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Cover:
The cover photographs were taken during loading of R/V Atlantis II and field work for the Joint Air-Sea Interaction (JASIN) experiment off Scotland in July and August of 1978 (see page 10). Clockwise from upper left: the spar buoy is tested off the Woods Hole pier; a mooring is launched from the A-2 fantail; A-2 in Glasgow with four of the thirteen other ships participating in JASIN; current meters are prepared for another mooring; ship's name gets touched up; Chief Scientist Mel Briscoe sports JASIN decal on hardhat; cloud formation over Rockall Trough; heavily loaded ship is nearly ready for departure; Bob McDevitt steadies conductivity-temperature-depth instrument with rosette of water samplers. In the two remaining photos, Dave Simoneau steadies handling line, and buoy for mooring designated W2 is ready for launch. Photos were taken by Keith Bradley, Mel Briscoe, Vicky Cullen, Jerry Dean, and Hank McComas.

Annual Report 1978:
Vicky Cullen, Editor
Leyden Press, Plymouth, MA, Printer

The Woods Hole Oceanographic Institution is an Equal Employment Opportunity/Affirmative Action Employer.
Bundled against the sub-Antarctic cold, physical oceanographers rig water bottles for studies of late winter/early spring hydrography between the south and east coasts of New Zealand and the Antarctic pack ice on R/V Knorr Voyage #73 in the fall of 1978.

A conductivity-temperature-depth instrument is lowered against an icy background on Knorr #73.

Tethered divers collect open-ocean organisms in the Atlantic on R/V Oceanus Voyage #52.
Research at sea should benefit both society and the science of oceanography. To accomplish both these ends, the organization of oceanographic research should correspond to the nature of oceanographic problems. The diverse and interesting scientific conclusions produced by loosely structured management may lack overall relevance to practical problems. On the other hand, tightly organized, rigid management presupposes a degree of ideological and technological exactness which does not exist in oceanography or in any of the other environmental sciences. Thus we are looking for a match between the present and future structure of the science and the organization of its future management to obtain the best use of the scientific results.

In considering possible approaches, I find it useful to think of two rather simple environmental problems. They are of quite different characters, but each is relevant to aspects of ocean management.

One of these is fisheries management, which has long been based on relatively simple but generally applicable concepts of maximum sustainable yield. These concepts assume the availability of an optimum biological yield for some intermediate fishing effort — which is usually below that actually existing in any heavily exploited fishery. The management problem has been to devise socially, economically, and biologically acceptable methods of change that will place the effort at the optimum level. In certain cases, such as Iceland, political imposition of restricted access to the fishery allows a limited number of fishermen to make a good living from the resource. But there may be ecological limitations to this simple economic concept of maintaining a high stock density to provide a high catch rate. High stock densities, in turn, require a much higher level of food intake by the fish than is necessary for more heavily exploited stocks, and this food may not be available because of limitations in basic productivity. The interactions of different species of fish can cause further complexities. Yields from one stock may be related to the stock size of other species of fish through their common dependence on certain food webs. The study of these relationships is a significant part of our present work, linking ecological research with fisheries management. Given all these complications, there is still one feature common to the possible strategies for fishery exploitation: we assume that somewhere between excessive fishing and zero effort there is an optimum level which satisfies both society’s need for food from the sea and the ecological need for maintenance of fish stocks.

The second example concerns a typical problem in waste disposal. Until a few years ago, sewage was released from short pipelines in many coastal areas. As populations have grown, this method of disposal has often become unacceptable and been replaced by offshore dumping of sludge. Nearly always there is an inevitable trend to require the furthest offshore disposal that is practicable. A middle ground solution to this problem is lacking literally and metaphorically.

There appears to be no possibility of a compromise until an extreme is reached. Even offshore disposal may be unacceptable, but there is evidence on this subject from only a small number of experimental studies. “Out of sight, out of mind” is not a truism in this case; in fact, the opposite appears to apply. There is greater concern expressed now about the ultimate effect of the same amount of material being dumped and dispersed offshore than was formerly voiced when it was a nuisance on people’s doorsteps.

These two examples from fisheries and environmental quality have in common the significant degree of uncertainty that always is and always will be associated with environmental problems. But there are also major differences between the two examples. In the fisheries case, there is a consensus that a middle ground does exist somewhere and that fishing must continue. For many environmental quality problems there is no agreement about the existence of any middle ground. In fact, we must often choose between extremes. Further, the available evidence is necessarily circum-

Director John H. Steele’s first dive in DSRV Alvin in November of 1978 was the sub’s 850th dive. The Director, wearing white shirt, accompanied Fred Grassle, to Steele’s left, on work for studies of colonization in the deep sea at 2,030 meters in the Bahamas. Alvin pilot George Ellis is at left, and swimmers for the dive were Kim Hill, in the foreground, and Chris Green, at right.
stantial — deduced from studies of current flow and sediment characteristics rather than from direct experience of dumping at the possible sites.

These two examples concern the application of science or the scientific method to practical problems. The present approved scientific method, known as the “hypothetical deductive” approach, has something in common with the long-standing practice of trial and error. The latter terminology may be unacceptable because of its Anglo-Saxon rather than Latin origin and also because “error” may now be considered an unacceptable consequence of human activity. This scientific method is, however, the implicit basis for our fisheries management. It has the advantage that, like so many other human activities, it evolves continually toward better practices and adaptation to changing environments.

The alternative, which could be categorized as trial and verdict, has perhaps become more common. It does not admit the possibility of improvement or correction as an integral part of the process. For any particular problem, the decision is made a priori and adaptation or development occurs as an accumulation of individual cases rather than by critical testing of general principles.

However, a major difference between the two examples and also between the two approaches concerns the idea of a middle ground — an area of compromise in social terms, or an optimal solution in scientific terms. In both cases, we would expect that this middle ground could be reached in some finite, acceptable length of time. It seems to me that the idea of a middle ground in the technical aspects of social problems corresponds to the need for a middle ground in scientific management. At present, we tend to have a dominance of two extremes. At one extreme is mission-oriented research that confronts short term problems requiring immediate and often ad hoc decisions. We accept the need, on occasion, for reaching rapid decisions, and we look to mission agencies for the evidence on which to base such decisions. Yet we feel the decisions should be made in the context of a larger view of the underlying problems. Therefore, I see value in some longer term studies being conducted within government agencies, particularly in the areas I have used as examples, fisheries and environmental protection. Further, I feel that such longer term studies should be conducted not by a succession of groups, but whenever possible in a continuing program by the same individuals.

For exactly the same reasons, I believe in the necessity for a strong and independent basic science. Because so many of our environmental problems in the oceans are scientific in character, I also believe it is desirable and possible for basic research institutions to be involved in problems of more immediate significance to society. In elucidating these problems, we are concerned as much with testing ideas as with applying rules. This scientific character makes the problems less amenable to legal solutions, and it also makes them interesting and exciting to research scientists. I sense a strong desire for involvement by our best scientists, especially by younger, more active members of the oceanographic community. Yet they are often discouraged. The academic community lives in a highly competitive, demanding world of “soft” money often acquired on a year-to-year basis. Though some longer term support is available, the present system generally leaves scientists constantly concerned about continuity in their research. The best scientific work requires continuity. The quantity of federal funds is important, but even more significant is the quality, defined by the conditions and the criteria for awarding grants. If we accept, as all the evidence indicates, that our environmental problems are not amenable to simple short term solutions, then we must allow for innovative and longer term studies. This is true not only for such global questions as the increase in carbon dioxide in the atmosphere, but also for such apparent local examples as those discussed above where the underlying fisheries and waste disposal problems are of more general significance.

The Office of Naval Research (ONR) has, for example, provided the Woods Hole Oceanographic Institution with long term support for studies of a wide range of problems from the very practical to the relatively basic. The underlying assumption of an enduring, broadly based relationship with ONR has helped fund some of the Institution's most important advances, particularly in the area of long-term oceanographic moorings and their instrumentation.

Very recently I have been impressed by the involvement of some of our best younger scientists in the developing relationship between the NOAA Sea Grant Program and the Woods Hole Oceanographic Institution. I am sure this will be to the scientists’ benefit, and I hope it will also fulfill the aims of Sea Grant.

Funding patterns can build bridges to ensure the flow necessary to establish continuity between basic and applied studies. My examples from fisheries and waste disposal were excessively simplified, and I further simplified the problems by considering only the search for a middle ground. There are other important, possibly more important, areas where common ground is needed: in the social and class divisions involved, in the political associations, and in the accumulating legal framework. All these look to the scientific community for input. It would be unrealistic always to expect a single or an unambiguous answer, but the system should be structured to provide the best possible scientific information.

I realize that even within this one scientific aspect, any proposed restructuring is not a simple matter but has its own political and legislative components. It is, however, urgent and essential that we make proper use of our scientific abilities in ocean management.

JOHN H. STEELE
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. Among the research interests of Institution biologists are microbiology, planktonology, benthic biology, physiology, aquaculture, and pollution. 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, and high pressures. 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 upwelling areas where deep nutrient-rich waters replace surface waters that are driven offshore by prevailing winds, and in laboratory experiments that complement field investigations. The use of sound by marine animals and their sensitivity to electrical fields are being studied. Other work concentrates on a salt marsh ecosystem, 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 manmade phenomena operating on a variety of time scales. Input from rivers and reactions at the air-sea and seawater-sediment boundaries are under investigation as chemists consider the processes taking place at major ocean boundaries. Some critical questions in chemical oceanography revolve around transformations in particles as they fall from the surface waters to the bottom of the water column. The genesis and composition of the oceanic crust and its interaction with seawater is important to a general understanding of the oceanic system. Work on the fluxes of organic carbon includes determination of the amount of organic carbon produced by photosynthesis in surface waters and studies of processes responsible for formation of organic matter in sediments. While studying radioactive isotopes in the oceans 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 and of biological and chemical processes that change the composition of seawater.

Geology & Geophysics

The shape of the sea floor and its underlying structures as well as the physical properties of sediment and sea floor are studied by marine geologists and geophysicists. The structure, evolution, and dynamics of the oceanic crust and lithosphere are investigated through studies of variations, often minute, in gravity, magnetism, and temperature along with seismic studies of crustal components and layering of underlying sediment. Detailed studies are being made of continental margins and marginal basins as well as the margins of the huge crustal plates on which the continents ride. Measurements of particulate flux and the dissolution of carbonates and silicates and determination of sediment dynamics contribute to an understanding of deposition on the sea floor. Analysis of the fossil record in rocks and sediment reveals historical changes in climate and oceanic circulation patterns, volcanic activity, and other geologic events.
Ocean Engineering

Scientists in the Ocean Engineering Department study sound propagation in seawater and how it is affected by temporal and spatial variations in temperature, density, and other factors. Sound waves are employed to detect and measure organisms, physical properties, and pollutants. Development of instruments for use in the hostile marine environment and their refinement for reliability, accuracy, and endurance are among the important tasks of the Ocean Engineering Department. Computers are vital to modern oceanography both at sea and in land-based analysis of data, and much of this development is the responsibility of computer groups within the Ocean Engineering Department. The Alvin group, responsible for development of the submersible as a unique scientific window on the depths of the ocean, is also based here.

Physical Oceanography

OCEAN currents, their driving forces, and their interactions are the major interest of physical oceanographers. Such properties as variations in temperature, salinity, pressure, and large and small scale motions of the waters are measured and plotted on long cruise tracks and with moored and drifting instruments. Exchanges of energy between air and sea present important questions as one affects the other and their interaction becomes part of the world climate. Effects of bottom and coastal topography on ocean circulation systems are under investigation. Advancement of technology for extended-period measurements is mandatory so that trends can be recognized. Large and small current systems are modelled toward the ultimate goal of understanding the structure and movement of the world’s oceans and the interaction of the sea with its boundaries.

Marine Policy & Ocean Management

The Marine Policy and Ocean Management program supports interdisciplinary research by marine and social scientists on problems generated by man’s increasing use of the sea. The program offers fellowships and research opportunities to individuals from such fields as anthropology, economics, international affairs, law, management, and political science. Program participants work with scientists while investigating marine-related problems in their own disciplines.
R/V Oceanus heads out on a summer voyage.

Benthic chamber for biogeochemical studies is lowered from Oceanus to capture a piece of Buzzards Bay.
This section is not an attempt to give an overall view of the more than 325 research projects underway at the Woods Hole Oceanographic Institution. It is rather a discussion of some of our scientists’ investigations into the processes taking place in the ocean. Dr. Derek Spencer, Associate Director for Research, has served as scientific editor for this report, and his introduction follows.

Last year, in the annual report for 1977, we described some of the Institution’s efforts in the benthic boundary of the ocean. This year we present some highlights of our work at two other important ocean boundaries, the upper ocean and the coastal zone. These boundaries, particularly the coastal zone, are, in general, characterized by the intense variability of both properties and processes. At the upper ocean boundary, the exchange of energy and momentum with the atmosphere provides a major driving force for ocean currents and also influences weather and climate in ways that are only poorly understood. The exchange of materials is now known to be significantly large; indeed much of the detectable pollution of the ocean is introduced from the atmosphere. It is in the upper ocean that biological production is at its maximum. This production is critically dependent upon energy from the sun and the exchange of water with the deeper ocean that supplies life-giving nutrients. The supply of deep water to the surface layers depends upon the ocean currents which, in turn, are forced by energy from the wind and sun.

In the coastal boundary the upper ocean and the benthic boundary are merged together, but, in addition, the coastal ocean is influenced greatly by the proximity and supply of materials from the land. This produces a perplexing plethora of processes operating over very wide ranges of time and spatial scales. The complexity of the coastal zone makes it one of the most demanding areas of study for oceanographers. It is not surprising that, despite its accessibility, the coastal ocean is only slowly revealing its secrets.

The brief articles that follow describe a selection of our studies, both complete and ongoing, on aspects of the biology, chemistry, geology, and physics of these important ocean boundaries.

DEREK SPENCER

Val Worthington plots XBT data aboard Oceanus.

Rich Harbison examines amphipod on A-II #101.

Breck Owen, Phil Richardson, and Bill Schmitz.

Jack Loramoto takes a break on Oceanus #46.

Nat Conwin at Clark Laboratory.

SOFAR float is moved across Oceanus deck.
Some of the earliest oceanographic studies concerned the motions of the upper ocean and how the atmospheric inputs of wind, heat, and rain influenced those motions. Studies of this kind are still going on at Woods Hole and elsewhere. As our perception of the coupling between the atmosphere and the deep and upper ocean increases, we find a complex system of energy sources and receivers: there are delays and transfer of energy between parts of the system, there are interactions between small-scale fluctuations and large-scale motions, and there is a rhythm of daily, seasonal, annual, and long-term cycles that is intimately connected with problems of weather, climate, and the very existence of life on the planet.

Although we have a general understanding of some of the physical processes that cause, enhance, or inhibit the energy transfers between the air and the sea, an embarrassing lack of detail exists. For example, the wind makes waves, and the motion and decay of the waves is somehow connected with the formation and maintenance of a mixed region in the upper layer (say, 20 to 50 meters) of the ocean, but we really do not understand how this occurs. Considerable theory and data exist; so do contradictions, inconsistencies, and confusion.

The sun and the winds are the sources of heat and momentum that enter the ocean, while the ocean motions themselves are responsible for vertical and horizontal redistribution of the energy. A slow return of energy to the atmosphere occurs: most of the energy that drives hurricanes, for example, comes from oceanic heat in the surface layer.

Meteorologists, who are mainly concerned with the effect of the ocean on the atmosphere, ask most often what is the surface temperature of the oceans? Oceanographers studying large-scale circulation problems are more interested in the movement of heat from the equatorial regions (where the sun's input is strongest to the largely water-covered earth) toward the temperate latitudes and the poles (where land masses and weather systems are strongly affected). Finally, there are the oceanographers investigating the processes that determine how much heat and momentum are actually transferred between the atmosphere and the ocean, how it is done, and how it is mixed vertically and redistributed horizontally to other parts of the planet.

In 1966 the International Joint Air-Sea Interaction Project (JASIN) was proposed on aspects of the problem, particularly the air-sea transfers and the vertical mixing processes. After several trial and developmental field programs, the main field experiment was held from July to September 1978 about midway between Scotland and Iceland, in a region of historically intense air-sea interactions. Nine countries contributed 14 ships, four aircraft, and about 60 meteorological and oceanographic research programs.

The United States' contribution was two aircraft and two ships, one of which was R/V Atlantis II from Woods Hole. On Atlantis II, in addition to the W.H.O.I. work, there were cooperating programs and scientists from Scripps Institution of Oceanography, Oregon State University, Stanford University, NOAA, and the
Artist's conception shows the Woods Hole Oceanographic Institution's contributions to the Joint Air-Sea Interaction Project (JASIN), a nine-country, 1-ship, international study of the response of the ocean to the motions of the atmosphere. The field experiment took place July-September 1978 northwest of Scotland, about halfway to Iceland, in one of the historically stormiest places in the North Atlantic Ocean. The figure shows the Institution's research vessel Atlantis III suspending an electronic conductivity (i.e., salinity), temperature, depth profiler (called a CTD) beneath the ship. Floating above the CTD is a meter to measure vertical currents. The three moorings—a subsurface mooring (W1) supported by an eight-foot, 4,000-pound buoyancy float, a toroid surface mooring (W2) carrying meteorological instruments, and a spar-sphere combination (W3)—all support current and temperature measuring instruments.

