overhaul in early 1983. The multi-beam echo sounder, Sea Beam, will also be installed on the ship. Plans to replace R/V *Lulu* resulted from the need to increase the endurance, range, speed, laboratory space, and personnel accommodations for *Alvin* operations. *Lulu* will remain at the pier in Woods Hole until the new *Atlantis II/Alvin* system is operational and will then be offered back to the Navy for possible use by its submersibles.

Biological, chemical, and physical oceanographic studies as part of the Warm Core Rings experiment occupied a good deal of R/V *Knorr*'s time during 1982. At year's end, the ship was at sea on a four-month voyage in the South Atlantic undertaking chemical studies for the Tropical Atlantic Study.

Senior Scientist Robert C. Spindel was awarded the A.B. Wood Medal and Prize in February from the British Institute of Acoustics for his work in ocean sound propagation.

Senior Scientist Henry M. Stommel was presented the Prince Albert 1st Medal for his work in oceanography by Princess Grace of Monaco during February ceremonies in New York. (The award was made in 1978 but the medal had not been presented until this year.)

A newly discovered copepod from the South Pacific, *Paracandacia worthingtoni*, was named for retiring Physical Oceanographer L. Valentine Worthington by Associate Director for Scientific Operations George D. Grice, Jr. The former Biology Department chairman had found the unknown species in a collection sent to him for identification.

Senior Scientist Holger W. Jannasch received the Fisher Scientific Company Award for Applied and Environmental Microbiology at the annual American Society for Microbiology (ASM) meeting in March. ASM cited Jannasch's work in pressure instrumentation and studies at hydrothermal vents in the Pacific.

Senior Scientist William A. Berggren was presented the Mary Clark Thompson Medal and prize from the National Academy of Sciences in April for his work in geology and paleontology. The medal has been presented about every four years since 1919.

Two Institution senior scientists were among the six to receive top awards from the Americal Geophysical Union (AGU) at its spring meeting in May. Physical Oceanographer Henry M. Stommel received the William Bowie Medal for "outstanding contributions to fundamental geophysics and for unselfish cooperation in research." Geophysicist John I. Ewing received the Maurice Ewing Medal for "significant contributions to the understanding of ocean processes and outstanding service to marine science." The Maurice Ewing Medal, named for Ewing's brother, is presented jointly by AGU and the U. S. Navy.

The National Science Foundation (NSF) presented its Distinguished Service Award to Facilities and Marine Operations Chair-

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Left: Newsman Walter Cronkite made a dive in *Alvin* for his "Universe" program.

Below: Dr. Steele addresses group assembled for dedication of Marine Policy Reading Room to Kaleroy Hatzikon.

Shelley Lauzon

Ashore & Afloat

man Robertson P. Dinsmore in May for "the high degree of exceptional service he has provided to the National Science Foundation and oceanographic community through his exemplary leadership." The award, a medal and certificate, is NSF's highest civilian award. Dinsmore stepped down from his post at WHOI in July to work part-time on the design of a new research vessel for the 1990s and on long-range Institution planning; he was succeeded by *Alvin/Lulu* Operations Manager John D. Donnelly, who will serve as Manager of Marine Operations.

Senior Scientist John M. Hunt became the first American to receive the Alfred Treibs Medal from the Geochemical Society at its October meeting. Hunt was cited for his "pioneering research in the application of organic geochemistry to the exploration for petroleum," for his "contributions to the administration of science in building a leading center of organic geochemistry at Woods Hole," and for his book, *Petroleum Geochemistry*, which "has become a standard reference work."

Scientist Emeritus Allyn C. Vine was one of 55 individuals elected to the National Academy of Engineering.

Associate Scientist John A. Whitehead was named a Guggenheim Fellow for 1982-1983 and spent the year at the University of Cambridge, England, pursuing geophysical fluid dynamics studies.

Three more departments had new chairmen by the fall. Senior Scientist Robert C. Spindel succeeded Senior Scientist Earl E. Hays 18 October in Ocean Engineering; Hays had been chairman for 11 years and spent another eight years directing other departments. Senior Scientist Robert B. Gagosian took the reins of the Chemistry Department in late October from Senior Scientist Geoffrey Thompson, who had been chairman since 1978 and wished to devote more time to research. On 31 October, Senior Scientist Richard P. Von Herzen succeeded Senior Scientist John I. Ewing as chairman of the Geology and Geophysics Department. Ewing left the Institution in July for a position with Gulf Oil Company; Scientist Emeritus Elizabeth T. Bunce served as department chairman in the interim.

Some 90 Associates and guests enjoyed the September whale watch off Provincetown, and nearly 300 Associates and guests attended the annual Day of Science in Woods Hole 8 October. Biology was the theme for two morning lectures and two afternoon lectures. Luncheon was served in a tent on the Iselin Mall in the village. Visitors had an opportunity to board R/V *Lulu* prior to her departure for a series of year-end dives in the Bahamas and heard Associate Director for Scientific Operations George D. Grice speak on R/V *Atlantis II*/*Alvin* conversion plans.

Thirty-year pins were presented 17 December to Senior Scientist Richard H. Backus, Research Specialist Alvin L. Bradshaw, Captain Paul C. Howland, and Property Clerk Gordon H. Volkmann. Ten retirees with a total of 200 years of service to the Institution were also honored.

A $1.1 million two-year grant from The Pew Memorial Trust received late in the year provided $400,000 to establish an Ocean Engineering Research Laboratory and $700,000 in continued support for the Marine Policy and Ocean Management Program. The Ocean Engineering Research Laboratory will be established within the Ocean Engineering Department and will provide a suitable environment for conducting state-of-the-art engineering research applied to the oceans. It will enable the Institution to enlarge its role in fostering a strong engineering research effort.


Anne Lannak

Bostwick H. Ketchum
1912-1982

The Ketchum Lecture has been established by the Institution in memory of Bostwick H. Ketchum, a major figure in oceanographic research, who died 15 July 1982. A memorial tribute to him was held in Woods Hole 23 October. The lectureship will support an annual lecture by an internationally recognized oceanographer or bring to the Institution a younger scholar for a longer visit.

An ecologist before the word was popular, Buck Ketchum urged mankind to learn to live in harmony with the environment rather than trying to dominate it. He played a principal role in the work done at the Woods Hole Oceanographic Institution during and after World War II on marine fouling. He was the leader of a group of scientists in Woods Hole whose pioneering research provided the basis for the present understanding of the productivity of the oceans. One of his great strengths was his broad view of oceanography. He followed the style of his distinguished mentor, Alfred Redfield, in being equally at home in the physical, chemical, and biological realms. His 70 scientific papers span a broad range of topics from estuarine physics to deep ocean biology. In recent years he turned his attention to the increasing problems of the coastal zone and the need for research in this area. He was an outstanding scientist at the international level, a strong force in the development of biological oceanography in Woods Hole, and a respected member of the community.

Dr. Ketchum was associated with the Woods Hole Oceanographic Institution for more than four decades beginning with summer cruises on R/V *Atlantis* in 1934 as he began his graduate education at Harvard University. Born in Cleveland, Ohio, he had done his undergraduate education at St. Stephen's College of Columbia University. He completed his Ph.D. at Harvard in 1938, where he continued for a year as a Research Assistant. Following a year of teaching at Long Island University, he returned to Woods Hole in 1940 and held successive positions as Associate Marine Biologist, Marine Microbiologist, Senior Biologist, Senior Scientist, Associate Director, and Member of the Corporation. He was concurrently Lecturer and then Associate Member of the Department of Biology at Harvard from 1960 to 1977, when he retired. He was a member of many scientific organizations, served on countless committees and advisory bodies, and was president of the Ecological Society of America and the American Society of Limnology and Oceanography.

