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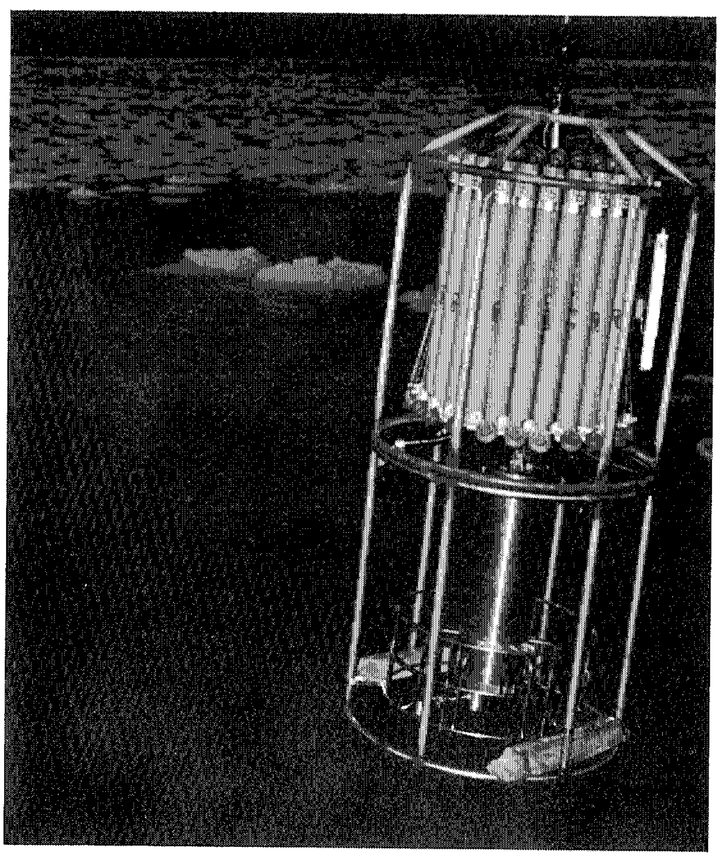
Cover:
The cover photographs were taken during loading of R/V *Atlantis II* and field work for the Joint Air-Sea Interaction (JASIN) experiment off Scotland in July and August of 1978 (see page 10). Clockwise from upper left: the spar buoy is tested off the Woods Hole pier; a mooring is launched from 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

GEORGE KNAPP

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.



GEORGE KNAPP

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

©ANITA BROSIUS

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 Hills, 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 insure 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

Nansen cast, *Oceanus* #52.

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 overlying 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.

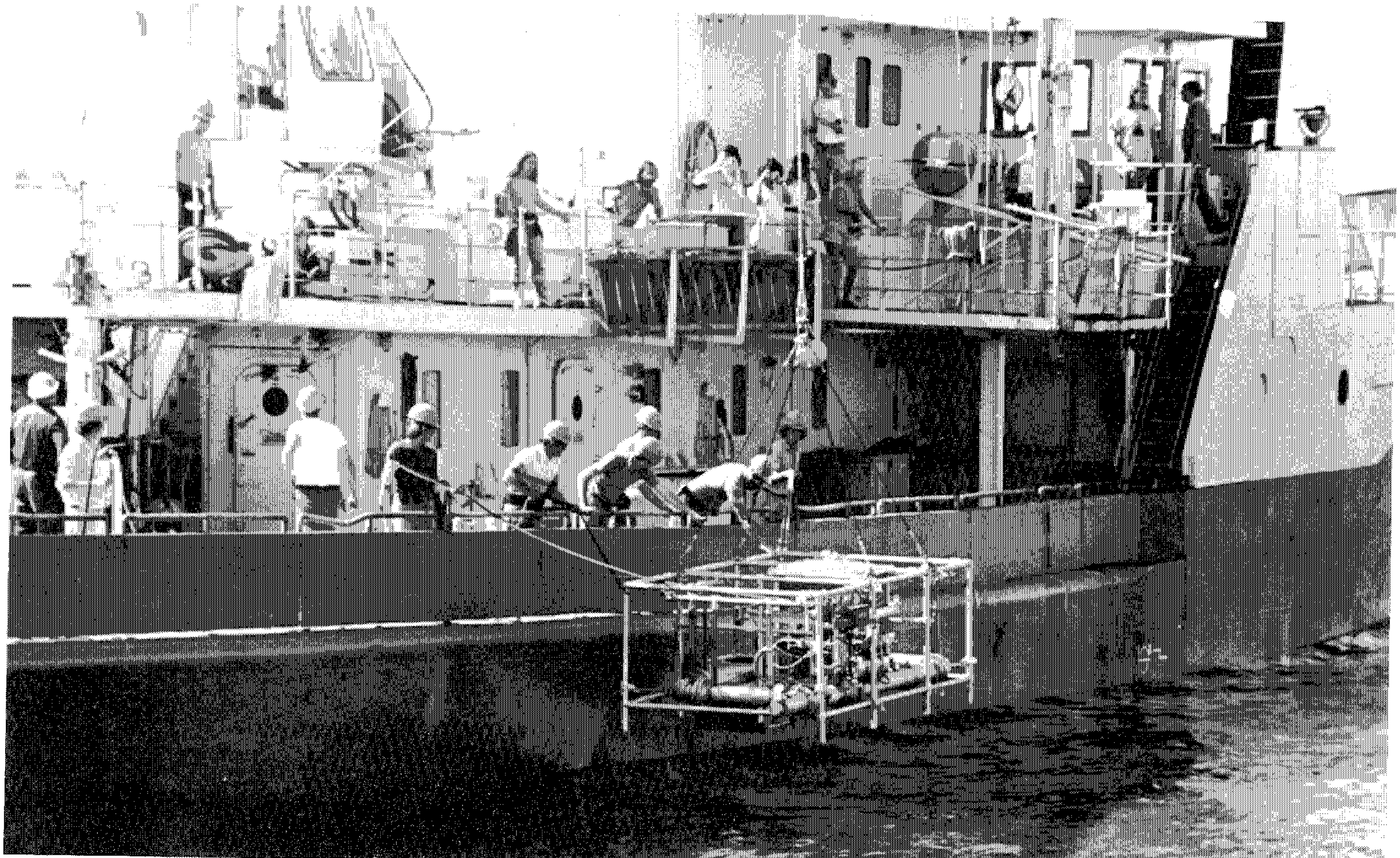
Marine Policy & Ocean Management

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.