The scale of the figure is distorted; the spar is 16 meters long, the water is 1,500 meters deep, and the ship is 64 meters long. The anchors alone weigh about 2½ tons each, and the value of the instrumentation shown is about $1 million dollars.

Bedford Institute in Canada. W.H.O.I. oceanographic teams also worked on the R/V Endeavor from the University of Rhode Island and on the Planet from West Germany.

Parts of JASIN were concerned with the development of the mixed layer itself, whereas the main W.H.O.I. project was an attempt to understand how much energy was being radiated by internal waves down into the body of the ocean and away from the mixed layer. Laboratory studies had suggested that the energy available to mix the layer could be reduced by as much as 50 percent by losses to the internal wave field; we wanted to know whether this was really true in the ocean. Additionally, the internal waves were thought to be a major source of the energy used to mix the interior of the ocean vertically; we also wanted to know if this were really true.

We are presently analyzing our data from the experiment. By relating our internal wave measurements to the measurements of those scientists studying the mixed layer and deep mixing, we hope to answer our specific questions concerning the role of internal waves in the overall problem of upper ocean variability as well as their relationship to upper ocean dynamics. At W.H.O.I., where considerable expertise exists on deep ocean variability and dynamics, we hope soon to connect our upper ocean studies to those deeper ocean investigations. Ultimately, we would like to place internal waves and other upper ocean processes in their correct context as part of the overall pattern of oceanographic physics.

Internal waves are similar to surface waves but occur on the gentle and gradual density gradients within the ocean. They have periods of hours, lengths of kilometers, heights of tens of meters, and exist at all depths in all oceans.

Surface wind speed (at 3 m height) and water current speeds from five depths; measurements are from the JASIN project. The approximately twice-daily current fluctuations are inertial oscillations forced by the wind and maintained by the rotation of the earth; also twice-daily are tidal currents. The strong currents in the upper 300 meters during the first part of the experiment are caused by a nearby oceanic frontal zone. The direct influence of the wind is most easily seen only in the 17 m current data; some correlation is also visible with the bursts of inertial oscillations.
Most bottom-dwelling invertebrate organisms are sedentary in habit and spend most of their lives either in tubes or burrows within the sediment or creeping upon the sea-floor surface. Such an existence makes it unlikely and in some instances impossible for adults to migrate over more than a very short distance. However, a large proportion of benthic invertebrate species have a free-drifting developmental stage — a planktonic larva — which allows their dispersal over wider areas.

Over the past decade, compelling evidence has been obtained that shows planktonic larvae are the means whereby invertebrate species are frequently dispersed over very great distances, not only along coastlines of continents, but also across biogeographic barriers such as ocean basins. This long-distance dispersal can be inferred from the occurrence of larval stages in major ocean currents which carry them many thousands of miles.

Studies made on larvae captured in plankton nets in the open ocean and subsequently maintained alive in the laboratory reveal that most of these long-
distance or "teleplanic" larvae have planktonic stages of many months, in some instances up to a year. For example, larvae of a species of polychaete worm belonging to the family Chaetopteridae have been maintained in the laboratory in a developing planktonic stage for over 12 months. Likewise, the veliger larvae of many tropical prosobranch snails, such as those of the families Cymatiidae and Bursidae, have a planktonic development stage exceeding six months. This long larval development makes possible a very widespread dispersal, the distance depending upon the direction and velocity of the surface currents.

The duration of the planktonic larval stage may be modified by seawater temperature and, in some species, by a settlement response induced by some attribute of the adult environment. In the absence of such a cue, the settlement of the larva may be delayed. The kind and quantity of food available may also modify the rate of larval development, but the factors that determine larval growth and settlement differ with different species and are the subject of continuing laboratory experimentation. Information on growth, survival, and metamorphosis are of considerable practical importance in the study of fouling organisms such as barnacles and encrusting serpulid worms.

Although it is now known that a wide variety of tropical benthic invertebrate taxa include species with a very long pelagic larval development, most of the familiar temperate species have a more restricted planktonic stage ranging from two to six weeks. There are also benthic species that have no pelagic stage at all. To understand the significance of these differences in dispersal capability, comparisons may be made of species that have long pelagic development of many months, those with a planktonic larval stage of only a few weeks, and those that lack any pelagic stage. Such comparisons suggest that species with teleplanic larvae usually have wider geographic ranges than those with pelagic development of shorter duration or those without any planktonic development. However, even species whose planktonic larvae develop within only a few weeks may sometimes have a wide geographic range; this is accomplished by a stepwise dispersal over hundreds of miles along the coastlines of continents through consecutive generations. Species with lesser dispersal ability differ from those with teleplanic larvae in that their geographic ranges seldom cross zoogeographic barriers.

Larval dispersal also appears to play a role in the geographic variation within species. To state the hypothesis in its simplest form, it is proposed that if on the one hand natural selection is responsible for genetically determined variation that may eventually lead to geographic speciation, while on the other hand larval transport provides genetic continuity or gene flow between populations that can lead to genetic homogeneity in species over large geographic areas. Although other factors complicate this over-simplified view, there is some evidence to support this theory. Among certain tropical prosobranch snail species with teleplanic larvae, there appears to be a direct correspondence between the estimated frequency of larval transport and the degree of morphological similarity between eastern and western Atlantic populations. Similarly, within the gastropod molluscan genus Crepidula, two species with a short pelagic development of two to three weeks show less genetically determined geographic variation than a third species within the same genus that has a nonpelagic development.

The significance of larval dispersal to the rate of evolution and species extinction can be investigated by a study of the fossil record and by making inferences from the knowledge of closely related contemporary forms. The information required is 1) a knowledge of the mode of reproduction of a fossil species; did it have a pelagic or a nonpelagic development? and 2) the longevity or geologic range of the species, derived from the first and last known occurrence in the fossil record. The evidence from bivalves and gastropods suggests that species with teleplanic larvae tend to have a greater than average geologic range, that is, they appear to resist extinction and to evolve more slowly than species lacking a pelagic stage. Studies of this kind are just beginning and much remains to be learned.

It is apparent, however, that the significance of larval dispersal lies in its long-term zoogeographic, genetic, and evolutionary consequences.

Living mesostroch larva of the polychaete worm Chaetopterus variopedatus taken from a plankton tow in the Gulf Stream. The two ciliated metatarsoch bands help propel the larva. Yellow to green in color, the mesostroch has three pair of "eyes," two pair small and black, the other larger and deep red, one of which can be seen here. Tentacles extend from the head, and there is a small structure at the end of the abdomen (left) whereby the larva may attach to a surface and later swim away. Eventually, after several months, the mesostroch settles and metamorphoses into a bizarre worm that lives in a parchmentlike U-shaped tube within the sediment of the sea bottom.
Biogeographic Zooplankton Boundaries: Studies in Gulf Stream Rings

Peter Wiebe

Free-drifting epipelagic zooplankton are generally believed to have little or no control of their horizontal distribution on space scales greater than one kilometer in their upper open ocean habitat. Their large-scale distributions across the ocean are thought to be determined to a large extent by the surface current systems and by the suitability for their survival of the biological, chemical, and physical properties of the various water masses they encounter as they drift with the currents. Characteristic patterns of population distribution that generally follow the distribution of water masses indicate that conditions are not equally suitable for the survival of zooplankton species across the broad expanses of the upper ocean. Although the large-scale distributions of most epipelagic zooplankton are reasonably well-known, the specific factors determining the suitability of a hydrographic regime for the survival of a given species cannot now be specified — we are investigating the relationships between oceanic zooplankton and their environment in order to understand the mechanisms responsible for biogeographic boundaries.

Gulf Stream cold core rings have been the focal point for these studies for the past six years. Large unstable southward meanders of the Gulf Stream break away to form rings of swiftly flowing Gulf Stream water around cores of cold Slope Water normally found to the north of the Gulf Stream. Following their formation along the Gulf Stream's course east of Cape Hatteras, these large eddies, 150 to 300 kilometers in diameter and 4,000 to 5,000 meters in vertical extent, move erratically through the Sargasso Sea. In a very general sense, the movement of most rings is to the south or southwest. However, cold core rings can have strong interactions with the Gulf Stream, with each other, or with deep-sea topographic features, and precise predictions about the movement of any particular ring is so far impossible.

Rings offer the biological oceanographer a unique setting for the study of oceanic populations because there are sharp biological contrasts between the center of a ring and the surrounding Sargasso Sea. After formation, the ring environment is in a dramatic state of transition from a cold water to a warm water environment, and the same populations can be tracked through time — a possibility that occurs in virtually no other open ocean situation.

In collaboration with physical and chemical oceanographers, our recent work has combined theoretical modeling and field experimentation for a unified attack on the processes of ring decay and on the impact of rings on the surrounding Sargasso Sea. A multidisciplinary time

Cruise tracks of the four time series Gulf Stream Ring voyages are shown on these charts, and the change in the ring picture can be clearly seen. Tallyies are listed for each voyage of expendable bathythermograph (XBT) measurements, lowering of a conductivity-temperature-depth (CTD) sensor, zooplankton tows (MOCNESS 1 and 10), and chlorophyll readings on a fluorometer for plant biomass assessment.
series study of a cold core ring in the field was initiated with a December 1976 cruise. Subsequent cruises took place in April, August, and October/November of 1977. Our plan was to sample the same ring on all four of the cruises, but this turned out to be impossible because target rings failed to persist for the duration of the study. Nevertheless, our understanding of the Gulf Stream ring phenomenon was considerably advanced.

The biological effort included the collection of samples for the assessment of phytoplankton, zooplankton, and midwater fish populations at various locations within the rings as well as in the surrounding Sargasso Sea and in the Slope Water. Samples for analysis of the vertical distribution and abundance of zooplankton were collected with a net system composed of nine one-meter-square nets which open and close sequentially upon command from the surface. Conductivity, temperature, and depth measurements as well as water flow through the net and oxygen content of the water are transmitted to the surface by net instrumentation to aid in sampling control. The depth strata normally sampled were 1,000–850 meters, and 850–700, 700–550, 550–400, 400–300, 300–200, 200–100, 100–0 meters, although this plan was occasionally altered to permit the bracketing of prominent hydrographic features.

Zooplankton biomass has been measured in all 617 samples collected on the time-series cruises. For the most part, these data provide additional support for our earlier findings, published this year, concerning the influence of cold core rings on biomass distribution in the Northwestern Atlantic. Counting of zooplankton species in these samples is well underway. A number of taxonomic groups are being enumerated both at Woods Hole and elsewhere. Our laboratory is presently concentrating on the euphausiids, small shrimp-like crustaceans. Although information is being gathered on all 34 species of euphausiids occurring in our study area, most of our attention has been focused on one species, Nematoscelis megalops, in an effort to understand the factors that control the geographic distribution of this particular species in the Northwestern Atlantic.

Nematoscelis megalops is a large Slope Water euphausiid found south of the Gulf Stream in our samples only in association with cold core rings. In the Slope Water, this species typically lives in the upper 600 meters with most individuals in the population occurring above 300 meters both day and night. A similar vertical distribution pattern was observed in a six-month-old cold core ring (labeled “Dave”) except that a larger fraction of the population was present below 300 meters and individuals occurred down to 800 meters. On a second cruise to Ring Dave, we found the vertical distribution had shifted significantly downward with the major portion of the population occurring below 300 meters. Comparison of the vertical distribution pattern of N. megalops with the temperature and salinity profiles obtained with the multiple net system indicates that the downward shift in the ring was an attempt by the population to maintain itself in an

Vertical section of Nematoscelis megalops population from center of Ring Franklin out into Sargasso Sea.

Changes in the vertical distribution of N. megalops in a ring through time compared to normal distribution in Slope Water.
optimal temperature and salinity regime. On the third cruise to Ring Dave some seven months later, there were no N. megalops in the single night sample taken in the ring core.

The apparent movement of N. megalops downward in the water column as the ring ages appears to cause a deterioration in the zooplankton's physiological and biochemical condition. This is evidenced by an increase in body water content and a reduction in total body lipid, carbon, respiration rates, and nitrogen as compared with Slope Water individuals. Our present interpretation of these data is that as the ring decays, N. megalops tends to live deeper in the water column and, as a result, farther and farther away from the relatively food rich surface layers until eventually food levels are inadequate for growth and reproduction. Despite a drastic lowering of the metabolic rate, body energy stores are used. Thus, in older rings, individuals appear to be starving, and this may be the major factor leading to the demise of the ring population.

It is possible, however, that physical processes may cause individuals expatriated in a ring to be lost from the ring system. Mathematical modeling strongly suggests that as a ring moves horizontally in the Sargasso Sea, only a portion of the ring water column will actually be transported. This water is advedted along with the ring in a "trapped region." The models show that the trapped portion of the ring is maximal at the surface and becomes smaller with increasing depth until below 1,000 to 1,500 meters no water is transported as the ring moves. Thus as the N. megalops individuals move deeper into the water column with ring decay, they could move out of the trapped region of the ring and be lost through dispersal into the Sargasso Sea. This could reasonably explain the occurrence of individuals in Sargasso Waters adjacent to Ring Franklin which was surveyed on the last time-series cruise. There are, in addition, other physical mechanisms that may cause individuals to be lost from a ring.

In order to assist us in evaluating the mechanisms that cause the cold water species, such as N. megalops, to become extinct in rings, Glenn Flierl of MIT and I are developing models to examine the relative importance of physical and biological processes as causes in the decline of ring populations. Our first tentative results suggest that in situ biological processes are more important in accounting for these changes than are the physical processes. The models need a number of refinements, however, before this conclusion can be regarded as valid.

Our new awareness that such large-scale mechanisms as Gulf Stream rings move large segments of oceanic communities away from the home range area and into areas of quite different environmental conditions has only just begun to be translated into ongoing research activities. As open ocean experimental sites, rings appear to offer expanding prospects for future multidisciplinary studies.

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**Distribution of Atlantic Mesopelagic Fishes**

Richard Backus

The Atlantic-wide distribution patterns of the small fish species of the upper 1,000 meters of the deep ocean have been an object of study at the Institution for about 15 years. So-called “mesopelagic” fishes are, for the most part, small (one to a few inches long at maturity), black or silvery, luminescent, and big-eyed and big-mouthed. They make a daily vertical migration that brings them up from a daytime depth of 700 or 800 meters to spend the night somewhere in the upper 100 meters. Most are carnivores, eating other fishes or crustaceans that sometimes are almost as big as themselves. The most important family of mesopelagic fishes, both from the number of its species and from its general abundance, is the Myctophidae or lanternfishes, of which there are about 80 kinds in the Atlantic.

Recently, we completed a study of the distribution of the lanternfishes taken in about 1,000 midwater trawl collections widely scattered over the Atlantic from Iceland south to Buenos Aires and Capetown, and from Rhodes in the eastern Mediterranean west to the Gulf of Mexico. (The Arctic Ocean, north of our northern limit, lacks a proper mesopelagic fish fauna; the Atlantic south of our southern limit at 35°S is better thought of as part of another system, the circumglobal Southern Ocean.) We looked at about 250,000 lanternfish specimens one at a time.

The Atlantic’s 80 lanternfishes appear to be distributed according to nine basic patterns. One of these is illustrated by the accompanying figure. The lanternfish to which this map applies, Lepidophanes gaussii, is one of several distributed according to the subtropical pattern. Furthermore, like many lanternfishes, L. gaussii has a bipolar distribution; it has a disjunct, or divided, range — there are both northern and southern hemisphere subranges between which there lies an extensive area not inhabited by the species. Bipolar distributions show the great dependence of mesopelagic species on the purely physical aspects of their environment and, also, the strongly latitudinal nature of the biogeographic structure of the world pelagic environment.
The heavier lines approximately coinciding with the limits of the black circles, which signify catches of *Lepidophanes gaussii*, are the limits of the Atlantic’s subtropical seas. (Not all Atlantic lanternfishes are so abundant and so evenly distributed, and thus so well sampled, as to allow such a comparison of faunal and physical limits.) The close correspondence between the range of *L. gaussii* and the physical limits of the Atlantic’s subtropical seas shows that *L. gaussii* is one of those animals especially adapted for life in these warm, blue, transparent, poorly productive central gyres.

The western half of the subtropical sea of the North Atlantic is the relatively well studied Sargasso Sea whose physical limits can be drawn using criteria generally accepted by oceanographers. In the eastern half of this same sea, however, gradients at the edges are much less sharp, and criteria for physically delimiting the subtropical sea are much more difficult to choose and apply. Here one might use the limits indicated by the fish for help in choosing the criteria to be employed. In a sense, then, the presence of *L. gaussii* is a positive “bioassay” for those parts of the Atlantic that are subtropical.

Thus, the study of the distribution of mesopelagic fishes together with the kind and scale of physical change that accompanies faunal change in the upper waters of the deep ocean tells us not only about the biology of the fish, but also may help delimit areas that are relatively homogeneous physically.

The unoccupied region between the North Atlantic and South Atlantic populations of *L. gaussii* (excluding the Gulf of Mexico and the half-moon-shaped upwelling area off west Africa) is the normal range for a number of lanternfishes of tropical distribution pattern. Some tropical species are swept north out of the Caribbean Sea by the Gulf Stream as far as the Grand Banks of Newfoundland.