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William J. Schmitz, ,Jr., Pearn P. Niiler, Robert L. Bernstein and William R. Holland. Recent long-term moored instrument observations in the western North Pacific. *J. geophys. Res.*, 87(C12):9425-9440. 4856

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Bruce A. Warren. The deep water of the Central Indian Basin. *J. mar. Res.*, 40 (Suppl):823-860. 5108

Robert A. Weller. The relation of near-inertial motions observed in the mixed-layer during the JASIN (1978) experiment to the local wind stress and to the quasi-geostrophic flow field. *J. phys. Oceanogr.*, 12(10):1122-1136. 5035

John A. Whitehead, Jr. Instabilities of fluid conduits in a flowing earth — are plates lubricated by the asthenosphere? *Geophys. Jl R. astr. Soc.*, 70(2):415-433. 4882

J. A. Whitehead, Jr. and L. V. Worthington. The flux and mixing rates of Antarctic Bottom Water within the North Atlantic. *J. geophys. Res.*, 87(C10):7903-7924. 4855

L. V. Worthington. The loss of dissolved oxygen in Nansen bottle samples from the deep Atlantic Ocean. *Deep-Sea Res.*, 29(10A):1259-1266. 5053

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Victor Zlotnicki, Barry Parsons and Carl Wunsch. The inverse problem of constructing a gravimetric geoid. *J. geophys. Res.*, 87(B3):1835-1848. 5134

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Kurt M. Shusterich. Funding crisis in the marine minerals industry. *MTS Conf., Oceans '82*: 1216-1221. 5190

David R. Watters. Relating oceanography to Antillean archaeology: implications from Oceania. *J. New World Archaeol.*, 5(2):3-12. 5070

Per Magnus Wijkman. UNCLOS and the redistribution of ocean wealth. *J. World Trade Law*, 16(1):27-48. 5000

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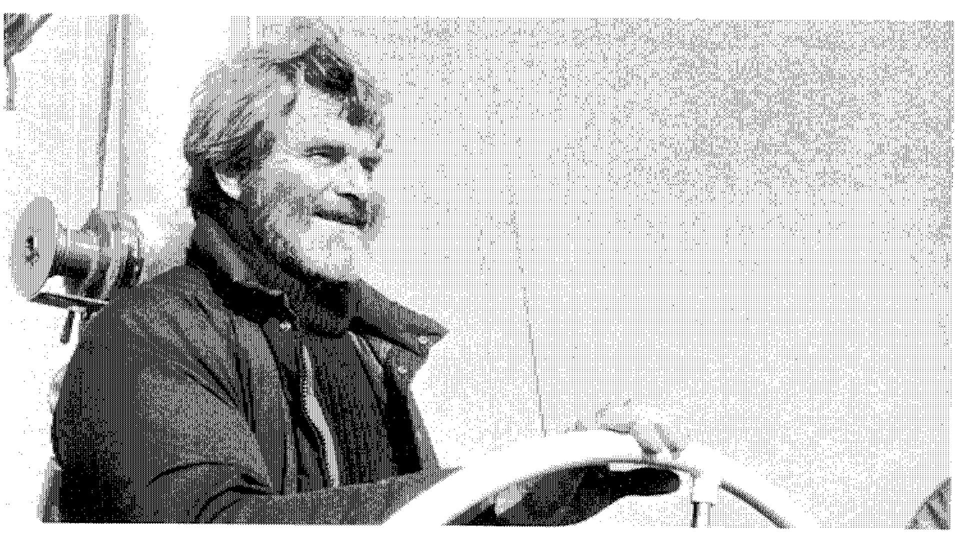
Right: Jim Craddock and Dick Backus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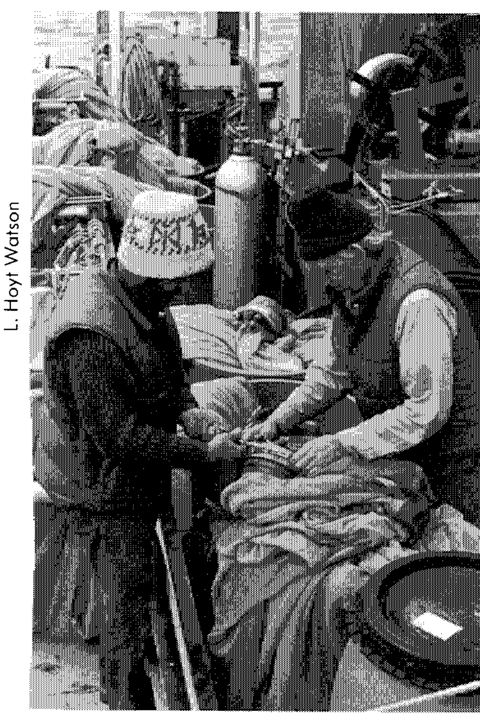
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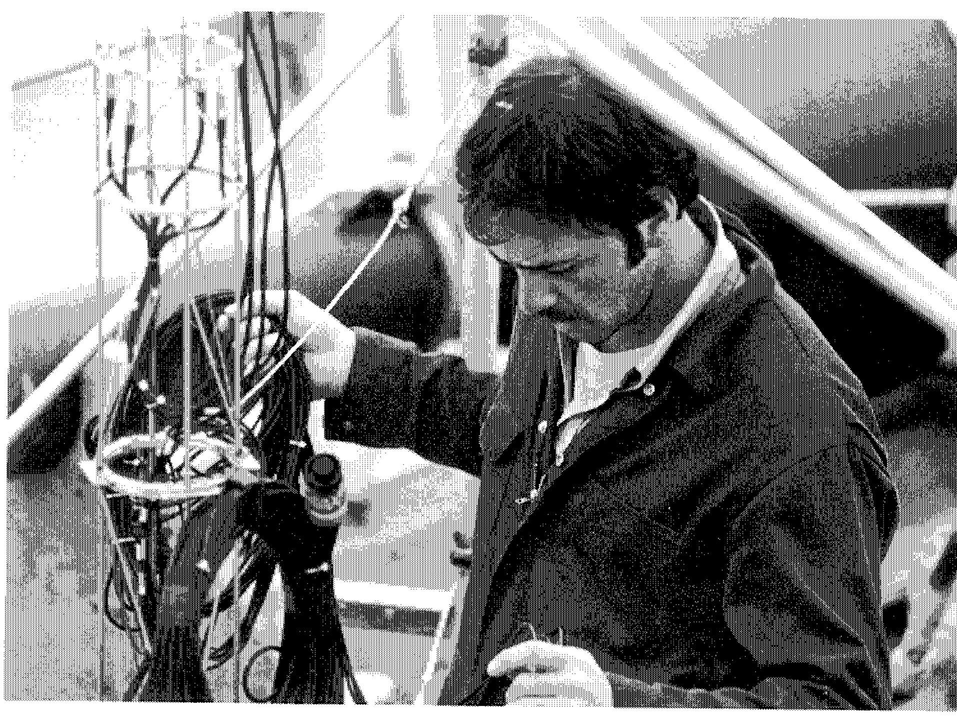