There are also lanternfish species that occupy both the tropical and subtropical parts of the Atlantic. These tropical-subtropical species together with the tropical and subtropical ones comprise about two-thirds of the Atlantic total. These three patterns plus four others (tropical-semisubtropical, temperate-

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semitropical, temperate, and subpolar-temperate) apply to lanternfish ranges that obviously are related to changing latitude. The final two patterns, the eastern and the Mauritanian upwelling ones, are respectively related to weak general and strong local upwelling in the eastern Atlantic.

If these overlapping distribution patterns are translated into a system of pelagic zoogeographic regions, the Atlantic north of 35° is found to consist of a Tropical Region poleward of which lie South and North Atlantic Subtropical Regions. Further north lie, successively, the North Atlantic Temperate Region (which includes the Mediterranean Sea) and the Atlantic Subarctic Region. The Gulf of Mexico and the Mauritanian Upwelling are small regions, neither of which can be combined with any other. The boundaries between these regions are represented by the heavier lines in the accompanying map and are places of both faunal and physical change. The lighter lines subdivide the regions into provinces and mark places of lesser faunal and physical change.

Recently, we have turned from studying lanternfish distribution on an Atlantic-
wide scale to studying it with respect to the Gulf Stream system. Because some lanternfishes normally find their southern limit at the Slope Water-Gulf Stream boundary while other species find their northern limit there, these species have proved useful in the study of Gulf Stream cold-core rings. We are also examining the mesopelagic fish fauna of the nascent Gulf Stream as it issues from the Straits of Florida. It has been estimated that each second about 24,000 lanternfish of tropical distribution pattern pass through a section of the Gulf Stream south of Nova Scotia. These little fishes, which must have a Caribbean origin, are tags of Gulf Stream water put there at no expense to oceanography and wait to be used in the solution of problems in Gulf Stream circulation on downstream off the Tail of the Grand Banks.

Sea-Air Exchange Processes
Robert Gagosian and Oliver Zafiriou

The atmosphere exchanges gaseous and particulate materials of a wide variety of chemical compositions with the underlying land and sea. The relatively rapid motion of air masses also facilitates atmospheric transport of these materials from land to sea and vice versa. Active physical and chemical processes in the air change the physical state or chemical structure of these materials during transport.

Recently, there has been increasing interest in the long range transport of natural and anthropogenic substances by the atmosphere, especially transport from land to oceans on a global scale. However, at present we know very little about the sources, fluxes, and exchange mechanisms involved in these processes; this information gap is most marked for the organic constituents of the atmosphere.

Recognizing this deficiency in our knowledge and the magnitude of the problem, a diverse group of investigators has initiated a multidisciplinary and multi-institutional program of research on Sea-Air Exchange Processes (SEAREX). This program is funded by the International Decade of Ocean Exploration office of the National Science Foundation. It involves eight American groups and one French team of investigators in a closely coordinated field and laboratory program designed to increase our understanding of atmospheric transport and transformations and their involvement as sources and sinks for materials found at the ocean surface. The program emphasizes processes active on a global scale.

Some major objectives of the SEAREX Program are: to measure the atmospheric concentrations and the fluxes to the ocean surface of selected heavy metals, radioisotopes, and trace organic compounds; to identify the sources of these substances in the marine atmosphere; and to conduct controlled laboratory and field experiments on the mechanisms of exchange across the sea surface.

One major tool the SEAREX Program is using to evaluate the underlying factors determining atmospheric concentrations and fluxes on a global scale is remote sampling sites situated far from major land masses and symmetrically placed in the northern and southern hemispheres. Both the relative land mass areas and the extent of anthropogenic emissions, as judged by economic activity, are markedly different in the two hemispheres, thus enhancing the contrast between land- and marine-derived materials. The sites to be investigated are Bolandretok, a small uninhabited island near Eniwetok Atoll, Marshall Islands, in the northwestern Pacific; and Tutula Island, American Samoa, in the south Pacific. To accommodate the large number of sampling devices and ancillary sensors and to minimize contamination, the experimental platforms are 18-meter towers mounted on the windward side of these islands (see figure). At each site, sampling will take place for about six contiguous weeks during the wet and the dry seasons.

During these sampling periods, hundreds to thousands of cubic meters of air will be sampled for both the particulate materials present and for some of the trace gas phase constituents. The size-distribution spectrum of the aerosol will also be recorded continuously. These
samples will establish the trace composition of the atmosphere. Rainfall and dry deposition collectors will also be used to sample the downward fluxes of materials by wet processes, and to obtain a rough idea of the dry fallout composition; however, no quantitative way of sampling dry deposition is available. These samples will be analyzed for a great variety of inorganic elements, mostly metals (such as lead, mercury, and cadmium). The organic constituents will be analyzed at the compound and compound class level, rather than for total elemental content. Expected components include alkanes, fatty acids, fatty alcohols, products of atmospheric chemical reactions such as formaldehyde, and anthropogenic compounds such as phthalates and heavier halogenated compounds.

In preparation for this effort, a test program was run at Pigeon Key, Florida, in early 1978 to test equipment, detect potential interferences, and gain experience with the automated sampling system. This system permits sampling to be controlled according to wind direction and speed and various indicators of local contamination, such as condensation nucleus counts. The Bokendretok (northern hemisphere) experiments are scheduled for 1979 and those in Samoa (southern hemisphere) tentatively for 1981.

In addition to these field sampling and flux programs, SEAREX is conducting two other experiments on the sources of components in the atmosphere. University of Rhode Island investigators have developed the Bubbling Interfacial Microlayer Sampler (BIMS), a catamaran-mounted device theoretically capable of sampling the very thin surface layer of the ocean which acts as an important, immediate source of particulate ocean-derived material ejected into the atmosphere. A cruise in the northwest Atlantic is scheduled in 1979, and in 1981 a major cruise utilizing BIMS will be conducted in the upwelling waters off the coast of Peru. The other SEAREX experimental facility is a laboratory laser fluorescence system for direct detection of traces of metals in air developed by Dr. E. D. Goldberg and collaborators at Scripps Institution of Oceanography. It will be used to study the emission of metals and other substances from such potential sources as rocks and land vegetation.

The two authors, along with Research Associate Edward Peltzer, are playing a major role in evaluating the organic compounds in the marine atmosphere. As these components are much less well-known than the radioisotopes or heavy metals, this work has a large exploratory dimension. Some of the principal goals in the early years of the program are: 1) to identify, if possible, “marker compounds” whose detailed molecular structures are unique fingerprints of specific sources, such as the sea surface, natural and vegetation, or anthropogenic emissions; 2) to estimate the fluxes of these materials to the marine environment; and 3) to attempt to understand the degree to which these primary inputs may be modified by physical and chemical processes in the atmosphere before exchange with the ocean.

Because of the very low levels and unknown structures of the materials involved, this work will utilize the most sophisticated and sensitive organic analytical techniques available, in particular, computerized gas chromatography-mass spectrometry. The GC-MS Facility at W.H.O.I. has long been one of the most up-to-date facilities in the country.

The organic compound and the other data gathered on metals and radioisotopes for this program will be stored in a computerized central file maintained by the SEAREX Program, along with ancillary meteorological data and air mass trajectory analyses performed at field sites. As the program advances, the SEAREX investigators plan to use factor analysis and correlation methods to identify unsuspected relationships in the atmospheric behaviors of various substances. These relationships may generate new hypotheses about sources that can, in turn, be investigated using the unique field and laboratory experimental approaches developed for SEAREX. The end result will be an improvement in our understanding of the composition of the marine atmosphere, the sources of material to it, and the processes responsible for exchange of these materials with the sea. This information will contribute to our understanding of global natural geochemical cycles, as well as to our assessment of the long-term and long-distance impact of anthropogenic emissions on the world ocean.

Air sampling equipment and meteorological sensors are located at the top of the SEAREX platform. Organic collectors are mounted on one side and the inorganic collectors on the other side.
Before 1970, much of our knowledge about the circulation of water over the continental shelf off the east coast of the United States came from hydrographic observations of temperature and salinity and from massive deployments of surface drift bottles and sea-bed drifters. Much of this pioneering work was conducted by early W.H.O.I. scientists — most notably Henry Bigelow, Mary Sears, Alfred Redfield, Columbus Iselin, Bostwick Ketchum, and Dean Bumpus — who were interested in understanding the relationship between the high biological productivity of the shelf ecosystem and coastal currents and water mass properties.

In this decade, self-contained current meters and temperature and pressure gauges originally developed for deep-ocean studies have been deployed on the continental shelf in a number of moored array experiments sponsored by NSF, NOAA, and other government agencies. These field experiments have provided direct current measurements of sufficient duration that we can, for the first time, begin to characterize rather accurately the current field and its temporal and spatial variability.

The mean currents observed in the first four moored array experiments are shown in the figure below. Only current time series of one month or longer have been used, and the mean currents are plotted as vectors with the magnitude of each vector representing the average speed observed with each instrument. The depth (in meters) of an individual measurement is indicated by the small number located next to the head of the current vector. The current observations are separated into winter (unstratified) measurements, denoted by solid vectors, and summer (stratified) measurements, dashed vectors. Measurements made by the W.H.O.I. Buoy Group at several sites on the continental rise and outer slope (sites 5 to 11 in the figure) are also included to show the mean south-southwestward flow of slope water.

These direct measurements of the mean current field on the continental shelf clearly demonstrate the subsurface flow of shelf water along the shelf towards the southwest. The mean currents generally increase in magnitude offshore and decrease with closeness to the bottom. At most sites, the mean current rotates towards shore with increasing depth. Most of the measurements are located along the three cross-shelf transects labeled I, II, and III in the figure, and the initial crude estimates of the long-shelf flux of shelf water through these transects do not vary much with season.

At most stations, the currents are composed of energetic lower frequency current driven by atmospheric transients and periodic tidal components, which can be quite strong in certain locations, such as Woods Hole and Nantucket Shoals. In the figure at right, the top panel shows the surface wind stress vector, the middle panel shows subtidal currents (i.e., with tidal components removed) at three measurement depths, and the bottom panel shows bottom pressure observed...
at a mid-shelf site south of Woods Hole — station III in the first figure — during March 1974. Note the coordinate system used with east (longshore) wind stress and currents plotted upward, and north (onshore) components plotted towards the left. Two major winter storms occurred during the experiment: storm "A" drove eastward longshelf currents of 30 centimeters per second with offshore flow near the surface and onshelf flow near the bottom; storm "B" drove equally strong westward longshelf currents, with now offshore flow near the bottom and onshelf flow near the surface. These storm-driven currents are associated with significant bottom pressure fluctuations which generally increase in amplitude towards the coast.

This is a brief description of the mean shelf circulation and the structure of wind-driven current fluctuations based on direct measurements made in recent years with modern equipment. While much has been learned from the early moored array work, more experimental work is clearly needed to improve our basic descriptive picture of shelf phenomena and processes and our still developing understanding of the governing dynamics.

The Longshore Sea-Level Slope

Gabriel Csanady

It has long been thought that sea level stands higher at Halifax than at Norfolk, but only recently have we been able to piece together evidence on the circulation of the waters of the east coast continental shelf that shows conclusively the presence of such a longshore sea-level slope.

To understand shelf circulation, it is necessary to take into account the increasing depth of the waters from the shore outward. If there is a longshore sea-level slope, the force of gravity will tend to accelerate the waters alongshore, requiring some balancing force. Where there is more water, more balancing force is needed. In shallow coastal waters, the balancing force is the drag of the bottom on the southwestward flow. If the longshore slope does not change much, the bottom drag must increase considerably from water 30 meters deep to water, say, 100 meters deep. The magnitude of the drag depends on the speed of the longshore flow; the faster the flow, the greater the drag. Thus a more or less constant longshore slope would be expected to be accompanied by a noticeable increase of longshore flow intensity with increasing depth, as, in fact, reported from current meter studies by Beardsley and colleagues in 1975.

A simple, variable depth model I constructed in 1976 simulated the known facts on shelf circulation fairly well. In particular, the model showed offshore drift at the surface, and at the bottom in water deeper than about 60 meters, while in shallower water the predicted cross-shore drift was shoreward. The reason for the change in bottom drift is the changing relative importance (with depth) of the various contributions to circulation from wind, fresh water influx, and longshore sea-level slope. The observed facts could not be reproduced by this model without involving a longshore sea-level slope.

The magnitude of the longshore sea-level slope may be estimated from a balance of forces acting on the entire water column in the longshore direction. Close to the coast, the main contributions to this balance are bottom drag and the force of the wind at the surface. These two may be estimated if the wind velocity above the water and the water velocity above the bottom are known. The force of gravity associated with longshore sea-level slope must account for any differences. From an empirical study of this force balance, Jon Scott of the State University of New York, Albany, and I estimated the longshore sea-level slope of Long Island to be about $1.4 \times 10^{-4}$, or 1.4 centimeters in 100 kilometers. This result was based on a one month-long data set and was...
subject to error due to short-term sea-
level response to wind stress variations.

An alternative estimate of the magni-
tude of the longshore sea-level slope
may be based on current observations in
rather deeper water, where, in the middle
of the water column, the direct influence
of wind and bottom drag is negligible.
The flow at this level should follow lines
of constant pressure, i.e., sea-level, and
hence have an onshore component. The
magnitude of the observed onshore
mean velocity is a direct measure of the
longshore sea-level slope. What causes
this longshore slope? Is it the distant
result of a remote pile-up of fresh water
corin in via the Labrador current and
the St. Lawrence, for example? Or is it
imposed on the shelf waters from off-
shore by the dynamics of the massive
deep-water gyres of the North Atlantic?

We found the answer to these ques-
tions very recently, and the excitement
is still with us. While fresh-water sources
do have some important local effects, the
main cause of the longshore slope is
undoubtedly the deep-water gyre
between the Gulf Stream and the North
American continental margin. The wind
is generally eastward in this region, and
its force on the water depends impor-
tantly on the air sea temperature differ-
ence. Over the warm waters of the Gulf
Stream, the continental air in winter rises,
churns up the air above, and transfers
downward some of the momentum of the
fast upper level winds. The wind force
over the water becomes very high here,
increasing rapidly from more moderate
values in the vicinity of the coast. Surface
waters acted upon by the force of the
wind deflect to the right under the
influence of the earth’s rotation, moving
toward the Gulf Stream and beyond, to
the middle of the Sargasso Sea. Close to
the Gulf Stream where the wind force is
larger, more water is moving away than is
coming in — the source of the incoming
water is a region of lesser wind force.

Hence a depression in surface level
tends to be generated by the variations of wind
force in the region between the continen-
tal margin and the Gulf Stream.

Owing to the sphericity of the earth,
such low pressure areas tend to move
westward and intensify near the western
boundary of an oceanic basin. (The prin-
ciple of “westward intensification,” which
is responsible for the existence of the
Gulf Stream, was elucidated by Henry
Stommel in 1948.) According to the
same principle, the center of the low
pressure area between the Gulf Stream
and the coast is to be found near the
western edge of the region, i.e., close to
Cape Hatteras. East of the low pressure
center over most of the region of interest,
the sea level slopes down toward the
west. Numerical model calculations, as
well as simple analytical estimates, show
an east to west slope of about 1 centime-
ter in 100 kilometers. An analytical
model of the adjacent shelf region has
shown that a longshore slope imposed at
the shelf edge by deep water dynamics
produces effects exactly as observed and
as modeled by the simple shelf dynamics
models described earlier.

In deep water the east-west sea level
slope is accompanied by onshore drift of
the top 200 meters or so of the water col-
umn. As this impinges on the upper con-
tinental slope and shelf, a southwestward
current develops, concentrated along the
edge of the shelf, just outside the 100
meter depth contour. A fairly substantial
amount of water moves southwestward
in this current, much more than along the
shelf proper. What we see as shelf circula-
tion is more or less a fallout from this
vigorous gyre north of the Gulf Stream.

My work on this problem has been
supported by the Department of Energy
and has as its primary focus the behavior
of the nearshore waters of the continent-
al shelves, where electric power stations
discharge their cooling waters and dis-
sipate their excess heat. Licensing of
some power plants has recently been
held up by questions concerning whether
such heat inputs might lead to a long-
term build-up of water temperatures. The
results of the above investigations allow
some fairly general comments in this
regard. Given that the longshore sea-
level slope is an imprint of a massive
deep-water oceanic gyre, it is essentially
a permanent feature, presumably subject
to relatively small seasonal or annual var-
ation. The longshore flow driven in shal-
low water by this sea level slope is
substantial enough to remove expedi-
tiously any reasonable amount of heat
which may be discharged into the ocean
by human activity, so that no long-term
heat build-up need be feared.

Source and Fate of Urban Estuarine
Sediments — Boston Harbor
Michael Fitzgerald and John Milliman

The urban estuary is a fragile resource
subjected to a variety of human pres-
sures. The estuary’s sedimentary regime
both influences and records the environ-
mental response to these pressures.
Understanding estuarine sedimentary
processes, therefore, is necessary for
wise coastal management.