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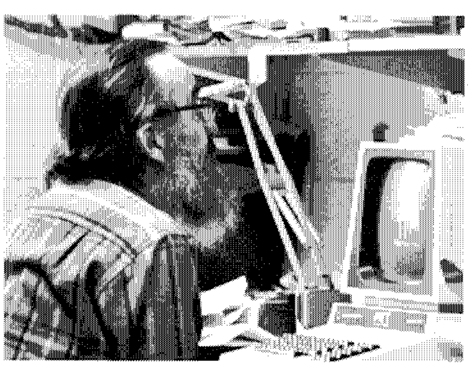
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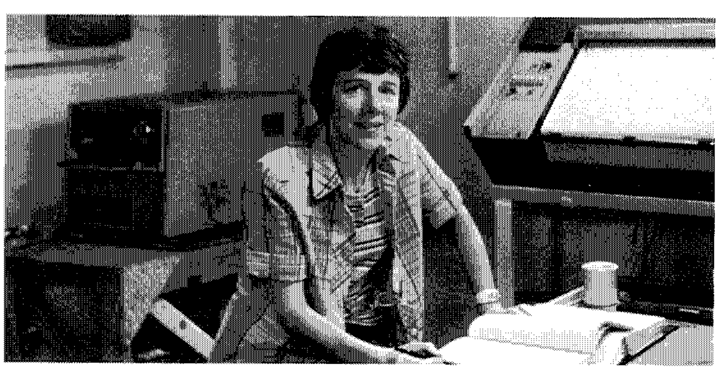
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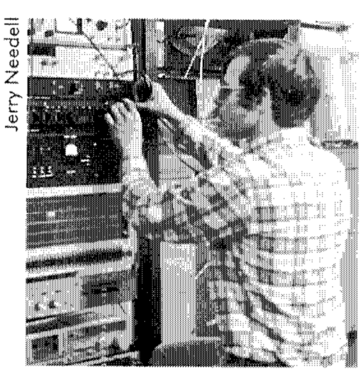
Robert Spindel

Opposite page: Fritz Fuglister meets computer (and is joined by George Knapp in the last frame).

This page, far left: Ann Spencer works in laboratory aboard R/V *Thomas Thompson* (University of Washington) on Pacific cruise.

Near left: Steve Liberatore works electronic magic.

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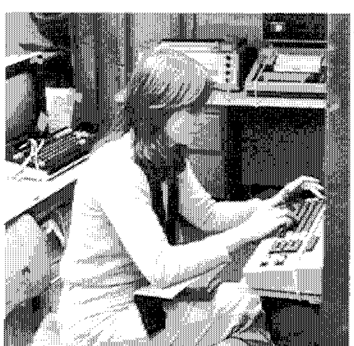

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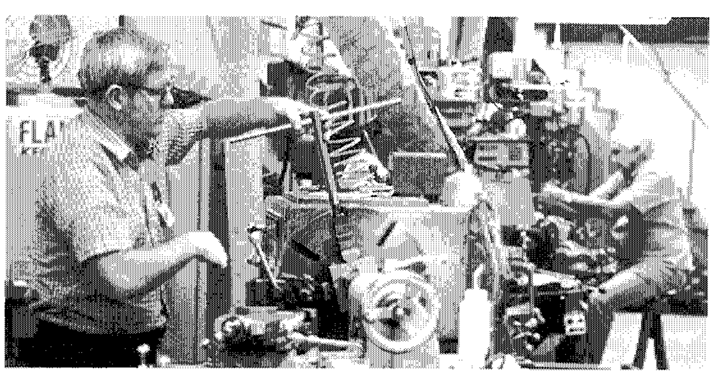

Shelley Lauzon

Opposite page, far left: Nan Galbraith in the *Oceanus* lab.

Opposite, center: From left, Sam Raymond of Benthos, Charlie Innis, Eddie Scheer, and Robert Zimmerman welcome *Lulu* home.

Opposite, right: Al Morton, left, and Harry Rougas aboard *Knorr*.

This page, left: John Romiza at work on the pier.

This page, right: Dan Dwyer, left, and Ed Acton in the instrument shop.

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Steven F. Tomkiewicz
Herman Wagner
Joseph Warecki
Ernest C. Wegman, Jr.
Stephen T. Wessling

#Disability Leave of Absence
+Leave of Absence
*Deceased, 31 March 1982
**Deceased, 23 July 1982

Left: ***Lulu*** **comes home with Ken Axelson, Navy Pilot Dave Brown, Shaun Nerolich, Jim Hardiman, Dave Sanders, and Dave Olmsted aboard.**

Right: ***Atlantis II*** **Bosun Ken Bazner at ship's crane.**

David Gray

Vicky Cullen

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Boris Moro
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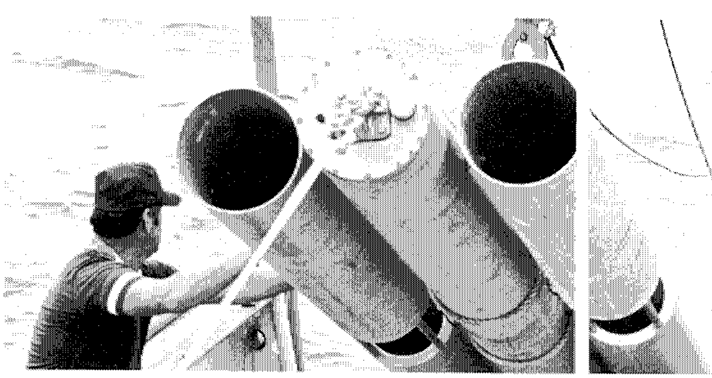
State University of New York, Stony Brook



Robert Spindel

Shelley Lauzon

Left: Paul Boutin steadies acoustic tomography gear.

Right: Wayne Dickinson at the Apple II.

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Lehigh University
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+ Leave of Absence

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*Michael C. Healey
University of Aberdeen, Canada
*Timothy M. Hennessey
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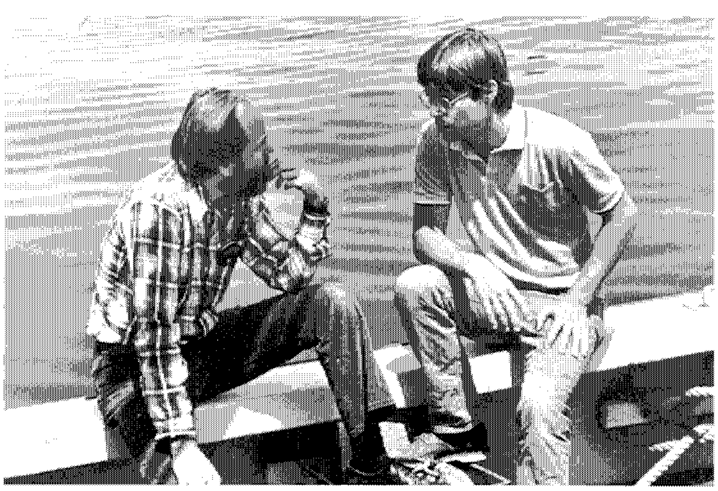
*Robert W. Knecht
University of Rhode Island

Right: Joint Program Student Scott Glenn on a Coastal Ocean Dynamics Experiment cruise.