Boston Harbor is perhaps an extreme
element of an urban estuary in that most
river flow has been stopped by dams and
urban development; dominant fresh
water and sediment input is from two
greater Boston area sewer outfalls
located near the mouth of the harbor
(see figure). Water column sampling plus
preliminary current measurements made
during a continuing Sea Grant-
sponsored program suggest that a con-
siderable portion of the outfall material
moves directly or indirectly into the har-
b. As a result, parts of the harbor bot-
tom are covered with organic-rich (three
to five percent organic carbon) polluted
sediment. The organic-rich sediment pro-
duces considerable quantities of meth-
ane gas, which in turn facilitates charting
of these sediments by remote sensing
(figure right above). Cores in these sedi-
ments show a major increase in pollutant
influx (including trace metals such as cad-
imus, lead, nickel, and copper) and sedi-
mentation rates of 0.5 centimeter per
year during the past 80 years (when out-
falls have grown in size and use).

We have documented the movement
of these anthropogenic contaminants
with suspended matter and water column
measurements that delineate spatial, tidal, diurnal, and seasonal variations within the system and outline the imprint of sewage upon the estuarine regime. Particulates come from three main sources: sewage outfalls proper, biologic production, and resuspension of bottom sediment (often modified material from the other two sources). Laboratory and scanning electron microscope analyses show that many particulates are totally or partly anthropogenic and suggest the influence of organics in the transport of heavy metals. The importance of resuspension is not fully understood, but preliminary sediment trap experiments indicate considerable bottom sediment resuspension in the outer harbor waters. The nature of some suspended particles also can be understood by documenting the dissolved nutrient content of the water mass in which they occur. For

Photomicrograph above shows suspended particulate collected near Deer Island. Elemental composition of the particulate within the boxed area is represented on the spectra below from a backscattering x-ray unit attached to the scanning electron microscope. The large Ni peak between 07 and 08 indicates the role of particulates in the transport of trace metals.

Sub-bottom echo sounding profile in Boston Harbor shows the configuration of the bottom (B) below the water surface (S). Acoustic bottom (AB) is assumed to be Paleozoic basement. The intervening layers between B and AB are well-defined sedimentary strata (mostly glacial in origin). Methane gas in highly organic (polluted) sediments, however, masks the acoustic returns, resulting in a blurred record as shown in the central portion of the figure. Vertical scale of the figure is 1 / 10 second or 93 meters. Horizontal distance is approximately one kilometer.

example, outfall waters tend to contain high levels of nutrients, while material suspended from bottom sediments is associated with relatively low nutrient concentrations.

Future research is aimed at better defining the current regime within the harbor so that movement of material can be predicted. These data, combined with further nutrient, suspended matter, and sediment trap observations should allow us to construct a numerical model to understand and predict the depositional regime within the harbor. Such a model will help public officials in planning future placement of sewer outfalls and storm drain overflows within the harbor area.

Offshore Clam Fisheries of the Middle Atlantic Bight
Roger Mann

There are two offshore clam fisheries in the Middle Atlantic Bight, the region extending from Cape Cod to Cape Hatteras. The species supporting these fisheries are the surf clam or sea clam (Spisula solidissima) and the ocean quahog or mahogany clam (Arctica islandica). In 1976, the two fisheries employed approximately 169 vessels varying in size from under 12 to over 45 meters in length. The dock value of their catch was approximately $25 million. During the last two years, the surf clam fishery has shown the effects of a number of years of sustained fishing effort; consequently, more and more vessels are turning to the ocean quahog as an alternative fishery. For many years, the latter fishery was small and centered mainly in Rhode Island; for example, in 1976 the ocean quahog fishery employed only 15 vessels, and landings totalled only $1.6 million. However, estimates by the Mid-Atlantic Fishery Management Council suggest that the value of landings of this species may exceed $21 million by 1982.

Despite the considerable economic importance of these fisheries, we are still remarkably ignorant of many relevant biological details of these two species, especially in the case of the ocean quahog. For example, estimates of the time required for an ocean quahog to grow large enough to be retained by the dredges used for their collection vary from less than 10 to more than 120 years depending upon which data set is used and how it is interpreted. Needless to say, such ambiguities make the production of a sound fishery management plan a major problem.

A small number of scientists at locations from Woods Hole to New Jersey are presently involved in studies of various aspects of the biology of surf clams and ocean quahogs. At Woods Hole, with the aid of funds from the NOAA Sea Grant Program, Rod Taylor and I are examining the relationship of the spawning activity of the ocean quahog to the seasonal changes in water temperature in the Middle Atlantic Bight.

During the spring and early summer months, the surface waters of the region are warmed by the sun. Wind mixing of the upper surface layers results in a thermocline where warm water, approximately 20 to 25 meters deep, overlies a deeper, colder layer. The Middle Atlantic Bight has a very intense seasonal thermocline (described in great detail by Henry Bigelow in 1933) that builds up during the spring and summer and then breaks down in the fall when surface temperatures decrease and vertical mixing increases.

Published material describing the horizontal and vertical distribution of the surf clam and ocean quahog suggests that this seasonal thermocline is of great significance in limiting the distribution of the two species. The surf clam is found in greatest abundance in the warmer waters above the seasonal thermocline, whereas the ocean quahog exists in the cold water beneath it. The surf clam spawns in early summer when water
temperatures exceed 20°. The free-swimming larvae require approximately 20 days to reach metamorphosis and settle to the bottom to prepare for a sedentary adult life.

We suspect that the ocean quahog differs considerably from the surf clam in its preferred time of spawning and are in the process of testing the following hypothesis: the bottom water temperature in the depth range occupied by the ocean quahog (30 to 70 meters in the Middle Atlantic Bight) reaches a maximum in the late fall when the summer thermocline breaks down and the water column mixes throughout its entire depth. If spawning activity in the ocean quahog is stimulated by high temperatures, as it is in many other bivalve mollusk species, then the maximum spawning activity will coincide with this period. Furthermore, the good horizontal and vertical mixing that occurs in the absence of an intense thermocline will favor survival and dispersion of the free-swimming larvae.

At present, we are collecting on a regular basis numbers of ocean quahogs from specific locations east and south of Block Island, RI. In our Woods Hole laboratory, we make histological examinations of their tissues for the presence of ripe eggs and sperm and attempt to correlate development with our records of temperature, depth, salinity, and dissolved oxygen. Once we have defined the spawning cycle, we hope, in turn, to study the effect of temperature on the rate of larval development. As water temperatures are considerably colder in the fall than in the summer, it is probable that larval development will be much slower in ocean quahogs than in surf clams. Presently available data suggest that the larval life of ocean quahogs lasts approximately 60 days at 10 to 12°C.

The ultimate aim of our research is to combine data on time of spawning and duration of larval life with water movement data to estimate the possible extent of larval dispersion from any one parent population. The possibility exists that with future answers to the growth rate dilemma and a knowledge of year class structure in the presently fished populations of ocean quahogs, we may be able to assess the effects of various physical factors on larval dispersion and subsequent recruitment. In turn, all of these data sets will be supplied to the Fisheries Management Council for incorporation into a plan for optimum use of this valuable resource.

### Plant Population Boundaries in Coastal Waters

**Lynda Murphy**

**HYDROGRAPHIC** boundaries in the sea correlate well with plant population boundaries, and certain species rosters are characteristic of certain water masses. In my laboratory, we try to determine what it is that the plants are responding to at the boundaries of water masses and why some species appear to cross boundaries.

We carry out physiological and genetic studies of phytoplankton with clonal cultures — cultures in which all of the cells are the asexual progeny of a single cell isolate. The culture collection of the Woods Hole Oceanographic Institution contains hundreds of such clones, isolated from all of the world’s oceans.

Off our coast, the slope water and the Gulf Stream form a complex, but effective, boundary between two water masses — the coastal or shelf water and the Sargasso Sea. Each of the water masses has its own definite species roster. To account for differences, we might try comparing the characteristics of coastal and oceanic waters: temperature varies seasonally, but the extremes are much greater in coastal waters than in the relative uniformity of Sargasso Sea; salinity is uniformly high in the oceanic waters, lower in coastal waters, and can become very low (and seasonally variable) in bays and estuaries; nutrients are generally much higher in coastal waters, but they can become severely depleted. In fact, variability itself is a characteristic of coastal waters as compared to the relatively uniform oceanic waters.

Interesting though these differences may be, there are others that we find even more interesting, and that we feel may hold the key to the basic question, What keeps coastal species in coastal waters and oceanic species in oceanic waters? Iron levels are higher in coastal than in oceanic waters, and coastal phytoplankton have a much higher requirement for iron than do related phytoplankton from the open ocean. There are more trace metals in coastal water than in oceanic, but there are also more organic chemicals and particles that can chelate or bind up these metals. It appears that for some metals, at least, the phytoplankton are sensitive only to the free metal ion and do not sense chelated metal. Thus, copper toxicity is a function of cupric ion activity, not of total copper in the water. When we compare the responses of healthy phytoplankton to cupric ion, we find that oceanic clones of phytoplankton are generally more sensitive than are coastal clones of the same, or closely related, species. But they are not very much more sensitive. The difference lies within half an order of
magnitude, and this may be an environmentally significant half an order. (Actually, we do not know the real levels of cupric ion activity in seawater. We can measure total copper, but the other ions in seawater interfere with the measurement of cupric ion.)

Iron requirements give us a useful tool because in almost every other regard, oceanic phytoplankton are more easily stressed than are coastal phytoplankton. But the coastal clones become iron-starved far more easily than do related oceanic clones. What happens to a coastal phytoplankter that is carried into iron-poor oceanic water? When iron-starved, does it then become more sensitive to other environmental factors? More sensitive even than oceanic phytoplankters? These are some of the questions we are addressing.

Some of the stresses that phytoplankton encounter are man-made chemical stresses — pollutants. Pollution is not just characteristic of coastal waters; PCBs and DDT have been measured in the open ocean. In local bays and estuaries, however, pollution levels can become very high. To avoid problems of local contamination, an area of ocean over the continental slope has been designated as a deep-ocean dumpsite. This area, called Deep Water Dumpsite 106, is located 106 nautical miles southeast of the apex of New York Bight. It is used as a disposal site for industrial wastes that can’t be disposed of ashore or closer to land.

In studying the effects of the dumping on phytoplankton from this site, which lies along the boundary between the coastal and oceanic domains, we have found that any evaluation of toxic effects in such a region should take into account the environmental origins of the organisms being tested. We might expect to find that coastal phytoplankton are less sensitive to industrial wastes than phytoplankton from the open ocean simply because coastal phytoplankton seem to be “tougher” in the face of other chemical and thermal stresses. In fact, some early studies did indicate just this. Coastal (high iron-requiring) clones appeared more sensitive than did oceanic (low iron-requiring) ones. But with closer scrutiny, we have found that the responses are much more complex. The pollution history of the original environment from which the clone was isolated is at least as important as any other factor in determining its ability to resist this chemical stress. Among coastal clones, those established from relatively clean waters such as those in the Woods Hole area and from Friday Harbor, Washington, can be as sensitive as oceanic clones, but Long Island Sound yields clones highly resistant to the waste.

We are concerned with the role of stress in pollution sensitivity. How do other environmental factors affect the responses of phytoplankton to pollutants? Do such interactions favor one type of phytoplankton over another? What would be the effect of such differential survival on the other organisms in the sea? We are approaching such questions and beginning to get answers.

**Chlorinated Cooling Waters and Marine Plankton**

_Judith Capuzzo_

**CHLORINATION** of cooling waters in power plant operations is a common practice for the removal of bacterial slime and the prevention of fouling organisms in condensers. Power generating stations vary in their chlorination procedures from continuous low-level (0.1 mg/l) application, common in Great Britain, to intermittent chlorination (2–3 hours per day), common in the United States. In the latter instance, levels of chlorine residuals typically range from 0.05 to 5.0 mg/l to ensure removal of mussels and barnacles from condensers.

However, investigations of chlorine toxicity to nontarget organisms have only recently been undertaken. Organisms small enough to become entrained in cooling waters, such as marine plankton, are exposed to this chlorine stress, which is compounded by the thermal and mechanical stresses of condenser passage. Exposure of planktonic organisms to these stresses may result in reduced plankton biomass at several trophic levels and lead to significant imbalances or alterations in food chain dynamics.

In cooperation with Joel Goldman of the Biology Department and George Wong, a Joint Program graduate from the Chemistry Department (now at Old Dominion University, Norfolk, Virginia), I have recently completed a three-year research program dealing with the problems associated with chlorination at coastal power plants. Our research focused on the chemistry of chlorine in seawater and responses of phytoplankton and zooplankton — including both permanent members of the plankton and larval and juvenile forms of larger species — to chlorine and thermal stresses.

Because of the reactivity of chlorine with several constituents of seawater, chlorination of seawater results in the production of several halogen toxicants in addition to free chlorine. These include free bromine, chloramine, and organohalogen compounds. The toxicants produced are dependent on the nature of the receiving waters: in seawater with low ammonia and organic concentrations, free bromine is readily formed and would be the dominant toxicant; where power plants are located near waste water treatment plants, receiving waters may have high concentrations of ammonia and organic matter, and the formation of chloramine and organohalogen compounds may be significant. Chlorine (or its derivatives) disappears from seawater fairly rapidly but the reasons for this disappearance, or “chlorine demand,” have been difficult to identify. We determined that there were two distinct phases to chlorine loss — an initial rapid loss attributed to the oxidation of organic matter, followed by a continuous loss at a reduced rate possibly due to the bromine chemical system in seawater. The lost chlorine comprising the difference between the chlorine dose in power plant cooling waters (applied level) and the level measured in discharged effluents using standard analytical techniques (residual level) must remain suspect as the basis for compounds potentially toxic to marine organisms. Thus, estimates of chlorine toxicity to biota based on residual levels alone may provide no informa-
nation stress will not be replaced, larval and juvenile organisms represent the component of the plankton most susceptible to adverse effects of power plant operations. The toxic effects of chlorine and chloramine on stage I larvae of the American lobster (*Homarus americanus*) and juveniles of the killifish (*Fundulus heteroclitus*) were assessed through a comparison of observed mortality data and changes in standard metabolic activity after exposure to the toxicants.

We observed a differential effect of free chlorine and chloramine that was species specific:
- Applied chloramine was more toxic to lobster larvae than corresponding concentrations of free chlorine (A in figure).
- A gradual increase in lobster mortality was observed with increase in concentration of both toxicants; approximately 20 percent mortality was observed at the lowest detectable level of residual chlorine (0.01 mg/L), whereas less than 10 percent mortality was observed at the lowest detectable level of residual chloramine (0.01 mg/L).

![Graph showing the effect of total chlorine residual on mortality rate](image)

The effect of chlorine residuals on stage I lobster larvae *Homarus americanus* and juvenile killifish *Fundulus heteroclitus*. Commonly detected residuals range from 0.05 to 1.0 mg/L but may occasionally reach higher levels — approximately 5 mg/L to ensure removal of mussels and barnacles and approximately 12 mg/L to deter ells and jellyfish. In this study, total residual chlorine equalled 18 percent of the applied chlorine or chloramine level due to the chlorine demand of seawater. A. *Homarus americanus* percent mortality 48 hours after 30 or 60 minute exposure to chlorine residuals at 25°C. No significant difference in mortality was observed between the 30 and 60 minute exposure periods. B. *Homarus americanus* percent reduction in respiration rate from that of control organisms (1.1 μl O₂/h/mg) 48 hours after 60 minute exposure to chlorine residuals at 25°C. Control and exposed animals averaged 2.6 mg dry weight. C. *Fundulus heteroclitus* percent mortality 48 hours after 30 minute exposure to chlorine residuals at 25°C. D. *Fundulus heteroclitus* percent reduction in respiration rate from that of control organisms (1.2 μl O₂/h/mg) during 30 minute exposure to chlorine residuals at 25°C. Control and exposed animals averaged 18.4 mg dry weight. The respiration rate of test organisms exposed to 0.3 mg/L was not restored to the control level even 48 hours after exposure, whereas control animals maintained a stable respiration rate during the 48-hour period.
percent mortality was observed among control organisms.

- In contrast, juvenile killfish were more susceptible to free chlorine than to chloramine and a significant threshold effect was observed (C in figure). Complete survival at 25°C occurred at concentrations less than 0.4 mg / l total residual chlorine, applied as free chlorine, and less than 0.8 mg / l total residual chlorine, applied as chloramine; complete mortality was observed at higher concentrations.

Temperature had a synergistic effect on the toxicity of both halogen forms in both species.

The results of our respiration studies are indicative of significant respiratory stress with exposure to both toxicants. Respiration rates of lobster larvae measured 48 hours after exposure to each toxicant were significantly lower than control organisms (B in figure); the percent reduction in respiration rates observed was proportional to the concentration of each toxicant. Respiration rates of juvenile killfish monitored during and 48 hours after exposure to each toxicant were significantly reduced only with exposure to concentrations approaching lethal levels (D in figure). Initial respiratory stress was detected with exposure to 0.3 mg / l total residual chlorine, applied as free chlorine or chloramine; the respiration rates of exposed organisms were not restored to the control level even 48 hours after exposure. A more drastic decrease in respiration rate was observed with exposure to higher concentrations, correlated with the increases in mortality observed.

Decreased metabolic activity of sensitive species, such as larval lobsters and juvenile fish — important marine food resources — could result in serious changes in growth and maturation and increased susceptibility to other environmental stresses including disease and predation. The differences in response of lobster larvae and juvenile killfish to the toxicants probably reflect differences in uptake and metabolic regulation. Juvenile killfish are apparently unaffected by short term exposure to toxicant concentrations less than 0.3 mg / l, while lobster larvae experience significant metabolic stress even at the lowest toxicant concentrations tested (0.01 mg / l).

Levels of chlorine residuals currently being detected in chlorinated cooling waters are high enough to cause significant stress to some organisms without immediate mortality. Thus, measurements of viability at the discharge point of entrainment in or receiving waters adjacent to chlorine discharges do not provide us with an accurate picture of chlorine toxicity to marine zooplankton. Sublethal effects of free and combined chlorinomarine animals — including fish and invertebrate species — should be considered when establishing regulations for chlorine residuals in cooling waters from power plant operations. Low level chlorination combined with dechlorination and rapid dilution of cooling waters would provide the greatest protection to entrained organisms and organisms residing in receiving waters.

The Salt Marsh as a Resource

John Teal

Since 1971, a group of Institution researchers and colleagues from MBL and Boston University have worked intensively on Great Sippewissett Marsh in Falmouth. Although our principal scientific interest has been the basic ecology of salt marshes, how they function and how their structure is controlled by natural phenomena, we have also looked at practical aspects of marsh use by people as well as potential use of marshes in the production of human food and the treatment of human waste. The notions that salt marshes might be useful as open aquaculture systems and that they might be useful as waste water treatment systems are separate ideas, but they could potentially be combined. Since our research on these two areas has been somewhat independent, we will take them up one at a time, first considering open aquaculture.

We began our work by laying out 10-meter-radius experimental plots of salt marsh each bisected by a small marsh creek. Some plots were retained as controls while others were fertilized with varying levels of commercial fertilizer. Though other elements showed some very minor effects, nitrogen in the fertilizer was the element that most affected the marsh. Addition of nitrogen increased average salt marsh productivity two- to threefold; the form of the grass changes from short, closely spaced plants to very much taller, widely-spaced plants, and grass protein content increases by almost a factor of two.

Both enhancement of productivity and increase in grass quality have important effects on marsh animals. Although a few larger animals such as rabbits, mice, and geese eat the grasses, most salt marsh herbivores are insects, and the effect on insects was most dramatic in our experiments. The fertilization resulted in approximately a sevenfold increase in abundance of such insects as grasshoppers and plant bugs which feed directly on the common marsh grass called Spartina. Our experiments show that the increase was due mostly to the greater protein content of the grass rather than to the overall increase in grass productivity. We have not quantified the effects on the larger animals, but we have noticed that Canada geese feeding on the plots concentrate markedly on the fertilized grass and stop feeding abruptly at the edge of the experiment area when they encounter the unfertilized grass. Presumably, the higher protein content in the experimental area makes the grass taste better to the geese.

Most salt marsh animals feed not directly on the standing grass but on the detritus formed when dead grass is decomposed by bacteria and fungi. Fertilization increases the decomposition rate as well as the attractiveness of the resulting material to such detritus feeding animals as amphipods or snails, which are a major food source for Fundulus, minnows that come onto the marsh to feed at high tide. The fertilization therefore also has important consequences to
marsh fishes. Because the detritus is enriched in protein as well as more abundant, fertilization also affects the growth and population size of marsh filter feeders such as marsh mussels and the clams and oysters that live in the marsh creeks. Marsh fish and shellfish are the animals of most interest to people since they serve directly as human food. Although people rarely eat marsh minnows, the minnows return at low tide to the marsh creeks where they are fed upon by larger fishes. Among the food fish we find in the marshes are striped bass, bluefish, eels, winter flounder, and various members of the herring family. Our present experiments indicate, as we would logically expect, that the productivity of fish and shellfish is enhanced by marsh fertilization. However, the small scale of our experiments and the dilution of the production of our small plots by normal production in surrounding marsh make it difficult to measure accurately the effects on fish and shellfish. We are, therefore, beginning another experiment in which we will fertilize one hectare (2.4 acres) of salt marsh in order to measure the effects on fish and shellfish directly.

Turning to waste water treatment, in some of our initial experiments, we used sterilized sewage sludge as the fertilizer in order to look at the consequences of such contaminants as heavy metals, hydrocarbons, and pesticides contained in the sludge. In the first two years of our study, before persistent chlorinated hydrocarbons were banned, appreciable quantities of the pesticide Aldrin in the sewage sludge killed substantial numbers of fiddler crabs in sludge-fertilized experimental plots. But we found the effect of the Aldrin limited very exactly to the fertilized area: in test areas only one meter outside the fertilized plots, the fiddler crab population was normal. Apparently the marsh sediments bind organic molecules such as PCBs, Aldrin, and hydrocarbons very tightly and hold them in place; the grasses, in turn, bind the mud in place. Therefore, marsh sediments might be useful in removing organic contaminants from circulation in coastal waters. It is interesting to note that the effects of Aldrin were no longer observable two years after its use was banned. Little is known, however, about the effects on marsh animals of such substances while they are still active.

Heavy metals are also retained by the sediments but the more soluble ones are not so completely bound. In the plots treated with sludge, we have found it quite easy to measure increases in concentration of heavy metal contaminants including copper, lead, mercury, zinc, cadmium, and iron. (Though lead is not necessarily abundant in marsh peats, we have watched its presence increase in all marshes from industrial activity and automobile emissions. Some other metals, such as iron and zinc, normally abundant in coastal sediments, show no overall increase, but there is a measurable increase from sewage sludge application.) These metals are retained in marsh sediments mostly by forming insoluble precipitates with sulfides that result from sulfate reduction by marsh bacteria. Some metal sulfides (including those of lead, copper, and mercury) are so insoluble that virtually all of the heavy metal penetrating more than a few millimeters into the marsh sediments has been retained as sulfide through the eight years of our experiments. Only about 20 percent of the metals we have added that form soluble complexes in seawater can still be found in the sediments of the regularly flooded low marsh area plots. All of the heavy metals are taken up by marsh grasses and appropriated into leaf tissue. In cases such as that of iron, where the leaf contains a large amount of the metal, the effect of the added iron is not detectable under normal conditions. In cases such as that of lead, where the normal leaves contain very little of the metal, the consequence of the soil contamination is more apparent, and appreciably greater quantities of the contaminants are found in the sludge-treated areas than in the controls. Increased metal in leaf tissue is likely to lead to increased metal in leaf detritus, and it then becomes likely that detritus feeders and other marsh animals will also have elevated levels of those contaminants.

In order to combine waste water treatment with open system aquaculture in salt marshes, we must have more information not only about how marsh fertilization enhances the productivity of useful fish and shellfish, but also about whether and to what extent contaminants contained in sewage effluent or sludge are transferred through the marsh ecosystem to those same useful animals. Although we are far from being able to recommend that salt marshes be used as sewage treatment systems, we have come a long way toward understanding how salt marshes might be useful in such systems and how marshes currently serve mankind in cleaning up coastal waters and enhancing coastal productivity.
Trainee Paula Randolph records measurements during summer work in the salt marsh.

Joint Program students Ping Tung Shaw, left, Paul May, and Neal Pettigrew share lab space.

Bruce Cornuelle applies chalk to board during class in Surface and Internal Gravity Waves.
PHOTOGRAPH: A group of students and faculty members at Woods Hole Oceanographic Institution.
for capital items, $2.5 million for operating costs in the first five years, and $17 million in endowment to sustain the program. Such funds were provided by foundations and by individual friends of the Institution. The greater part of the endowment funds came through the magnificent generosity of Mr. J. Seward Johnson and Mr. and Mrs. W. Van Alan Clark whose two gifts in 1968 totalled $13 million.

The Program would not have been possible without such endowment funds. They have allowed us to provide fellowships, particularly for first and second-year students, without burdening research projects. Not only do fellowships allow students to study full-time, but they also provide flexibility in the choice of research subjects. In many instances, because they were on fellowships, students have been able to choose thesis topics without reference to existing research grants and contracts, thus broadening the research interests of the departments. This has been especially valuable in fields such as biological oceanography where research funds are quite limited.

The Education Committee estimated in 1966 that there should be enough endowment by 1975 to support 50 fellowships of $4,000 each. In 1978 we have 35 students on fellowships at nearly $12,000 each, a measure both of inflation and the success of the program.

A central question prior to the initiation of a degree program was staffing requirements. In the early '60s the education interests of the Woods Hole staff ranged from none whatsoever to considerable. A few of the staff held appointments in universities and taught more or less regularly. A considerably larger group regularly worked with students from other institutions in their laboratories. Thus, although students were not new for many staff members, formal and regular attention to education was.

At the outset, two alternatives for dealing with the educational staffing problem seemed possible. The simplest and most direct solution would have been to create a set of "faculty" appointments for capable existing staff willing to teach in the new program. This faculty could then have been augmented by recruitment from universities. This alternative, however, was rejected as a two-class system which, in the long run, could only be divisive. The route chosen, more difficult and certainly more ambiguous, was to develop the new educational program from within the existing staff structure on an essentially voluntary basis. The only title alteration was the abolishment of all joint appointments between Woods Hole and MIT on the ground that the Joint Program automatically gave joint status to all faculty of both institutions.

It is most interesting to observe that though a potential staff member's interest in working with students is considered, in the history of the Joint Program no new appointments have ever been made for the purpose of strengthening the education program. The initiative for making new staff appointments has continued to remain with the departments, and criteria for appointment have continued to be based on research capability.

Obviously, the decision to maintain a single staff to conduct both research and education created problems in providing a reward system for staff participation in education. Those of us who have worked in universities with graduate students believe that the association of good students with a scientist's research cannot help but amplify the scientist's research productivity; we believe that evaluations for promotion based on research criteria do not really penalize scientists who work with graduate students. But clearly this reasoning was not entirely appropriate in the Woods Hole situation. There were courses to be taught, committees to be manned, applications to be read, and all such activities take time away from research. Moreover, until the program had been underway for several years, it was not at all obvious that having graduate students to supervise would help a scientist get more research done.

In 1971, Dean Steinbach, in a memorandum to the Staff Council, urged that the assessment of teaching activity should "play a real role in considerations of promotion and advancement to tenure." The Council supported this view and the written criteria for appointment and promotion were changed to make educational activity a positive factor in promotions. A written evaluation from the Dean is requested in promotion considerations, and in several instances educational contributions have been decisive in promotion.

In 1975 the Educational Assembly, a faculty-like forum, was created. One of its first debates concerned a proposal that the official policy on participation of staff in the education program statement be changed from a statement that staff are "encouraged" to participate to a statement that they are "expected" to participate. After considerable debate, the proposal was overwhelmingly defeated, with most of the strong supporters of the educational program voting against it.

Clearly, while the importance of the graduate program is now accepted, at the same time the staff feels strongly that the Institution must have room in it for scientists who wish to devote their entire time to research.

The Institution's graduate program has been introduced over the years with a deliberate philosophy of integrating it as closely as possible with research activity. This has created little obvious change in the structure of the Institution, but the full participation of bright and energetic students has certainly provided a perceptible and positive change of atmosphere.

ROBERT W. MORSE
1978 Degree Recipients
Massachusetts Institute of Technology/Woods Hole Oceanographic Institution
Joint Program in Oceanography/Oceanographic Engineering

Doctor of Philosophy

ROBERT S. DETRICK
B.S., Lehigh University
M.S., Scripps Institution of Oceanography
Special Field: Marine Geology
Dissertation: The Crustal Structure and Subsidence History of Aseismic Ridges and Mid-Plate Island Chains

ERIC FIRING
B.S., Massachusetts Institute of Technology
Special Field: Physical Oceanography
Dissertation: Seasonal Oscillations in a Mid-Latitude Ocean with Barriers to Deep Flow

ROGER D. FLOOD
B.S., Massachusetts Institute of Technology
Special Field: Marine Geology

WILFORD D. GARDNER
S.B., Massachusetts Institute of Technology
Special Field: Marine Geology
Dissertation: Fluxes, Dynamics, and Chemistry of Particulates in the Ocean

GWEN GRABOWSKI KRIVI
A.B., Bucknell University
Special Field: Biological Oceanography
Dissertation: The Enzymatic Synthesis of the Yellow Pigment, Septaspherin, in Drosophila Melanogaster

GEORGE RODENBUSCH
B.S., M.M.E., Rice University
Special Field: Oceanographic Engineering
Dissertation: Response of a Pendulum Spar to Two-Dimensional Random Waves and a Uniform Current

NICK STARESINIC
B.S., University of Pittsburgh
Special Field: Biological Oceanography
Dissertation: The Vertical Flux of Particulate Organic Matter in the Peru Coastal Upwelling as Measured with a Free-Drifting Sediment Trap

JOHN S. TOCHKO
B.E., The Cooper Union
Special Field: Oceanographic Engineering
Dissertation: A Study of the Velocity Structure in a Marine Boundary Layer — Instrumentation and Observations

Ocean Engineer

HAROLD DAVID LEISLE
B.S.E., Princeton University
B.S., University of Wisconsin
Special Field: Oceanographic Engineering
Dissertation: Attenuation of Low Order Modes in Lossy/Acoustic Waveguides

Woods Hole Oceanographic Institution Doctoral Program

Doctor of Philosophy

PETER B. ORTNER
B.A., Yale University
Special Field: Biological Oceanography
Dissertation: Investigation into the Seasonal Deep Chlorophyll Maximum in the Western North Atlantic, and its Possible Significance to Regional Food Chain Relationships
Preliminary plans for the Institution's 50th anniversary celebration in 1980 were discussed by Director John H. Steele at the winter meeting of the Corporation 17 January at the American Meteorological Society Headquarters in Boston. Members of the Directorate and scientific staff also discussed changes in the Institution over the past ten years, present programs and their future role, and the Institution's role in science in the next decade.

The Third International Congress on the History of Oceanography will be held in Woods Hole 22-26 September 1980 in conjunction with the 50th anniversary celebration. An assembly on current and future oceanography will follow the Congress 29 September-4 October; Senior Scientist Peter Brewer is chairman of the assembly's organizing committee.

The Institution received word in March of Dr. Steele's election as a Fellow of the Royal Society of London. The Director was cited for "distinguished work on marine production and mathematical models for the prediction of primary production steady-state conditions."

Several other honors and awards were presented to staff members in 1978. Physical oceanographer Henry Stommel received the American Association for the Advancement of Science (AAAS) Rosenstiel Award in Oceanographic Science for 1977 for his "outstanding achievement in oceanography and chemistry of the water column and the atmosphere." Senior Scientist John Ryther and Associate Scientist David Ross were elected AAAS Fellows. Ryther was cited "for research on general marine ecology and particularly in the area of waste management and recycling and food produced from the sea." Ross was cited for his work in marine geology and geophysics of marginal seas and for involvement with marine scientists from numerous countries in multidisciplinary programs in the sea. In May Dr. Paul M. Fye received an honorary Doctor of Science degree from Long Island University for his "contributions to the field of oceanography."

Dr. Ferris Webster, Associate Director for Research, took a leave of absence from the Institution in June to accept a visiting the Institution in 1978 were: the New England Section of the American Chemical Society, A.D. Little Conference on Drifting Buoy Technology, Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES), American Society of Metals, Air National Guard and the U.S. Air Force Reserve Officers Weather Orientation course, U.S. Navy Long Range Acoustic Propagation Project (LRAPP), and the New England Section for Applied Spectroscopy.

Approximately 150 Associates, Corporation Members, and guests attended the Associates Dinners in Boston, New York, and Woods Hole in April. Dr. Steele discussed scientific experiments in general and Biology Department Chairman George D. Grice presented an illustrated lecture, "Giant Test Tubes in the Ocean," on work in the Controlled Ecosystems Pollution Experiment (CEPEX).

More than 300,000 specimens of Atlantic fishes are being transferred to Harvard University's Museum of Comparative Zoology (MCZ) Fish Department by Senior Scientist Richard H. Backus, Research Specialist James E. Craddock, and Associate Scientist Richard L. Haedrich. The collection represents over 13 years of research and was said to be "unparalleled in the history of the MCZ."

Dr. Jean Mayer, President of Tufts University, gave the tenth J. Seward Johnson Lecture 4 April on "The World Food Situation: 1978" in which he cited the vast improvement in nutrition for the poor in the past decade.

Representatives of the 15 petroleum companies which participate in the...
Ocean Industry Program attended two major seminars in 1978. "Chemical Environment of Marine Sediments" in May focused on the geological aspects of benthic boundary layer mixing in the deep ocean and on several research programs in the low energy and high energy benthic boundary layer. On 14 and 15 September "Deep Water Mapping Techniques" focused on the Institution's work in surveying and photographing active spreading centers such as the Mid-Atlantic Ridge, Cayman Trough, and Galapagos Rift.

Dean of Graduate Studies Dr. Robert W. Morse reviewed the joint M.I.T./W.H.O.I. graduate program in oceanography, which celebrated its 10th anniversary in 1978, at the 49th Annual Meeting of the Trustees and Corporation Members 22 June in Woods Hole. Seventy-nine degrees have been awarded in biology, chemistry, marine geology and geophysics, and ocean engineering. Dr. Morse shared the podium with Associate Scientist Melbourne G. Briscoe who spoke on "Interdisciplinary Oceanography of Internal Waves in Massachusetts Bay."

The Annual Sea Grant site visit was made 2 May and a grant of $550,000 awarded, a 30 percent increase over 1977. In September, some 25 representatives from the Office of Naval Research and other agencies spent three days in Woods Hole reviewing the ONR Atlantic Oceanography contract for 1979.