Below: Joint Program Student Josh Hoyt, right, talks with Al Bradley aboard *Asterias*.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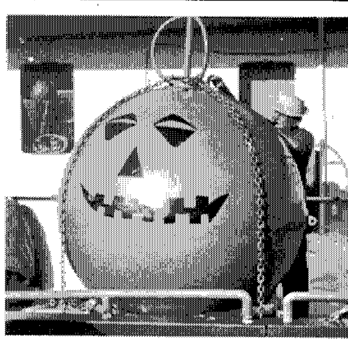
Manfred G. Höfle
Limnology Institute of the University of Konstanz, West Germany

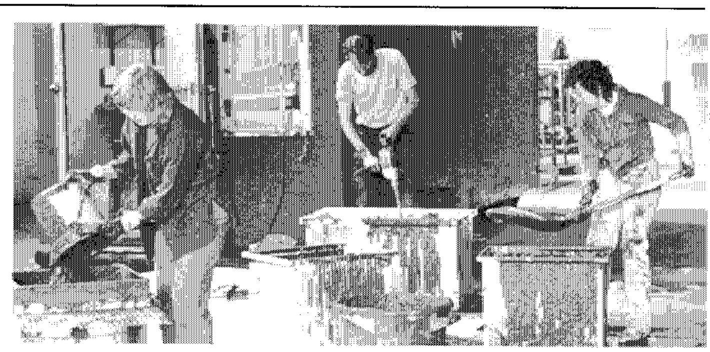
Robert Howarth
Marine Biological Laboratory, Ecosystems Center

Right: *Oceanus* Bosun Whitey Warecki secures mooring flotation scheduled for use during a Halloween cruise.

Far right: Brenda Olson, left, Ed Sholkovitz, and Anne Carey experience the joys of using sediment for experiments.



Shelley Lauzon



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Voyage Statistics

R/V Atlantis II

Atlantis II was at the Institution pier during 1982 for continuation of the mid-life refit and overhaul begun in 1980 and for conversion to handle DSRV *Alvin*. The work, which extended into 1983, included installation of an over-the-stern submersible handling system, a fantail hangar for *Alvin*, an upgraded bow thruster, and Sea Beam, a multi-beam echosounder.

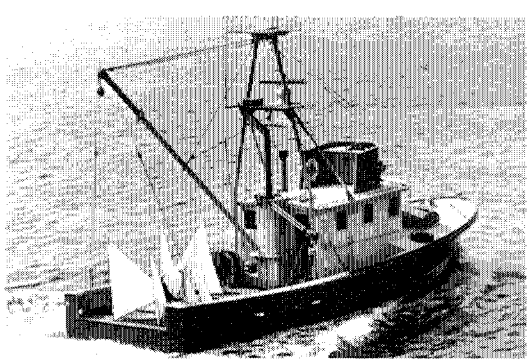
R/V Knorr

Total Nautical Miles for 1982 — 26,575 miles
Total Days at Sea — 244 days

Voyage	*Cruise Period*	*Principal Objective, Area of Operations*	*Ports of Call (Destination)*	*Chief Scientist*
92-I	28 Jan - 1 Mar	Monitoring microearthquake activity on the Mid-Atlantic Ridge, determination of structure of uppermost kilometer of crust and crust thickness	San Juan, Puerto Rico	Purdy
92-II	6 Mar - 7 Apr	Continued geological and geophysical studies on the Mid-Atlantic Ridge	Woods Hole	Purdy
93	19 Apr - 6 May	Biological, chemical, and physical oceanographic studies of a warm core ring in the slope water of the northwest Atlantic for the Warm Core Rings experiment	Woods Hole	Kester (URI)
94	18 May - 5 Jun	Collection, observation, and laboratory experimentation with gelatinous zooplankton in the Sargasso Sea	Woods Hole	Madin
95	12 June - 29 Jun	Continuation of Warm Core Rings experiment	Woods Hole	McCarthy (Harvard)
96	7 Jul - 30 Jul	Coring, hydrographic, and photographic studies on the Nova Scotian Continental Rise for the High Energy Benthic Boundary Layer Experiment (HEBBLE)	Woods Hole	Hollister
97	7 Aug - 24 Aug	Continuation of Warm Core Rings experiment	Woods Hole	McCarthy (Harvard)
98	24 Sep - 17 Oct	Continuation of Warm Core Rings experiment	Woods Hole	Wiebe
99-I	26 Oct - 7 Nov	Chemical studies of seasonal changes in sedimentation rates and composition in the deep North Atlantic	San Juan, Puerto Rico	Deuser
99-II	11 Nov - 27 Nov	Chemical studies in the Cariaco Trench, Caribbean Sea	San Juan, Puerto Rico	Bacon
99-III	30 Nov - 21 Dec	Hydrographic studies in the tropical and equatorial Atlantic, geochemical measurement in the Amazon River freshwater plume for the Tropical Atlantic Study	Belem, Brazil	Sarmiento (LDGO)
99-IV	28 Dec - 31 Dec	Continuation of studies on circulation and mixing processes in the tropical and equatorial Atlantic for the Tropical Atlantic Study	Dakar, Senegal	Key (Princeton)

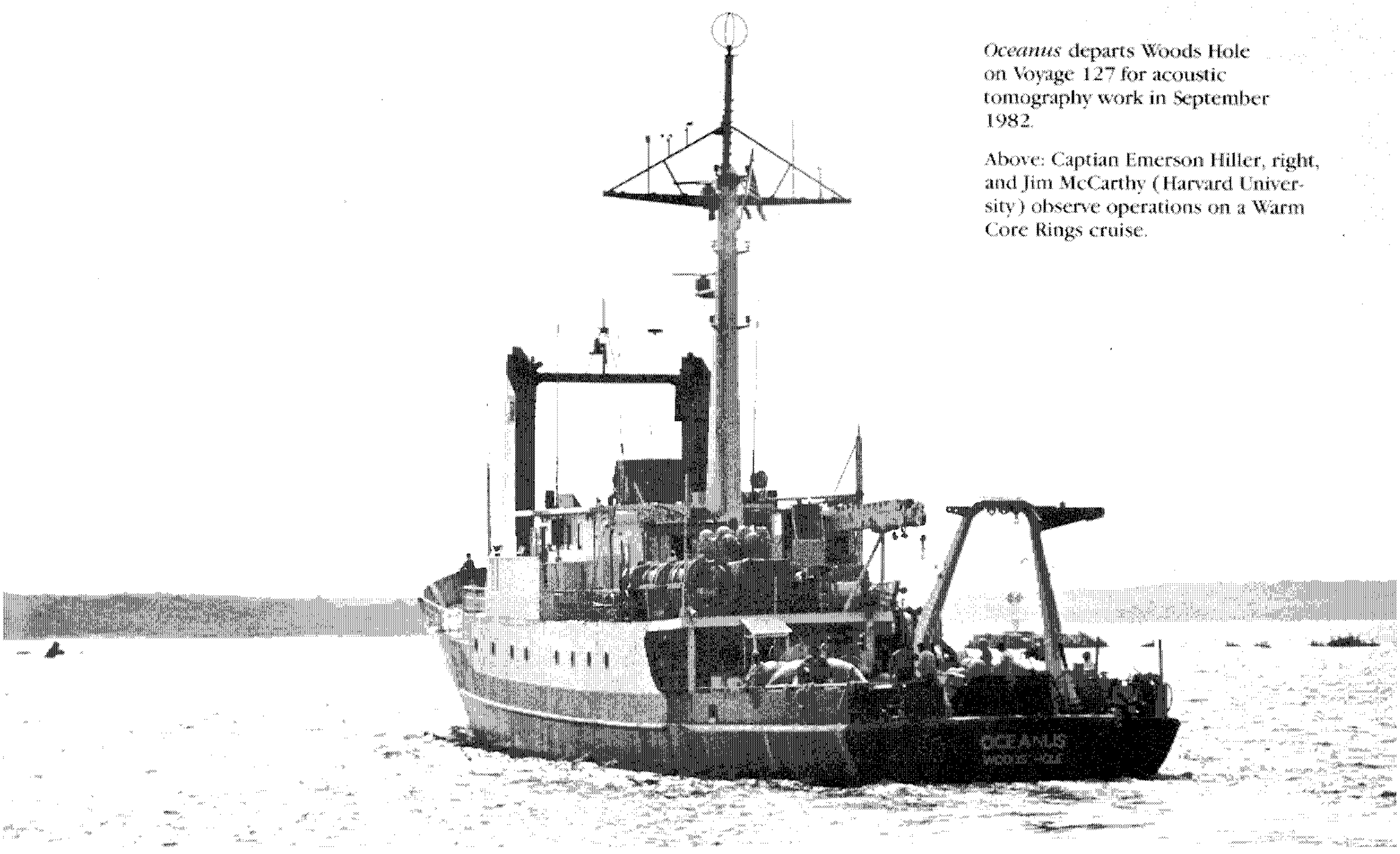
Right: *Asterias* heads out to test a Loran-C drifting buoy and drogue.