A total of 23 non-Institution vessels made 63 calls to the Institution pier in 1978 including six foreign vessels from Poland, Spain, West Germany, and the Soviet Union participating in a cooperative program with the National Marine Fisheries Service. Vessels from NOAA, USGS, Alcoa, University of Miami, Texas A & M, University of Rhode Island, Massachusetts Institute of Technology, and a cruise ship also called at the Woods Hole pier.

R/V *Knorr* departed in January for an 18-month cruise covering all disciplines. Port calls were scheduled for San Juan, Panama, Callao, Kwajalein, Samoa, Wellington, Christ Church, Tahiti, and Honolulu before *Knorr* returns to Woods Hole in August 1979.

The 1978 *Alvin* diving season began in May after an extensive overhaul of the sub which included replacement of the 23-foot aluminum frame with a stronger 25-foot titanium frame and addition of an optional second arm. The new frame supports increased instrumentation and allows accommodation of a fourth battery to increase the submersible's endurance.

Extensive refitting was also done on *Lulu* including installation of new main propulsion engines and improvement of living quarters for additional comfort and privacy. *Alvin* and *Lulu* made biological dives off the Atlantic Coast and in the Azores before departing in October for extended work in the Pacific and a second look at the Galapagos Rift vents discovered in 1977.

R/V *Atlantis II* participated in the International Joint Air Sea Interaction (JASIN) Project with 13 other vessels and four aercraft in a North Atlantic study. Following a study of the feasibility of repow-
During the luncheon the Institution awarded a doctorate in oceanography, the second degree awarded by the Institution alone since the charter was amended in 1967, and presented the first Paul M. Fye Fellowship for 1978–1979.

In April the Executive Committee of the Board of Trustees designated Dean Bumpus, Gifford C. Ewing, Frederick C. Fuglister, Bostwick Ketchum, Frank J. Mather III, and Mary Sears as Scientists Emeritus. Dr. Steele presented 30-year service pins to six employees in December. Eleven employees who had reached retirement age in 1978, with a total of 195 years of service, were also honored.

R/V Oceanaus spent much of the year in close proximity to Woods Hole, making short trips in all disciplines until September, when the ship departed on a cruise in the Atlantic. Port calls were made in the Azores, Portugal, Senegal, and Brazil before Oceanaus returned to Woods Hole in December.

The 24th Annual Associates Day of Science attracted some 225 persons to Woods Hole 6 October for lectures.

Oceanaus, the Institution’s quarterly magazine, reached a circulation of 13,000 during the year with a renewal rate holding steady at 50 percent. The magazine had a free distribution of 4,000 before it was put on a subscription basis in 1974.

Scientists welcomed the arrival of the Institution’s new computer, VAX 11/780, in October. The need for more computer memory and disc storage, greater speed, and a reduction in operating costs prompted the $250,000 purchase. A computer center was built on the first floor of Clark Laboratory during the summer to house the new computer system, which includes a high speed digital plotter for plotting contour maps and other graphic data, and an interactive graphics terminal with light pen which enables the user to develop graphic images on a display screen. The Institution also ordered a Wang Word Processor, a mini-computer for the entry, editing, and printing of manuscripts and technical reports.
THE seventh Henry Bryant Bigelow Award in Oceanography was presented to Paleontologist Wolfgang Helmut Berger, Associate Professor at the Scripps Institution of Oceanography, University of California, at the winter meeting of the Trustees and Corporation 9 January 1979.

The award certificate citation reads: "... in recognition of his creative contribution to paleoceanography by opening the doors of perception on the controlling factors governing carbonate sedimentation in the oceans and for providing us with a unifying conceptual model for interpreting the geological evolution of ocean basins."

Following presentation of gold and bronze versions of the medal, a certificate, and a $2,500 honorarium to Berger, Dr. William A. Berggren, paleontologist on the Institution staff, reviewed Berger's career and scientific contributions for the meeting.

There is little or no dissolution of the carbonate precipitated by near-surface organisms through depths of about four kilometers, where carbonate dissolution accelerates notably; this area of accelerated dissolution is called the lysocline. At some depth around five kilometers, all carbonate is dissolved; this is called the carbonate compensation depth.

Berger's contributions to understanding of the carbonate cycle in the oceans began ten years ago with his Ph.D. thesis on the production and preservation of calcium carbonate shells in plankton and includes such outstanding achievements as the concepts of the lysocline and the carbonate compensation depth.

Berggren's written tribute to Berger's work read, in part: "[His] unique contribution lies in the methodical and comprehensive manner in which he examined the sedimentary record. By combining empirical observations on the sedimentary record itself with field and laboratory experiments which led to empirical models for the nature and behavior of carbonate dissolution, he has demonstrated his breadth as a scientist."

A native of Erlangen, Germany, Berger completed a master's degree at the University of Colorado in 1963 and received his Ph.D. from the University of California in 1968, when he joined the staff of the Scripps Institution of Oceanography, University of California, San Diego. He is Associate Editor of the Journal of Foraminiferal Research, and his professional memberships include the Society of Economic Paleontologists and Mineralogists, American Society of Limnology and Oceanography, American Association for the Advancement of Science, Geologische Vereinigung, Geological Society of America, and the American Geophysical Union.

Berger was selected by a committee of senior Institution staff members from a field of 52 nominees. Dr. Bigelow was particularly interested in nurturing young scientists, and the committee was especially mindful of this in selecting the 41-year-old Berger for the honor.
Publications

Publications of record as of 6 March 1979. Institution contribution number appears at end of each entry.

Biology


A. S. Merrill, J. D. Davis and K. O. Emery. The Latitudinal and Bathymetric Ranges of Living and Fossil Miosedemaria newtoni (Bryozoa) with Notes on Habitats and Habitat Requirements. The Nautilus, 92(3):108-112. 1978. No. 4123


Geology & Geophysics


Ocean Engineering


Physical Oceanography


Scientific & Technical Staff

As of 31 December 1978

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nonresident.

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Boston College-Law School

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 Scripps Institution of Oceanography

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Research Affiliate of the Marine Sciences
Research Center, State University of New York, Stony Brook, Associate in
Invertebrate Zoology, Harvard University

Rudolf S. Scheltema, Associate Scientist
Senior Fulbright-Hays Fellow (Australian
American Educational Foundation), James
Cook University of North Queensland,
Toursville, Australia

William E. Schevill, Biological
Oceanographer, nonresident

Associate in Mammalogy,
Museum of Comparative Zoology,
Harvard University

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Geochemist

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John C. Beckerle, Associate Scientist

William A. Berggren, Senior Scientist
Adjunct Full Professor, Brown University;
Adjunct Docent, University of Stockholm

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Henry Bryant Bigelow Oceanographer

Robert G. Goldsborough, Research Associate

Robert C. Gromov, Research Associate

Bilal U. Haq, Associate Scientist

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University of Stockholm

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Susumu Honjo, Associate Scientist

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Sydney T. Knott, Hydroacoustics Engineer

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George P. Lohmann, Associate Scientist

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Nonresident Staff Member, West Indies
Laboratory, Fairleigh Dickinson University

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Graham M. Purdy, Assistant Scientist

David A. Ross, Associate Scientist

Visiting Instructor, Dept. of International
Law, Fletcher School of Law and
Diplomacy, Tufts University; Visiting
Instructor, Dept. of Ocean Engineering,
Massachusetts Institute of Technology

Hans A. Schouten, Associate Scientist

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Donald C. Bankston, Analytical Inorganic Geochemy, Instructor, Mathematics,
Cape Cod Community College

Vaughan T. Bowen, Senior Scientist

Visiting Lecturer in Radiobiology,
AIDS-AEC, several campuses

Peter G. Brewer, Senior Scientist

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Werner G. Deuser, Associate Scientist

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Nelson M. Frew, Analytical Mass Spectrometrist

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David J. Hydes, Assistant Scientist

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Hugh D. Livingstom, Analytical Radiochemist

Paul C. Mangelsdorf, Jr., Physical Chemist
nonresident

Don R. Mann, Research Associate

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Senior Scientific Officer, Institute for
Marine Environmental Research, England

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Geological Advisor to Office of the Geographer, U.S. State Department
Lincoln Baxter II, Applied Physicist
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Advanced Wastewater Treatment System, Research Associate
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William M. Marquet, Manager, Deep Submergence Engineering, Instrumentation Engineer
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George H. Power, Computer Analyst
Melvin A. Rosenfeld, Manager, Information Processing Center, Senior Scientist
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Woollcott K. Smith, Research Statistician
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Physical Oceanography Department

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Professor of the Practice of Physical Oceanography, Harvard University:
Associate of the Center for Earth and Planetary Physics, Harvard University
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Gerald J. Needell, Research Associate
W. Brechner Owens, Assistant Scientist
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Marine Policy & Ocean Management

Thomas M. Leschine, Policy Associate
Susan B. Peterson, Policy Associate
Leah J. Smith, Policy Associate
H. Burr Steinbach, Dean Emeritus, Special Consultant in Marine Policy

Postdoctoral Investigators

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Robert R. P. Chase (Physical Oceanography)
Bruce H. Corliss (Geology & Geophysics)
Kathleen Crane (Geology & Geophysics)
Rober S. Detrick, Jr. (Geology & Geophysics)
Jonathan Erez (Geology & Geophysics)
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Robin S. Keir (Geology & Geophysics)
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John S. Tochio (Ocean Engineering)
Thomas L. Torgersen (Chemistry)
Craig S. Tucker (Biology)
Wendy I. Willett (Biology)

+ Leave of Absence
# Disability Leave of Absence
Full-Time Support Staff

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Listing as of 31 December 1978

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+Lois G. Toner
Sandra M. Tonge
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Christine M. Woodward

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Barbara Breivogel
+Margaret A. Chafee
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Kaleroy L. Hatziolos ...................................................... Executive Assistant/Marine Policy & Ocean Management
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Hartley Hoskins ........................................................... Coordinator, Ocean Industries Program
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Carolyn B. Miller ........................................................ Affirmative Action Administrator & Housing Coordinator
Suzanne B. O’Connell ................................................... JOIDES Coordinator
A. Lawrence Persson III ................................................ Assistant Dean & Registrar
Eleanor P. Picard ........................................................ Sponsored Programs Administrator
R. David Ruddon, Jr ..................................................... Senior Accountant
Paul R. Ryan ............................................................... Associate Editor, "Oceanus"
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L. Hoyt Watson ........................................................... Executive Secretary/Associates Program
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Bernard L. Zentz ........................................................ Personnel Manager

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Linda C. Wicks
Clarice S. Willert
Jane P. Zentz

Matt Gould labels a buoy for JASIN voyage.
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Clifton C. Benoit .............................................................. Chief Engineer, R/V LULU
John P. Bizzozero .............................................................. Acting Chief Engineer, R/V ATLANTIS II
Edward L. Bland, Jr. ............................................................ Research Associate
James R. Boord ............................................................... Master, R/V LULU
David F. Castles .............................................................. Master, R/V ATLANTIS II
Richard H. Dimmock ......................................................... Port Engineer
John D. Donnelly .............................................................. Acting Manager, ALVIN/LULU Operations
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+Richard C. Flegenheimer ................................................... Master, R/V LULU
Dudley B. Foster .............................................................. Chief Pilot, DSRV ALVIN
Emerson H. Hiller ............................................................. Master, R/V KNORR
Ralph M. Hollis ................................................................. Pilot, DSRV ALVIN
Paul C. Howland ............................................................. Master, R/V OCEANUS
Walter G. Huckabee, Sr. ....................................................... Project Engineer, R/V ATLANTIS II
Jonathan Leiby ................................................................. Naval Architect
Barrett H. McLaughlin ......................................................... Chief Engineer, R/V KNORR
Paul R. Mercado .............................................................. Chief Engineer, R/V OCEANUS
James R. Mitchell ............................................................ Manager of Facilities
Donald A. Muller .............................................................. Marine Operations Coordinator
David M. Owen ............................................................... Diving Supervisor
+Lawrence A. Shumaker ...................................................... Manager, Deep Submergence Operations
J. Paul Thompson ............................................................ Assistant Facilities Manager
Andrew L. Westling, Jr. ...................................................... Manager of Services

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Gustaf A. Carlson
Ernest G. Charette
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William R. Baker
#Kenneth E. Bazner
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Edward R. Broderick
+Paul F. Carty
Harry F. Clinton
Arthur D. Calburn, Jr.
+Lawrence P. Costello
Jeremy M. Cotter
John M. Daly

Marine Personnel

Gene Mylona on Oceanaus bridge.

ALVIN/LULU Operations

Charles F. Adcock
Stephen S. Bates
James L. Bishop
George F. Brady
George Broderson
Joseph M. Cawieze
George C. Ellis
Kevin C. Grady
+Theodore Hardy, Jr.
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+Philip W. Hodgkins
Jack W. McCarthy
William F. Page
+David J. W. Parrott
+James R. Roseland, Jr.
Dennis J. Simonds
Ernest G. Smith, Jr.
Margaret P. Stern

+Deceased, December 5, 1978

Safety

Cyril L. Fennelly
Ann C. Henry

Bob Davis finishes fiberglass mold of specially built instrument.
# Services Personnel

<table>
<thead>
<tr>
<th>Francisco D. Aguier</th>
<th>Porter A. Crouse</th>
<th>Mark V. Hickay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edgar L. Aiguier</td>
<td>Judith O. Cushman</td>
<td>Robert J. Hindley</td>
</tr>
<tr>
<td>Robert M. Alexander</td>
<td>Frances L. Davis</td>
<td>Howard A. Holland</td>
</tr>
<tr>
<td>Norman E. Anderson</td>
<td>Ruth H. Davis</td>
<td>Steven W. Howell</td>
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<tr>
<td>James M. August</td>
<td>Judith DeSanti</td>
<td>Lawrence M. Johnson</td>
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<tr>
<td>Karen H. Baker</td>
<td>William B. Dodge</td>
<td>Robert F. Kelley</td>
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<tr>
<td>Pamela R. Barrows</td>
<td>Catherine H. Ferreira</td>
<td>Percy L. Kennedy, Sr.</td>
</tr>
<tr>
<td>&quot;Earle N. Black&quot;</td>
<td>Steven R. Ferreira</td>
<td>Daniel M. Lewis</td>
</tr>
<tr>
<td>Bruce A. Bowden</td>
<td>David L. Fish</td>
<td>Lomnie Lewis</td>
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<tr>
<td>Richard J. Breivogel</td>
<td>Victor Fontana</td>
<td>Stella J. Livingston</td>
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<tr>
<td>Frederick V. Brown</td>
<td>Elizabeth R. Fye</td>
<td>Samuel J. Lomba</td>
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<tr>
<td>Sandra J. Burt</td>
<td>Irving A. Gaffney</td>
<td>Gary R. Lowe</td>
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<tr>
<td>Bernard J. Cassidy</td>
<td>Lillian M. Gallant</td>
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<td>Stephen M. Clifford</td>
<td>Curtis Gandy III</td>
<td>Roland G. Masse</td>
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<td>Edna W. Coveybeer</td>
<td>James E. Gifford</td>
<td>Manon B. McAdams</td>
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<tr>
<td>James P. Corr</td>
<td>David L. Gray</td>
<td>Moses McCull</td>
</tr>
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<td>Ronald C. Craft</td>
<td>James E. Gray</td>
<td>Richard E. McCloskey</td>
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<td>Charles A. Greenawalt</td>
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<td>William G. Gubbins</td>
<td>Frank Medetrios</td>
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<td>Harold E. Croft</td>
<td>Carol A. Gunter</td>
<td>Dorothy Meinert</td>
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<td>Cynthia Moor</td>
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<td>Juanita A. Mogardo</td>
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<td>Joseph F. Motta</td>
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<td>Terry G. Mogardo</td>
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<tr>
<td>Jay R. Murphy</td>
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<td>Eugene A. Pinault</td>
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<td>Betsey G. Pratt</td>
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<td>Diane L. Pulsifer</td>
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<td>John M. Ranney</td>
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<td>John E. Rice</td>
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<td>Robert R. Rioux</td>
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<td>Roland R. Simmons</td>
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<td>Donald P. Souza</td>
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<td>James A. Swan</td>
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<td>Jean D. Walker</td>
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<td>Robert Wichterman</td>
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<td>Ronald E. Woods</td>
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<tr>
<td>Jeffrey A. Zwinakis</td>
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</tr>
</tbody>
</table>

*Disability Leave of Absence

+Leave of Absence

**Deceased, April 5, 1978

---

**Last minute lashing before A-1 departs for Voyage #101.**

**A.B. Larry Costello mans A-1 wheel.**

Crowd gathered on pier in June to see Atlantis II off on Voyage #101.
Postdoctoral Scholars 1978–79
Gayle A. Brenchley
Johns Hopkins University
James T. Carlton
University of California, Davis
John J. Molongoski
Michigan State University
Raymond W. Schmitt
University of Rhode Island
Anne M. Thompson
Bryn Mawr College
Robert C. Thunell
University of Rhode Island
Robert S. White
Cambridge University, England
Daniel G. Wright
University of British Columbia

Marine Policy and Ocean Management 78–79
Donna R. Christie
University of Georgia
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Johns Hopkins University
Margaret E. Dewar
Massachusetts Institute of Technology
Thomas Hruby
University of Glasgow, Scotland
James R. McGoodwin
University of Texas
Johns K. Moore
Salem State College
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City University of New York
Herbert Owens
Massachusetts Institute of Technology
Alison Rieser
George Washington University
Judith Spiller
State University of New York, Stony Brook
Per Magnus Wijkman
Stockholm University, Sweden