Far right: Kevin Kay, Dick Edwards, and Paul Mercado attend to adjustments on *Oceanus*.



Vicky Cullen

Peter Wiebe



Oceanus departs Woods Hole on Voyage 127 for acoustic tomography work in September 1982.

Above: Captian Emerson Hiller, right, and Jim McCarthy (Harvard University) observe operations on a Warm Core Rings cruise.

Voyage Statistics

R/V Oceanus

Total Nautical Miles for 1982 — 21,146 miles
Total Days at Sea — 229 days

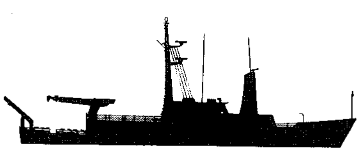
Voyage	*Cruise Period*	*Principal Objectives, Area of Operations*	*Ports of Call (Destination)*	*Chief Scientist*
112	5 Jan - 6 Jan	Zooplankton sampling for studies of histories of key slope water species south of Cape Cod	Woods Hole	Cowles
113	25 Jan - 4 Feb	Recovery and deployment of current meter and tripod moorings on the Continental Shelf near Georges Bank and Lydonia Canyon	Woods Hole	Butman (USGS)
114	8 Feb - 9 Feb	Zooplankton sampling for studies of life histories of key slope water species south of Cape Cod	Woods Hole	Cowles
115	16 Feb - 4 Mar	Collection, observation, and laboratory experimentation with gelatinous plankton in the Sargasso Sea	Woods Hole	Madin
116	11 Mar - 16 Mar	Continuation of time series study of life histories of key slope water species south of Cape Cod	Woods Hole	Cowles
117	29 Mar - 10 Apr	Determination of concentration, distribution, and contribution of cyanobacteria to primary productivity in the Sargasso Sea, Gulf Stream, and Slope waters	Woods Hole	Watson
118	18 Apr - 3 May	Biological, chemical, and physical oceanographic studies of a warm core ring in the North Atlantic for the Warm Core Rings experiment	Woods Hole	Wiebe
119	6 May - 14 May	Mooring deployment for the Long Term Upper Ocean Study (LOTUS) at 39°30'N, 70°W and 34°N, 70°W	Woods Hole	Briscoe
120	19 May - 6 Jun	Recovery and resetting net of Autonomous Listening Stations (ALS) in the North Atlantic	Woods Hole	Valdes
121	14 Jun - 1 Jul	Continuation of Warm Core Rings experiment	Woods Hole	Wiebe
122	6 Jul - 15 Jul	Recovery and deployment of subsurface moorings, tripods, and surface buoys in the vicinity of Georges Bank, Lydonia Canyon, and Oceanographer Canyon	Woods Hole	Butman (USGS)
123	19 Jul - 20 Jul	Recovery of Bottom Ocean Monitor mooring on the Continental Shelf	Woods Hole	Biscaye (LDGO)
124	21 Jul - 29 Jul	Collection of sediment and biological samples for Georges Bank Sediment and Organism Monitoring Program	Woods Hole	Hampson
125	6 Aug - 23 Aug	Continuation of Warm Core Rings experiment	Woods Hole	Wiebe
126-I	27 Aug - 7 Sep	Biological studies in the Carson Canyon area of the Grand Banks	St. John's, Newfoundland	Jannasch
126-II	10 Sep - 23 Sep	Collection of benthic invertebrates and deep water fishes in Carson Canyon area of the Grand Banks	Woods Hole	Copeland (MBL)
127	28 Sep - 9 Oct	Deployment of mooring array and transponders for acoustic tomography experiment off the Florida Coast	Woods Hole	Spindel
128	12 Oct - 12 Oct 20 Oct. - 20 Oct	To shipyard From shipyard	Newport, Rhode Island Woods Hole	
129	28 Oct. - 4 Nov.	Recovery and deployment of moorings, SOFAR float launch, CTD stations, and XBT section for Long Term Upper Ocean Study (LOTUS) in the western North Atlantic	Woods Hole	Briscoe
130	9 Nov - 16 Nov	Recovery and deployment of subsurface moorings, tripods, and surface moorings in vicinity of Georges Bank and Lydonia Canyon	Woods Hole	Butman (USGS)
131	19 Nov - 30 Nov	Collection of sediment and biological samples for Georges Bank Sediment and Organism Monitoring Program	Woods Hole	Grassle
132	4 Dec - 13 Dec	Recovery of mooring array and transponders set during Voyage #127; deployment and recovery of short-term mooring in the western North Atlantic	Woods Hole	Spindel

DSRV Alvin and R/V Lulu

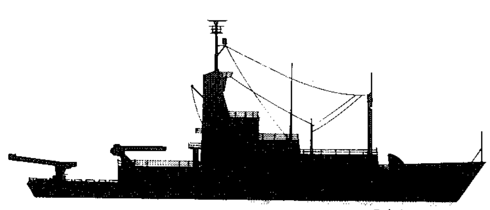
Total Nautical Miles for 1982 — 17,104 miles
Total Days at Sea — 229 days
Total Dives — 133

Voyage	*Cruise Period*	*Principal Objectives, Area of Operations*	*Ports of Call (Destination)*	*Chief Scientist*
111-VIII	5 Jan - 23 Jan	10 dives for biological and geological investigations in the Guaymas Basin	Mazatlan, Mexico	Lonsdale (SIO)
111-IX	28 Jan - 14 Feb	10 dives for geological and volcanological studies on the East Pacific Rise	San Diego	Lonsdale (SIO)
111-X	19 Feb - 2 Mar	11 dives for biological investigations in the Catalina, San Clemente, and Cortes Basins	San Diego	Childress (USCB)
111-XI	5 Mar - 15 Mar	9 dives for biological studies in the Catalina Basin	San Diego	Smith (SIO)
111-XII	2 Apr - 6 Apr	3 dives for biological studies in the Santa Barbara Channel	San Diego	Smith (SIO)
111-XIII	11 Apr - 28 Apr	10 dives for biological investigations at hydrothermal vents on the East Pacific Rise	Mazatlan, Mexico	Smith (SIO)
111-XIV	2 May - 16 May	9 dives for continued biological studies at East Pacific Rise hydrothermal vents	Manzanillo, Mexico	Smith (SIO)
111-XV	19 May - 30 May	Transit	Puntarenas, Costa Rica	
111-XVI	2 Jun - 16 Jun	10 dives for biological investigations in the Panama Basin	Balboa, Panama	Grassle
111-XVII	19 Jun - 29 Jun	Transit	San Juan, Puerto Rico	
111-XVIII	5 Jul - 30 Jul	9 dives for chemical studies on the Mid-Atlantic Ridge	St. George's, Bermuda	Rona (NOAA)
111-XIX	5 Aug - 19 Aug	8 dives for training, chemical investigations, corrosion studies, equipment recovery at Deep Ocean Station #2	Woods Hole	Sayles, Tupper Williams (KAPL)
112	25 Aug - 3 Sep	6 dives for biological and geological studies in Oceanographer Canyon	Woods Hole	Uzmann (NMFS)
113	9 Sep - 20 Sep	8 dives for biological and geological investigations in Lydonia Canyon	Woods Hole	Hecker (LDGO)
114-I	9 Oct - 17 Oct	Transit	Freeport, Bahamas	
114-II	18 Oct - 27 Oct	8 dives for geological investigations of the sea floor west and south of Grand Bahama Island	Freeport	Neumann (UNC)
114-III	31 Oct - 3 Nov	3 dives to investigate recolonization in sediments in the Northeast Providence Channel	Nassau, Bahamas	Hecker (LDGO)
114-IV	3 Nov - 10 Nov	Transit	Frederiksted, St. Croix	
114-V	11 Nov - 13 Nov	3 dives for training and indoctrination	Frederiksted	Walden
114-VI	14 Nov - 18 Nov	5 dives for biological studies at Deep Ocean Station #2	Frederiksted	Grassle
114-VII	21 Nov - 28 Nov	8 dives for engineering tests of a large area imaging system	Frederiksted	Ballard
114-VIII	1 Dec - 4 Dec	3 dives for geological investigations in the Puerto Rico vicinity	Yabucoa, Puerto Rico	Sasscer (UPR)
114-IX	4 Dec - 17 Dec	Transit	Woods Hole	

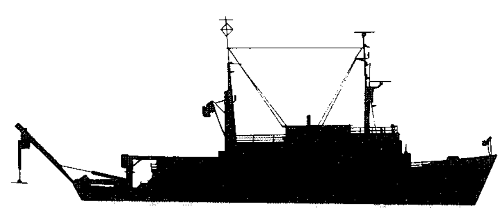
Robert Kelley



R/V Oceanus



R/V Knorr



R/V Atlantis II

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Right: Carol Mills cleans marine growth from a Coastal Ocean Dynamics Experiment (CODE) buoy aboard R/V *Wecoma* (Oregon State University).

Far right: Chris Dunn is prepared for rough weather during CODE.

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Knorr departs as a Steamship Authority ferry comes into Woods Hole where _Atlantis II_ and _Cape Florida_ (University of Miami) are tied up.

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*Deceased 12 January 1983
**Deceased 20 February 1983
***Deceased 17 March 1983

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In Memoriam

The Institution gratefully acknowledges the service and support of Honorary Trustees Hudson Hoagland and Raymond Stevens and Corporation Members Percy Chubb 2nd, Henry S. Morgan, and John M. Olin, who died in 1982.

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Financial Statements

Highlights

The Institution's total operating revenue increased 1% in 1982 to $38,318,740 compared with a 16% increase and total revenues in 1981 of $37,961,310. Excess current unrestricted funds of $1,200,000 were transferred to Unexpended Plant Funds.

Income for sponsored programs was derived from the following sources:

	1982	*1981*	*Increase (Decrease)*
National Science Foundation:			
Science Projects	$10,300,000	$ 9,014,000	14.3%
Facilities Projects	6,421,000	7,858,000	(18.3%)
Office of Naval Research	7,808,000	7,311,000	6.8%
Department of Energy	701,000	1,022,000	(31.4%)
National Oceanic & Atmospheric Administration	1,735,000	1,881,000	(7.8%)
Other Government	2,033,000	1,636,000	24.3%
Restricted Endowment Income	457,000	313,000	46.0%
Other Restricted Gifts, Grants, and Contracts	3,600,000	4,137,000	(13.0%)
	$33,055,000	$33,172,000	(.4%)

Other statistics of interest are:			
Full-time Equivalent Employees	800	813	(.3%)
Total Compensation (including Overtime & Benefits)	$21,269,000	$20,141,000	5.6%
Retirement Trust Contribution	1,932,000	1,873,000	3.2%
Endowment Income (net)	2,969,000	2,372,000	25.2%
Endowment Principal (year-end at market value)	52,793,000	42,371,000	24.6%
Capital Expenditures	1,816,000	2,080,000	(12.7%)

Gifts and grants from private sources including the 1,336 Institution Associates totaled $2,127,000 in 1982 of which $1,384,000 was restricted as follows:

Addition to Endowment Principal	$ 137,000
Laboratory Construction	135,000
Marine Policy & Ocean Management	350,000
Ocean Engineering Research Center	250,000
Benthonic Foraminifera Studies	120,000
Education Program	46,000
Center for Analysis of Marine Systems	100,000
Coastal Studies Center	40,000
Other Research Programs	206,000
	$1,384,000

Funds availed of in support of the Education Program were derived principally from endowment income received in 1982 totaling $1,508,000. In addition to other funds restricted for education, unrestricted funds of $305,000 were availed of for the Education Program. Research contracts and grants provided student support in the amount of $515,000.

Your attention is invited to the Financial Statements and the notes accompanying them, audited by Coopers & Lybrand.

Joseph Kiebala, Jr.
Assistant Director for Finance & Administration
Kenneth S. Safe, Jr.
Treasurer
Gary B. Walker
Controller

Balance Sheets, December 31, 1982 and 1981

ASSETS	1982	1981
Current Fund Assets (Note A):		
Cash	$ (206,598)	$ 1,235,688
Short-term investments, at cost which approximates market	9,815,000	6,885,001
Accrued interest	50,981	80,519
Reimbursable costs:		
Billed	773,076	1,958,498
Unbilled	344,955	991,278
Other receivables	123,503	111,086
Inventories	594,770	611,766
Deferred charges and prepaid expenses	76,140	166,361
Deferred fixed rate variances	1,572,330	849,764
Due (to)/from other funds	(4,011,319)	(3,681,536)
	9,132,838	**9,208,425**
Endowment and Similar Fund Assets (Notes A and B):		
Investments, at market:		
Bonds	15,361,934	15,093,394
Stocks	33,339,147	23,107,670
Other	110,944	141,516
Total investments (cost $37,864,530 in 1982 and $34,959,561 in 1981)	48,812,025	38,342,580
Cash and cash equivalents	3,960,444	4,034,464
Due (to)/from current fund	20,050	(5,768)
	52,792,519	**42,371,276**
Annuity Fund Assets (Note A):		
Investments, at market (cost $67,255 in 1982 and $71,729 in 1981)	97,280	83,124
Cash	2,718	2,338
	99,998	**85,462**
Plant Fund Assets (Note A):		
Land, buildings and improvements	18,914,176	18,471,506
Vessels and dock facilities	7,363,584	7,362,401
Laboratory and other equipment	3,441,500	3,691,554
Construction in progress	1,065,112	44,974
	30,784,372	29,570,435
Less accumulated depreciation	10,687,476	10,242,165
	20,096,896	19,328,270
Due from current fund	3,991,269	3,687,304
	24,088,165	**23,015,574**
	$86,113,520	**$74,680,737**