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Marine Biological Laboratory
Alexander Spoorh
University of Pittsburgh
James B. Zaitzeff
NOAA National Environmental Satellite Service

M.I.T. / W.H.O.I. Joint Graduate Program 1978–79
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Mary L. Bremer
Chico State University
University of Cincinnati
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University of Texas
University of Southern California
Scott R. Briggs
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Bruce D. Cornuelle
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University of California, San Diego
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Swarthmore College
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Harvard University
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Delft University of Technology, The Netherlands
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Ohio State University
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Concordia University, Canada
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Hebrew University, Israel
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Massachusetts Institute of Technology
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University of New Orleans
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University of Rochester
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University of Bristol, England
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Massachusetts Institute of Technology
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Stanford University
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University of Paris, France

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Holderness School

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St. Mary's College of Maryland

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Massachusetts Institute of Technology

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University College, Galway, Ireland

John A. Moody
Falmouth High School

Dwight Muschenheim
Yale University

Luis Najera
Spanish Oceanographic Institute, Madrid
## R/V Atlantis II

<table>
<thead>
<tr>
<th>Voyage</th>
<th>Cruise Period</th>
<th>Principal Objectives, Area of Operations</th>
<th>Port of Call</th>
<th>Chief Scientist</th>
</tr>
</thead>
<tbody>
<tr>
<td>97 I</td>
<td>6 Jan–4 Feb</td>
<td>Geological and geophysical investigations of the Bahama Escarpment and of the intersection of the Cayman Trough and the Greater Antilles Ridge</td>
<td>San Juan, Puerto Rico</td>
<td>Uchupi</td>
</tr>
<tr>
<td>97-II</td>
<td>9 Feb–22 Feb</td>
<td>Deployment of navigation net, seismic reflection profiling, piston coring, and heat flow measurements</td>
<td>San Juan, Puerto Rico</td>
<td>Ewing</td>
</tr>
<tr>
<td>98</td>
<td>26 Feb–14 Mar</td>
<td>Recover Parflux E mooring array, deploy in situ filtration system (LVFS) in Guiana Basin, biological collecting in Guadaloupe-Martiniq area</td>
<td>Woods Hole</td>
<td>Honjo</td>
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<tr>
<td>99</td>
<td>3 Apr–14 Apr</td>
<td>Investigation of dynamics and distribution of chemical constituents, pelagic and benthic organisms, and water mass circulation in New York Bight area</td>
<td>Woods Hole</td>
<td>Walsh (Brookhaven)</td>
</tr>
<tr>
<td>100 I</td>
<td>21 Apr–12 May</td>
<td>CTD and XBT survey along 70°W</td>
<td>Bermuda</td>
<td>Bradley</td>
</tr>
<tr>
<td>100-II</td>
<td>16 May–4 Jun</td>
<td>Biology of North Atlantic gelatinous zooplankton</td>
<td>Woods Hole</td>
<td>Tupper</td>
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<tr>
<td>101</td>
<td>20 Jun–20 Jul</td>
<td>International Joint Air Sea Interaction (JASIN) Project; deployment and recovery of moorings and drifters in Rockall Bank area</td>
<td>Glasgow, Scotland</td>
<td>Harbison</td>
</tr>
<tr>
<td>102 I</td>
<td>25 Jul–16 Aug</td>
<td>Continuation of JASIN work</td>
<td>Woods Hole</td>
<td>Briscoe</td>
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<tr>
<td>102-II</td>
<td>21 Aug–21 Sep</td>
<td>Study currents and sediment transport of Continental Shelf and Slope Waters</td>
<td>Woods Hole</td>
<td>Briscoe</td>
</tr>
<tr>
<td>103</td>
<td>28 Sep–5 Oct</td>
<td>Examine zooplankton-phytoplankton dynamics for US-Canadian larval herring experiment on Continental Shelf and Slope Waters</td>
<td>Woods Hole</td>
<td>Walsh (USGS)</td>
</tr>
<tr>
<td>104</td>
<td>11 Oct–23 Oct</td>
<td>Test expendable transponders in deep water and recover mooring at 38°03'N–68°56'W</td>
<td>Woods Hole</td>
<td>Walsh (Brookhaven)</td>
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<tr>
<td>105</td>
<td>25 Oct–28 Oct</td>
<td>Placed out of service for conversion from steam to diesel</td>
<td>Woods Hole</td>
<td>Walden</td>
</tr>
</tbody>
</table>

## R/V Knorr

<table>
<thead>
<tr>
<th>Voyage</th>
<th>Cruise Period</th>
<th>Principal Objectives, Area of Operations</th>
<th>Port of Call</th>
<th>Chief Scientist</th>
</tr>
</thead>
<tbody>
<tr>
<td>73-Ia</td>
<td>28 Jan–3 Feb</td>
<td>Dump site studies off Puerto Rico</td>
<td>San Juan, Puerto Rico</td>
<td>Mayer (NOAA)</td>
</tr>
<tr>
<td>73-Ib</td>
<td>4 Feb–10 Feb</td>
<td>Organic chemical-biological studies in the Peru upwelling zone</td>
<td>Balboa, Canal Zone</td>
<td>Gagosian</td>
</tr>
<tr>
<td>73-II</td>
<td>11 Feb–16 Mar</td>
<td>Study of nitrogen cycle in water and sediment in an upwelling area and microbiological studies in the Eastern Equatorial Pacific</td>
<td>Callao, Peru</td>
<td>Watson</td>
</tr>
<tr>
<td>73-III</td>
<td>20 Mar–31 Mar</td>
<td>Study of a low geothermal heat flow region west of the East Pacific Rise</td>
<td>Honolulu</td>
<td>Von Herzen</td>
</tr>
<tr>
<td>73-IV</td>
<td>6 Apr–9 May</td>
<td>Current and density structure measurements in the Gilbert Island area</td>
<td>Kwajalein Atoll, Marshall Islands</td>
<td>Eriksen (MIT)</td>
</tr>
<tr>
<td>73-V</td>
<td>15 May–13 Jun</td>
<td>Artificial radionuclide studies around the U.S. Pacific Ocean nuclear test site</td>
<td>Kwajalein Atoll</td>
<td>Noskin (L.L. Lab)</td>
</tr>
</tbody>
</table>

Total Nautical Miles for 1978 – 27.650
Total Days at Sea – 226
73-VII 19 Jul–30 Aug  Chemical studies in the Southwest Pacific including interstitial chemistry, photochemistry, and the radiation spectrum of the euphotic zone  Pago Pago, Samoa  Sayles

73-VIII 30 Aug–18 Sept  Shipyard and overhaul  Wellington, New Zealand  Sayles

73-IX 18 Sep–9 Oct  Physical oceanographic survey of the later winter-early spring hydrography between the south and east coasts of New Zealand and the Antarctic pack ice  Christchurch, New Zealand  McCartney

73-X 13 Oct–5 Nov  Study of the dynamics of eddies and of interleaving water masses and their effects on mean circulation in the Southern Ocean  Christchurch  Bryden

73-XI 12 Nov–9 Dec  Coring and in situ interstitial water studies in the South Pacific and Antarctic waters  Wellington, New Zealand  Sayles

R/V Oceanus

<table>
<thead>
<tr>
<th>Voyage</th>
<th>Cruise Period</th>
<th>Principal Objectives, Area of Operations</th>
<th>Port of Call</th>
<th>Chief Scientist</th>
</tr>
</thead>
<tbody>
<tr>
<td>37</td>
<td>10 Jan–13 Jan</td>
<td>Recovery of current meters in Hudson Canyon</td>
<td>Woods Hole</td>
<td>Reid (Draper Lab)</td>
</tr>
<tr>
<td>38</td>
<td>19 Jan–26 Jan</td>
<td>Current and sediment transport study of the Continental Shelf</td>
<td>Woods Hole</td>
<td>Butman (USGS)</td>
</tr>
<tr>
<td>39-I</td>
<td>2 Feb–6 Feb</td>
<td>Recover and deploy current meter and tripod moorings, conduct hydrographic measurements on Continental Shelf</td>
<td>Savannah, GA</td>
<td>Butman (USGS)</td>
</tr>
<tr>
<td>39-II</td>
<td>7 Feb–15 Feb</td>
<td>Collect high resolution reflection data in Virgin Passage and north of St. Thomas</td>
<td>San Juan, Puerto Rico</td>
<td>Holmes (USGS)</td>
</tr>
<tr>
<td>40</td>
<td>20 Feb–4 Mar</td>
<td>Sampling and coring, deploy and recover tripod; collect phytoplankton clones in the Puerto Rico Trench</td>
<td>Woods Hole</td>
<td>Jannasch</td>
</tr>
<tr>
<td>41</td>
<td>20 Mar–27 Mar</td>
<td>Newport, RI, Shipyard</td>
<td>Woods Hole</td>
<td>Sanford</td>
</tr>
<tr>
<td>42</td>
<td>1 Apr–7 Apr</td>
<td>Velocity profiles in the Gulf Stream and Caryn Seamount</td>
<td>Woods Hole</td>
<td>Stegeman</td>
</tr>
<tr>
<td>43</td>
<td>11 Apr–18 Apr</td>
<td>Slope water benthic and mesopelagic fish sampling near 40°N–71°W and 36°N–71°W</td>
<td>Woods Hole</td>
<td>Wirsen</td>
</tr>
<tr>
<td>44</td>
<td>26 Apr–3 May</td>
<td>Gravity coring and microbiological deep water sampling, surface fish sampling and bacteriological isolations; deploy and recover tripod in situ sediment incubations</td>
<td>Woods Hole</td>
<td>Butman (USGS)</td>
</tr>
<tr>
<td>45</td>
<td>10 May–18 May</td>
<td>Current and sediment transport study on the Continental Shelf</td>
<td>Woods Hole</td>
<td>Teal</td>
</tr>
<tr>
<td>46</td>
<td>24 May–27 May</td>
<td>Biological sampling of sediment, organisms, and water in the New York Bight Apex; equipment test in Buzzards Bay</td>
<td>Woods Hole</td>
<td>Sanford</td>
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<tr>
<td>47</td>
<td>3 Jun–23 Jun</td>
<td>Vertical profiling around 31°N–69°30′W for Local Dynamics Experiment (LDE) of POLYMODE</td>
<td>Woods Hole</td>
<td>Murphy</td>
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<td>48</td>
<td>27 Jun–10 Jul</td>
<td>Biological and chemical studies in Western North Atlantic</td>
<td>Woods Hole</td>
<td>Backus</td>
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<td>49</td>
<td>26 Jul–17 Aug</td>
<td>Biological study in the Florida Current between the Straits of Florida and Cape Hatteras</td>
<td>Woods Hole</td>
<td>Farrington</td>
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<td>50</td>
<td>22 Aug–26 Aug</td>
<td>Deploy benthic chamber in Buzzards Bay and conduct biological sampling in New York Bight Apex</td>
<td>Woods Hole</td>
<td>Spindel</td>
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<tr>
<td>51</td>
<td>1 Sep–20 Sep</td>
<td>Underwater acoustics experimentation</td>
<td>Woods Hole</td>
<td>Jenkins</td>
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<td>52-I</td>
<td>26 Sep–23 Oct</td>
<td>Chemical sampling in the North Atlantic</td>
<td>Ponta Delgada, Azores Lisbon, Portugal</td>
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Total Nautical Miles for 1978 — 34,577
Total Days at Sea — 238
DSRV Alvin and R/V Lulu

The submersible Alvin is a Navy-owned national oceanographic facility supported by NSF, ONR, and NOAA and operated by this institution.

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<thead>
<tr>
<th>Voyage</th>
<th>Cruise Period</th>
<th>Principal Objectives, Area of Operations</th>
<th>Port of Call</th>
<th>Chief Scientist</th>
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<tr>
<td>97</td>
<td>6 Jan–24 Mar</td>
<td>Newport, RI Shipyard</td>
<td>Andros Island, Bahamas</td>
<td>Shumaker</td>
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<tr>
<td></td>
<td>2 May</td>
<td>Test dive in Woods Hole Harbor</td>
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<td>98-I</td>
<td>5 May–14 May</td>
<td>Transit</td>
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<td>98-II</td>
<td>16 May–18 May</td>
<td>3 dives in Tongue of the Ocean for training and certification of Alvin</td>
<td>Andros Island</td>
<td>Shumaker</td>
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<td>98-III</td>
<td>21 May–23 May</td>
<td>2 dives (#800 and #801, the latter for 4,000-meter certification) for training and testing in Tongue of the Ocean</td>
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<td>Shumaker</td>
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<td>98-IV</td>
<td>23 May–5 Jun</td>
<td>5 dives for shelf transport research off Cape Hatteras</td>
<td>Norfolk</td>
<td>Rona (NOAA)</td>
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<tr>
<td>98-V</td>
<td>6 Jun–15 Jun</td>
<td>5 dives to study slump physiography in Norfolk and Baltimore canyons</td>
<td>Woods Hole</td>
<td>Malahoff (NOAA)</td>
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<td>99-I</td>
<td>20 Jun–1 Jul</td>
<td>6 dives for radioactive waste studies and waste drum recovery at New York Bight dump site</td>
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<td>Jannasch (EPA)</td>
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<td>100-I</td>
<td>13 Jul–25 Jul</td>
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<td>Ponta Delgada, Azores</td>
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<td>100-II</td>
<td>27 Jul–5 Aug</td>
<td>5 dives to study tectonic structure of the FAMOUS Rift Valley</td>
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<td>10 geological and geophysical dives on the Mid-Atlantic Ridge</td>
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<td>St. Georges, Bermuda</td>
<td>Jannasch</td>
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<td>100-V</td>
<td>14 Sep–19 Sep</td>
<td>2 dives to Deep Ocean Stations 1 and 2 to study boring and fouling molluscs</td>
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<td>22 Sep–1 Oct</td>
<td>6 dives in Oceanographer Canyon for biological and geological studies</td>
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<td>102-II</td>
<td>26 Oct–30 Oct</td>
<td>1 dive on Continental Shelf for instrument recovery</td>
<td>Freeport, Bahamas</td>
<td>Neumann (U. of N.C.)</td>
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<td>102-III</td>
<td>31 Oct–6 Nov</td>
<td>7 dives in the Northwest Providence Channel for deep carbonate bank margin work</td>
<td>Andros Island</td>
<td>Grassle (U. of Miami)</td>
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<td>102-IV</td>
<td>8 Nov–13 Nov</td>
<td>5 dives in Tongue of the Ocean to study benthic populations</td>
<td>Andros Island</td>
<td>Schlager (U. of Miami)</td>
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<td>102-V</td>
<td>15 Nov–22 Nov</td>
<td>7 dives in the Northeast Providence Channel to study erosion and carbonate deposits</td>
<td>Nassau</td>
<td>Ryan (LDGO)</td>
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<td>102-VIII</td>
<td>14 Dec–21 Dec</td>
<td>6 biology dives; establishment of new bottom station in St. Croix Channel</td>
<td>Roosevelt Roads</td>
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Total Nautical Miles for 1978 – 15,830
Total Days at Sea – 173
Total Dives – 81
Many willing hands haul in the absolute velocity profiler after data recording trip to the depths.

Nick Fofonoff in his Clark Laboratory office.

George Tupper, left, and Jim Luyten discuss buoy work.
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<td>Texaco, Inc.</td>
</tr>
<tr>
<td></td>
<td>Textron Charitable Trust</td>
</tr>
<tr>
<td></td>
<td>Textron, Inc.</td>
</tr>
<tr>
<td></td>
<td>Time, Inc.</td>
</tr>
<tr>
<td></td>
<td>Union Oil Company of California</td>
</tr>
<tr>
<td></td>
<td>United States Government Commerce Department</td>
</tr>
<tr>
<td></td>
<td>National Oceanic and Atmospheric Administration</td>
</tr>
<tr>
<td></td>
<td>National Marine Fisheries Service</td>
</tr>
<tr>
<td></td>
<td>Energy Department</td>
</tr>
<tr>
<td></td>
<td>Environmental Protection Agency</td>
</tr>
<tr>
<td></td>
<td>Health, Education &amp; Welfare Department</td>
</tr>
<tr>
<td></td>
<td>National Institutes of Health</td>
</tr>
<tr>
<td></td>
<td>Interior Department</td>
</tr>
<tr>
<td></td>
<td>Bureau of Land Management</td>
</tr>
<tr>
<td></td>
<td>U.S. Geological Survey</td>
</tr>
<tr>
<td></td>
<td>National Science Foundation</td>
</tr>
<tr>
<td></td>
<td>Navy Department</td>
</tr>
<tr>
<td></td>
<td>Naval Underwater Systems Command</td>
</tr>
<tr>
<td></td>
<td>Office of Naval Research</td>
</tr>
<tr>
<td></td>
<td>Nuclear Regulatory Commission</td>
</tr>
<tr>
<td></td>
<td>United States Steel Foundation</td>
</tr>
<tr>
<td></td>
<td>Western Electric Company</td>
</tr>
<tr>
<td></td>
<td>Whitehall Foundation</td>
</tr>
<tr>
<td></td>
<td>Xerox Corporation</td>
</tr>
</tbody>
</table>

Night net haul comes aboard *Oceanus*.