LIABILITIES AND FUND BALANCES	1982	1981
Current Fund Liabilities and Balances:		
Accounts payable, other accrued expenses and deferred revenues	$ 1,142,157	$ 2,291,891
Accrued payroll related liabilities	1,549,298	1,151,832
Unexpended balances restricted for:		
Sponsored Research	1,978,008	2,024,581
Education Program	581,329	372,532
Total restricted balance	2,559,337	2,397,113
Unrestricted balances designated for:		
Income and salary stabilization	2,733,720	2,487,168
Ocean industry program	289,064	264,797
Unrestricted current funds	543,619	454,647
Fiftieth Anniversary Fund	315,643	160,977
Total unrestricted balances	3,882,046	3,367,589
	9,132,838	**9,208,425**
Endowment and Similar Fund Liabilities and Balances:		
Endowment:		
Income restricted	31,887,114	25,577,009
Income unrestricted	4,034,639	3,228,246
Term endowment	4,891,543	3,939,117
Quasi-endowment:		
Income restricted	7,771,385	6,238,368
Income unrestricted	4,207,838	3,388,536
	52,792,519	**42,371,276**
Annuity Fund Liabilities and Balance:		
Annuities payable	24,406	25,292
Fund balance	75,592	60,170
	99,998	**85,462**
Plant Fund Balances:		
Invested in plant	20,096,896	19,328,270
Unexpended:		
Restricted	—	752,906
Unrestricted	3,991,269	2,934,398
Total unexpended balances	3,991,269	3,687,304
	24,088,165	**23,015,574**
	$86,113,520	**$74,680,737**

The accompanying notes are an integral part of the financial statements

Financial Statements

Statement of Current Fund Revenues, Expenses and Transfers for the years ended December 31, 1982 and 1981

Revenues	**1982**	**1981**
Sponsored research:		
Government	$28,997,875	$28,722,154
Nongovernment	4,057,523	4,450,148
	33,055,398	33,172,302
Education funds availed of	1,543,083	1,300,753
Total restricted	34,598,481	34,473,055
Unrestricted:		
Fees	329,532	311,264
Endowment and similar fund income	739,657	596,400
Gifts	743,158	916,003
Tuition	515,884	470,932
Investment income	954,900	887,132
Oceanus subscriptions	203,618	209,545
Other	233,510	96,979
Total unrestricted	3,720,259	3,488,255
Total revenues	**38,318,740**	**37,961,310**
Expenses and Transfers		
Sponsored research:		
Salaries and fringe benefits	10,664,731	10,145,935
Ships and submersibles	5,711,909	7,218,272
Materials and equipment	4,794,727	4,264,553
Subcontracts	1,475,814	1,219,275
Laboratory cost	2,539,980	1,837,220
Other	4,681,775	4,842,483
General and administrative	3,186,462	3,644,564
	33,055,398	33,172,302
Education:		
Faculty expense	385,819	324,006
Student expense	773,395	667,827
Postdoctoral programs	286,380	276,451
Other expense	185,018	165,756
General and administrative	217,924	140,086
	1,848,536	1,574,126
Unsponsored research	550,966	609,919
Oceanus magazine	261,874	281,320
Other activities	590,809	485,074
General and administrative	132,432	94,172
	1,536,081	1,470,485
Total expenses	**36,440,015**	**36,216,913**
Nonmandatory transfers:		
To quasi-endowment fund	10,332	–
To plant fund, unexpended	1,200,000	1,000,000
Total expenses and nonmandatory transfers	**37,650,347**	**37,216,913**
Net increase in unrestricted current fund	**$ 668,393**	**$ 744,397**
Designated for:		
Income and salary stabilization	246,552	198,800
Ocean industry program	178,203	46,537
Unrestricted current funds	88,972	247,447
Fiftieth Anniversary Fund	154,666	251,613
	$ 668,393	**$ 744,397**

The accompanying notes are an integral part of the financial statements.

Report of the Certified Public Accounts

To the Board of Trustees of
Woods Hole Oceanographic Institution:

We have examined the balance sheets of Woods Hole Oceanographic Institution as of December 31, 1982 and 1981, and the related statements of changes in fund balances, and of current fund revenues, expenses and transfers for the years then ended. Our examinations were made in accordance with generally accepted auditing standards and, accordingly, included such tests of the accounting records and such other auditing procedures as we considered necessary in the circumstances.

In our opinion, the financial statements referred to above present fairly the financial position of Woods Hole Oceanographic Institution as of December 31, 1982 and 1981, the changes in its fund balances, and its current fund revenues, expenses and transfers for the years then ended, in conformity with generally accepted accounting principles applied on a consistent basis.

Coopers & Lybrand

Boston, Massachusetts
March 29, 1983

Statement of Changes in Fund Balances for the years ended December 31, 1982 and 1981

	Current Fund					Plant Fund		
1982	Restricted	Unrestricted	Total	Endowment and Similar Funds	Annuity Funds	Invested in Plant	Unexpended	Total Funds
Increases:								
Gifts, grants and contracts:								
Government	$28,690,477		$28,690,477					$28,690,477
Nongovernment	3,715,232	$ 743,158	4,458,390	$ 136,359			$ 134,751	4,729,500
Endowment and similar funds investment income (Note D) . .	2,228,882	739,657	2,968,539					2,968,539
Net increase in realized and unrealized appreciation			—	10,273,911				10,273,911
Other	78,334	2,237,443	2,315,777		$15,422			2,331,199
Total increases	34,712,925	3,720,258	38,433,183	10,410,270	15,422		134,751	48,993,626
Decreases:								
Expenditures (including $739,365 of funded depreciation)	(34,598,481)	(1,841,534)	(36,440,015)				739,365	(35,700,650)
Depreciation (Note A)						$(1,001,179)		(1,001,179)
Other	(105,514)		(105,514)			(346)		(105,860)
Total decreases	(34,703,995)	(1,841,534)	(36,545,529)			(1,001,525)	739,365	(36,807,689)
Net change before transfers	8,930	1,878,724	1,887,654	10,410,270	15,422	(1,001,525)	874,116	12,185,937
Transfers — additions (deductions):								
Current revenues to plant fund . .		(1,200,000)	(1,200,000)				1,200,000	—
Current revenues to endowment	(641)	(10,332)	(10,973)	10,973				—
Current revenues to innovative research fund	153,935	(153,935)						—
Plant asset additions						1,771,137	(1,771,137)	—
Other						(986)	986	—
Total transfers	153,294	(1,364,267)	(1,210,973)	10,973		1,770,151	(570,151)	—
Change in fund balance for the year	162,224	514,457	676,681	10,421,243	15,422	768,626	303,965	12,185,937
Fund balance, December 31, 1981 .	2,397,113	3,367,589	5,764,702	42,371,276	60,170	19,328,270	3,687,304	71,211,722
Fund balance, December 31, 1982 .	$ 2,559,337	$3,882,046	$ 6,441,383	$52,792,519	$75,592	$20,096,896	$3,991,269	$83,397,659
1981								
Increases:								
Gifts, grants and contracts:								
Government	$28,027,140		$28,027,140					$28,027, 140
Nongovernment	4,130,081	$ 916,003	5,046,084	$ 539,349			$ 400,000	5,985,433
Endowment and similar funds investment income (Note D) . .	1,775,935	596,400	2,372,335					2,372,335
Net increase in realized and unrealized appreciation			—	(365,184)				(365,184)
Other	122,630	1,975,852	2,098,482		$(3,465)		(150,000)	1,945,017
Total increases	34,055,786	3,488,255	37,544,041	174,165	(3,465)		250,000	37,964,741
Decreases:								
Expenditures (including $624,465 of funded depreciation)	(34,473,055)	(1,743,858)	(36,216,913)				624,465	(35,592,448)
Depreciation (Note A)			—			$(892,564)		(892,564)
Total decreases	(34,473,055)	(1,743,858)	(36,216,913)			(892,564)	624,465	(36,485,012)
Net change before transfers	(417,269)	1,744,397	1,327,128	174,165	(3,465)	(892,564)	874,465	1,479,729
Transfers — additions (deductions):								
Current revenues to plant fund . .		(1,000,000)	(1,000,000)				1,000,000	—
Fiftieth Anniversary to endowment and similar funds		(242,376)	(242,376)	242,376				—
Fiftieth Anniversary to plant fund		(245,035)	(245,035)				245,035	—
Plant asset additions			—			2,080,412	(2,080,412)	—
Other	(444)		(444)	444		(851)	851	—
Total transfers	(444)	(1,487,411)	(1,487,855)	242,820		2,079,561	(834,526)	—
Change in fund balance for the year	(417,713)	256,986	(160,727)	416,985	(3,465)	1,186,997	39,939	1,479,729
Fund balance, December 31, 1980 .	2,814,826	3,110,603	5,925,429	41,954,291	63,635	18, 141,273	3,647,365	69,731,993
Fund balance, December 31, 1981 .	$ 2,397,113	$3,367,589	$ 5,764,702	$42,371,276	$60,170	$19,328,270	$3,687,304	$71,211,722