Current meter string is hauled on *Oceanus* deck.
The Institution's total operating revenue increased 14% in 1978, compared with 7% in 1977. Unrestricted income increased 1% during 1978, compared with an 11% increase in 1977.

The Institution transferred excess current unrestricted income to Quasi-Endowment ($25,000) and to Unexpended Plant Funds ($314,000). In 1977, $275,000 and $275,000, respectively, were transferred.

Operating costs for 1978 compared with 1977 are as follows:

<table>
<thead>
<tr>
<th></th>
<th>1978</th>
<th>1977</th>
<th>Increase (Decrease)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Costs of Sponsored Research</td>
<td>$21,941,000</td>
<td>$18,946,000</td>
<td>16%</td>
</tr>
<tr>
<td>Direct Costs of Education Programs</td>
<td>847,000</td>
<td>864,000</td>
<td>( 2%)</td>
</tr>
<tr>
<td>Direct Costs of Institutional Research</td>
<td>634,300</td>
<td>656,000</td>
<td>( 3%)</td>
</tr>
<tr>
<td>General and Administrative</td>
<td>3,282,000</td>
<td>2,820,000</td>
<td>16%</td>
</tr>
<tr>
<td>Other</td>
<td>630,300</td>
<td>506,000</td>
<td>25%</td>
</tr>
<tr>
<td>Total</td>
<td>$27,333,300</td>
<td>$23,792,000</td>
<td>15%</td>
</tr>
</tbody>
</table>

Other statistics of interest are:

<table>
<thead>
<tr>
<th></th>
<th>1978</th>
<th>1977</th>
<th>Increase (Decrease)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross Payroll</td>
<td>$12,775,000</td>
<td>$11,640,000</td>
<td>10%</td>
</tr>
<tr>
<td>Retirement Trust Contribution</td>
<td>1,504,000</td>
<td>1,474,000</td>
<td>2%</td>
</tr>
<tr>
<td>Total Employee Benefits</td>
<td>4,203,000</td>
<td>3,883,000</td>
<td>8%</td>
</tr>
<tr>
<td>Endowment Income</td>
<td>1,820,000</td>
<td>1,761,000</td>
<td>3%</td>
</tr>
<tr>
<td>Endowment Principal (year end, at market)</td>
<td>35,033,300</td>
<td>35,280,000</td>
<td>( 1%)</td>
</tr>
<tr>
<td>Additions to Endowment Principal</td>
<td>74,000</td>
<td>617,000</td>
<td></td>
</tr>
</tbody>
</table>

Gifts and grants from private sources including the 1,107 Institution Associates totaled $1,325,000 in 1978.

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

Joseph Kiebala, Jr.
Assistant Director for Finance and Administration
Edwin D. Brooks, Jr.
Treasurer
George E. Conway
Controller
We have examined the balance sheets of Woods Hole Oceanographic Institution as of December 31, 1978 and 1977, 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 aforementioned financial statements present fairly the financial position of Woods Hole Oceanographic Institution as of December 31, 1978 and 1977, 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
April 9, 1979

The accompanying notes are an integral part of the financial statements.
Statement of Current Fund Revenues, Expenses and Transfers for the years ended December 31, 1978 and 1977

<table>
<thead>
<tr>
<th>Revenues</th>
<th>1978</th>
<th>1977</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sponsored research:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Government</td>
<td>$22,411,236</td>
<td>$19,894,748</td>
</tr>
<tr>
<td>Nongovernment</td>
<td>2,512,083</td>
<td>1,673,916</td>
</tr>
<tr>
<td>Education funds available of</td>
<td>24,923,319</td>
<td>21,568,664</td>
</tr>
<tr>
<td>Total restricted</td>
<td>953,367</td>
<td>962,870</td>
</tr>
<tr>
<td>Unrestricted:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fees</td>
<td>194,291</td>
<td>257,272</td>
</tr>
<tr>
<td>Endowment and similar fund income</td>
<td>465,916</td>
<td>447,128</td>
</tr>
<tr>
<td>Gifts</td>
<td>420,028</td>
<td>606,401</td>
</tr>
<tr>
<td>Tuition</td>
<td>296,156</td>
<td>262,988</td>
</tr>
<tr>
<td>Other</td>
<td>517,382</td>
<td>305,493</td>
</tr>
<tr>
<td>Total unrestricted</td>
<td>1,893,773</td>
<td>1,879,222</td>
</tr>
<tr>
<td>Total revenues</td>
<td><strong>27,770,459</strong></td>
<td><strong>24,410,756</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Expenses and Transfers</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sponsored research:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salaries and fringe benefits</td>
<td>7,525,727</td>
<td>6,574,110</td>
</tr>
<tr>
<td>Ships and submersibles</td>
<td>5,448,887</td>
<td>5,409,160</td>
</tr>
<tr>
<td>Materials and equipment</td>
<td>5,365,035</td>
<td>4,030,287</td>
</tr>
<tr>
<td>Laboratory overhead</td>
<td>1,545,853</td>
<td>1,336,920</td>
</tr>
<tr>
<td>Other</td>
<td>2,055,420</td>
<td>1,595,999</td>
</tr>
<tr>
<td></td>
<td><strong>21,940,922</strong></td>
<td><strong>18,946,476</strong></td>
</tr>
<tr>
<td>Education:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Faculty expense</td>
<td>257,790</td>
<td>224,779</td>
</tr>
<tr>
<td>Student expense</td>
<td>479,494</td>
<td>522,757</td>
</tr>
<tr>
<td>Other expense</td>
<td>109,235</td>
<td>116,524</td>
</tr>
<tr>
<td></td>
<td><strong>846,519</strong></td>
<td><strong>864,060</strong></td>
</tr>
<tr>
<td>Un-sponsored research and other activity</td>
<td><strong>1,263,934</strong></td>
<td><strong>1,161,739</strong></td>
</tr>
<tr>
<td>General and administrative:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Allocated to sponsored research</td>
<td>2,982,397</td>
<td>2,622,188</td>
</tr>
<tr>
<td>Allocated to education</td>
<td>106,848</td>
<td>98,810</td>
</tr>
<tr>
<td>Allocated to un-sponsored activity</td>
<td>192,279</td>
<td>99,196</td>
</tr>
<tr>
<td></td>
<td><strong>3,281,524</strong></td>
<td><strong>2,820,194</strong></td>
</tr>
<tr>
<td>Total expenses</td>
<td><strong>27,332,899</strong></td>
<td><strong>23,792,469</strong></td>
</tr>
<tr>
<td>Nonmandatory transfers:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>To quasi-endowment fund</td>
<td>25,000</td>
<td>275,000</td>
</tr>
<tr>
<td>To plant fund, unexpended</td>
<td>314,400</td>
<td>275,000</td>
</tr>
<tr>
<td>Total expenses and nonmandatory transfers</td>
<td><strong>27,672,299</strong></td>
<td><strong>24,342,469</strong></td>
</tr>
<tr>
<td>Net increase in unrestricted current fund</td>
<td>$98,160</td>
<td>$68,287</td>
</tr>
</tbody>
</table>

Designated for:
- Income and salary stabilization | 155,305 | 149,044 |
- Ocean industry program | (38,309) | (62,918) |
- Working capital and contingency | (18,636) | (17,839) |
| | **98,160** | **68,287** |

The accompanying notes are an integral part of the financial statements.
Statement of Changes in Fund Balances for the years ended December 31, 1978 and 1977

<table>
<thead>
<tr>
<th>Year</th>
<th>Restricted</th>
<th>Unrestricted</th>
<th>Total</th>
<th>Endowment and Similar Funds</th>
<th>Annuity Fund</th>
<th>Plant Fund</th>
<th>Total Funds</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1978</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increases</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gifts, grants and contracts</td>
<td>$24,701,796</td>
<td>$420,028</td>
<td>$25,121,824</td>
<td>$48,834</td>
<td>$75,000</td>
<td>$25,245,658</td>
<td></td>
</tr>
<tr>
<td>Endowment and similar funds investment income</td>
<td>1,280,268</td>
<td>465,916</td>
<td>1,746,184</td>
<td></td>
<td></td>
<td>1,746,184</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>1,007,829</td>
<td>1,007,829</td>
<td>2,015,658</td>
<td></td>
<td></td>
<td>1,008,532</td>
<td></td>
</tr>
<tr>
<td>Total increases</td>
<td>25,982,064</td>
<td>1,893,773</td>
<td>27,875,837</td>
<td>48,834</td>
<td>703</td>
<td>75,000</td>
<td>28,000,374</td>
</tr>
<tr>
<td>Decreases</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expenditures (including $501,863 of funded depreciation)</td>
<td>(25,876,686)</td>
<td>(1,456,213)</td>
<td>(27,332,899)</td>
<td>501,863</td>
<td>26,831,036</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depreciation (Note A)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(765,091)</td>
<td></td>
<td>765,091</td>
</tr>
<tr>
<td>Net decrease in realized and unrealized appreciation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(321,247)</td>
<td></td>
<td>(321,247)</td>
</tr>
<tr>
<td>Total decreases</td>
<td>(25,876,686)</td>
<td>(1,456,213)</td>
<td>(27,332,899)</td>
<td>(321,247)</td>
<td></td>
<td>(263,228)</td>
<td>(27,917,374)</td>
</tr>
<tr>
<td>Net change before transfers</td>
<td>105,378</td>
<td>437,560</td>
<td>542,938</td>
<td>(272,413)</td>
<td>703</td>
<td>(188,228)</td>
<td>83,000</td>
</tr>
<tr>
<td>Transfers — additions (deductions)</td>
<td>(413)</td>
<td>(339,400)</td>
<td>(339,813)</td>
<td></td>
<td></td>
<td>314,400</td>
<td></td>
</tr>
<tr>
<td>Change in fund balance for the year</td>
<td>104,965</td>
<td>98,160</td>
<td>203,125</td>
<td>(247,000)</td>
<td>703</td>
<td>126,172</td>
<td>83,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>Restricted</th>
<th>Unrestricted</th>
<th>Total</th>
<th>Endowment and Similar Funds</th>
<th>Annuity Fund</th>
<th>Plant Fund</th>
<th>Total Funds</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1977</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increases</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gifts, grants and contracts</td>
<td>21,453,339</td>
<td>606,401</td>
<td>22,059,740</td>
<td>186,588</td>
<td>50,000</td>
<td>22,296,128</td>
<td></td>
</tr>
<tr>
<td>Endowment and similar funds investment income</td>
<td>1,244,855</td>
<td>447,128</td>
<td>1,691,983</td>
<td></td>
<td></td>
<td>1,691,983</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>825,693</td>
<td>825,693</td>
<td>1,651,386</td>
<td></td>
<td></td>
<td>833,237</td>
<td></td>
</tr>
<tr>
<td>Total increases</td>
<td>22,698,194</td>
<td>1,879,222</td>
<td>24,577,416</td>
<td>186,588</td>
<td></td>
<td>57,544</td>
<td>24,821,548</td>
</tr>
<tr>
<td>Decreases</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expenditures (including $441,737 of funded depreciation)</td>
<td>(22,531,534)</td>
<td>(1,260,935)</td>
<td>(23,792,469)</td>
<td>441,737</td>
<td>(704,965)</td>
<td>(704,965)</td>
<td></td>
</tr>
<tr>
<td>Depreciation (Note A)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(7,323)</td>
<td></td>
<td>(7,323)</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(85)</td>
<td></td>
<td>(85)</td>
</tr>
<tr>
<td>Total decreases</td>
<td>(22,531,534)</td>
<td>(1,260,935)</td>
<td>(23,792,469)</td>
<td>(2,985,966)</td>
<td>(7,323)</td>
<td>(253,580)</td>
<td>(27,049,338)</td>
</tr>
<tr>
<td>Net change before transfers</td>
<td>166,660</td>
<td>618,287</td>
<td>784,947</td>
<td></td>
<td>(2,799,378)</td>
<td>(7,323)</td>
<td>(263,036)</td>
</tr>
<tr>
<td>Transfers — additions (deductions)</td>
<td>(5,143)</td>
<td>(560,000)</td>
<td>(555,143)</td>
<td></td>
<td></td>
<td>430,143</td>
<td>125,000</td>
</tr>
<tr>
<td>Change in fund balance for the year</td>
<td>161,517</td>
<td>67,287</td>
<td>229,804</td>
<td>(2,369,235)</td>
<td>(7,323)</td>
<td>(81,036)</td>
<td>(2,227,790)</td>
</tr>
<tr>
<td>Fund balance December 31, 1976</td>
<td>1,253,233</td>
<td>2,005,540</td>
<td>3,258,773</td>
<td>37,649,577</td>
<td>52,484</td>
<td>18,569,118</td>
<td>59,529,952</td>
</tr>
</tbody>
</table>

The accompanying notes are an integral part of the 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.

Net investment income is distributed to all funds in the year received and for pooled investments, income is distributed on a 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 investment income is recorded on a cash basis. The difference between such bases 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

B. ENDOWMENT AND SIMILAR FUND INVESTMENTS:

The cost and market value of separately invested and pooled investments are as follows:

<table>
<thead>
<tr>
<th>December 31, 1978</th>
<th>December 31, 1977</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>Market</td>
</tr>
<tr>
<td>------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>Separately invested:</td>
<td></td>
</tr>
<tr>
<td>Government and government agencies</td>
<td>$2,894,349</td>
</tr>
<tr>
<td>Bonds</td>
<td>2,963,048</td>
</tr>
<tr>
<td>Common stocks</td>
<td>12,204,211</td>
</tr>
<tr>
<td>Savings deposits</td>
<td>524,267</td>
</tr>
<tr>
<td>Cash</td>
<td>46,099</td>
</tr>
<tr>
<td>Call options written</td>
<td>(41,225)</td>
</tr>
<tr>
<td>Total separately invested</td>
<td>$17,750,749</td>
</tr>
<tr>
<td>Pooled investments:</td>
<td></td>
</tr>
<tr>
<td>Pool A</td>
<td></td>
</tr>
<tr>
<td>Government and government agencies</td>
<td>2,079,711</td>
</tr>
<tr>
<td>Bonds</td>
<td>2,079,773</td>
</tr>
<tr>
<td>Preferred stocks</td>
<td>59,704</td>
</tr>
<tr>
<td>Common stocks</td>
<td>8,984,052</td>
</tr>
<tr>
<td>Savings deposits</td>
<td>28,115</td>
</tr>
<tr>
<td>Real estate</td>
<td>429,153</td>
</tr>
<tr>
<td>Cash</td>
<td>113,862</td>
</tr>
<tr>
<td>Other assets written</td>
<td>7,000</td>
</tr>
<tr>
<td>Call options written</td>
<td>(29,112)</td>
</tr>
<tr>
<td>Total Pool A</td>
<td>$13,090,020</td>
</tr>
</tbody>
</table>

December 31, 1978 | December 31, 1977 |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Pool B</td>
<td></td>
</tr>
<tr>
<td>Government and government agencies</td>
<td>1,661,463</td>
</tr>
<tr>
<td>Bonds</td>
<td>1,370,298</td>
</tr>
<tr>
<td>Common stocks</td>
<td>2,299,099</td>
</tr>
<tr>
<td>Savings deposits</td>
<td>22,035</td>
</tr>
<tr>
<td>Cash</td>
<td>4,914</td>
</tr>
<tr>
<td>Call options written</td>
<td>(6,791)</td>
</tr>
<tr>
<td>Total Pool B</td>
<td>$5,351,013</td>
</tr>
<tr>
<td>Total pooled investments</td>
<td>$18,441,033</td>
</tr>
</tbody>
</table>

C. POOLED INVESTMENTS UNITS:

The value of a pooled investment unit was as follows:

<table>
<thead>
<tr>
<th>December 31, 1977</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pool A</td>
</tr>
<tr>
<td>Pool B</td>
</tr>
</tbody>
</table>

The pooled investment income per unit was as follows:

<table>
<thead>
<tr>
<th>December 31, 1977</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pool A</td>
</tr>
<tr>
<td>Pool B</td>
</tr>
</tbody>
</table>

D. ENDOWMENT AND SIMILAR FUND INCOME:

Income of endowment and similar funds consisted of the following:

<table>
<thead>
<tr>
<th>December 31, 1977</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distributions</td>
</tr>
<tr>
<td>Interest</td>
</tr>
<tr>
<td>Other</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

Investment management costs | (73,628) |
| Net investment income | $1,746,184 |
| Total | $1,691,983 |

E. RETIREMENT PLAN:

The Institution has a noncontributory, fixed benefit/unfunded retirement plan covering substantially all full-time employees. The Institution’s policy is to fund pension costs accrued which includes amortization of prior service costs over a 30-year period. Retirement plan costs charged to operating expense amounted to $1,535,000 in 1978 and $1,513,700 in 1977, including $31,000 and $39,700, respectively, relating to expenses of the retirement trust. As of the most recent valuation date (January 1, 1978), the unfunded prior service costs, which will be funded through future annual accruals, approximated $6,970,000.

F. CALL OPTIONS WRITTEN:

In 1978 the Institution began writing covered call options on the endowment fund’s investment securities. The call option gives the holder of the option the right to purchase the underlying security at a specified price at any time until the option expires. Call options are valued at their market value as reported on the last business day of the year, and presented as a reduction in the market value of the underlying securities.
Bow chamber of *Atlantis II* provides marine life observation post.