The accompanying notes are an integral part of the financial statements.

Financial Statements

Notes to Financial Statements

A. Summary of Significant Accounting Policies:

Fund Accounting

In order to comply with the internal designations and external restrictions placed on the use of the resources available to the Institution, the accounts are maintained in accordance with the principles of fund accounting. This procedure classifies resources into various funds in accordance with their specified activities or objectives.

Investments

Investments in securities are stated at market value determined as follows: securities traded on a national securities exchange are valued at the last reported sales price on the last business day of the year; securities traded in the over-the-counter market and listed securities for which no sales prices were reported on that day are valued at closing bid prices. Investments for which a readily determinable market value cannot be established are stated at a nominal value of $1; income from such investments is not significant.

Income, net of investment expenses, is distributed on the unit method. Unrestricted investment income is recognized as revenue when received and restricted investment income is recognized as revenue when it is expended for its stated purpose. Realized and unrealized gains and losses are attributed to the principal balance of the funds involved.

The Institution follows the accrual basis of accounting except that endowment and similar fund investment income is recorded on a cash basis. The difference between such basis and the accrual basis does not have a material effect on the determination of investment income earned on a year-to-year basis.

Contracts and Grants

Revenues associated with contracts and grants are recognized as related costs are incurred. Beginning with fiscal 1978, the Institution has negotiated with the government fixed rates for the recovery of certain indirect costs. Such recoveries are subject to carryforward provisions that provide for an adjustment to be included in negotiation of future fixed rates.

Gifts

Gifts are recorded in the applicable funds when received. Noncash gifts are generally recorded at market value on the date of gift although certain noncash gifts for which a readily determinable market value cannot be established are recorded at a nominal value of $1 until such time as the value becomes known. Unrestricted gifts are recognized as revenue when received and restricted gifts are recognized as revenue as they are expended for their stated purposes.

Plant

Plant assets are stated at cost. Depreciation is provided at annual rates of 2% to 5% on buildings, 3⅓% on Atlantis II and 5% to 33 ⅓% on equipment. Depreciation expense on Institution-purchased plant assets amounting to $739,365 in 1982 and $624,465 in 1981 has been charged to operating expenses. Depreciation on certain government funded facilities (Atlantis II, Laboratory for Marine Science and the dock facility, amounting to $261,814 in each year) is accounted for as a direct reduction of the plant asset and invested in plant fund. Title to the research vessel Atlantis II is contingent upon its continued use for oceanographic research.

The Institution consolidates available cash from the plant fund with other cash in the current fund for investment.

Annuity Funds

On the date of receipt of annuity fund gifts, the actuarially computed value of the future payments to annuitants is recorded as a liability and any excess amount of the gift is credited to the fund balance. The actuarial values of the liabilities are recomputed annually.

Reclassification of 1981 Balances

Certain balances in the 1981 financial statements have been reclassified to conform with the 1982 presentation.

B. Endowment and Similar Fund Investments:

The cost and market value of investments held at December 31, 1982 and 1981 are as follows:

	December 31, 1982		December 31, 1981	
	Cost	Market	Cost	Market
Government and government agencies	$12,188,174	$13,482,335	$10,469,136	$10,396,270
Corporate bonds	1,540,047	1,683,224	4,791,653	4,459,624
Convertible bonds	200,500	196,375	260,625	237,500
Common stocks	23,835,809	33,339,147	19,292,646	23,107,670
Real estate	—	—	45,501	45,501
Fiduciary Trust Co. Fund	100,000	110,944	100,000	96,015
Total investments	**$37,864,530**	**$48,812,025**	**$34,959,561**	**$38,342,580**

C. Pooled Investment Units:

The value of an investment unit at December 31, 1982 was $1.2011 as compared to the unit value of $.9672 at December 31, 1981. The investment income per unit at December 31, 1982 was $.0677 as compared to the investment income per unit of $.0547 at December 31, 1981.

D. Endowment and Similar Fund Income:

Income of endowment and similar funds consisted of the following:

	1982	1981
Dividends	$ 710,187	$ 1,018,483
Interest	2,513,261	1,472,841
Other	2,994	2,994
	3,226,442	2,494,318
Investment management costs	(257,903)	(121,983)
Net investment income	$2,968,539	$2,372,335

E. Retirement Plan:

The Institution has a noncontributory defined benefit trusteed retirement plan covering substantially all full-time employees. The Institution's policy is to fund pension cost accrued which includes amortization of prior service costs over a 30-year period. Retirement plan costs charged to operating expense amounted to $2,072,000 in 1982 and $2,045,000 in 1981, including $140,000 and $172,000, respectively, relating to expenses of the retirement trust. As of the most recent valuation date (January 1, 1982), the comparison of accumulated plan benefits and plan net assets is as follows:

	January 1, 1982	January 1, 1981
Actuarial present value of accumulated plan benefits:		
Vested	$16,977,517	$15,386,694
Nonvested	954,693	321,223
Total actuarial present value of accumulated plan benefits	$17,932,210	$15,707,917
Net assets available for plan benefits	$19,202,572	$16,785,727

The assumed rate of return used in determining the actuarial present value of accumulated plan benefits was six and one-half percent compounded annually.

Right: Sunset view of R/V *Knorr* on a Warm Core Rings cruise.

Opposite: A Warm Core Rings rosette sampler just below the water's surface.

Peter Wiebe