VICKY CULLEN

R/V *Oceanus* heads out on a summer voyage.

VICKY CULLEN



Benthic chamber for biogeochemical studies is lowered from *Oceanus* to capture a piece of Buzzards Bay.

Research: Ocean Boundaries

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

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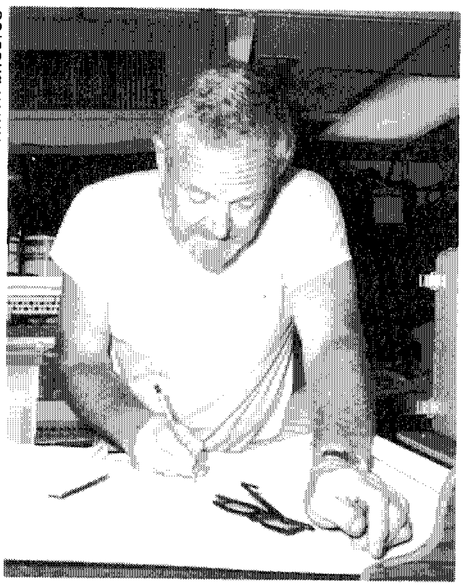

Val Worthington plots XBT data aboard *Oceanus.*

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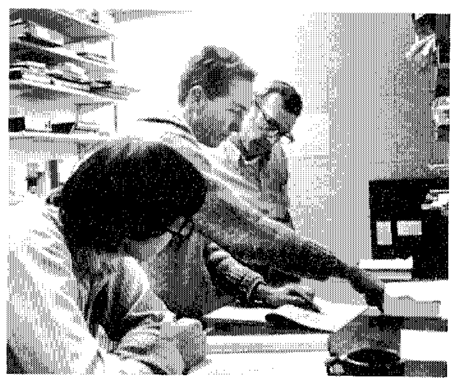
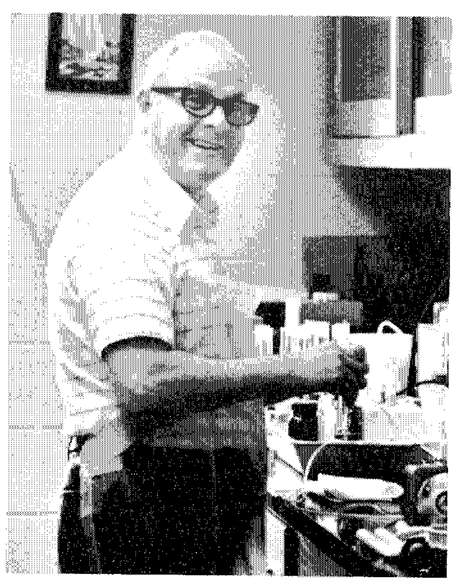
Rich Harbison examines amphipod on *A-II* #101.

VICKY CULLEN



Breck Owen, Phil Ri hardson, and Bill Schmitz.

VICKY CULLEN

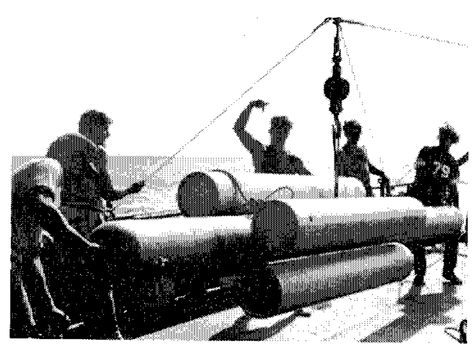


Nat Corwin at Clark Laboratory.

BRUCE TRIPP

Jack Livramento takes a break on *Oceanus* #46.

JIM DOUTT



SOFAR float is moved across *Oceanus* deck.

Upper Ocean Variability

Melbourne Briscoe

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.

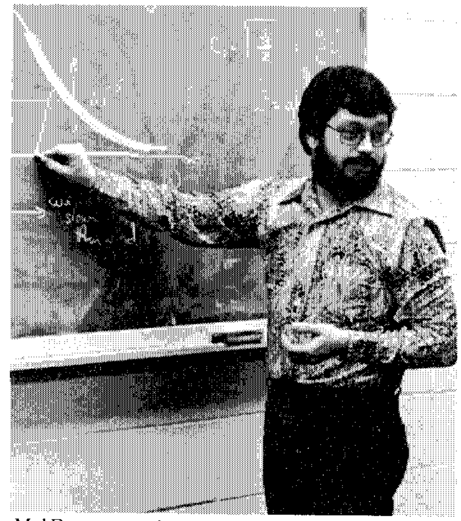
Although we have a general understanding of some of the physical processes that cause, enhance, or inhibit the energy transfers between the air and the sea, an embarrassing lack of detail exists. For example, the wind makes waves, and the motion and decay of the waves is somehow connected with the formation 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.

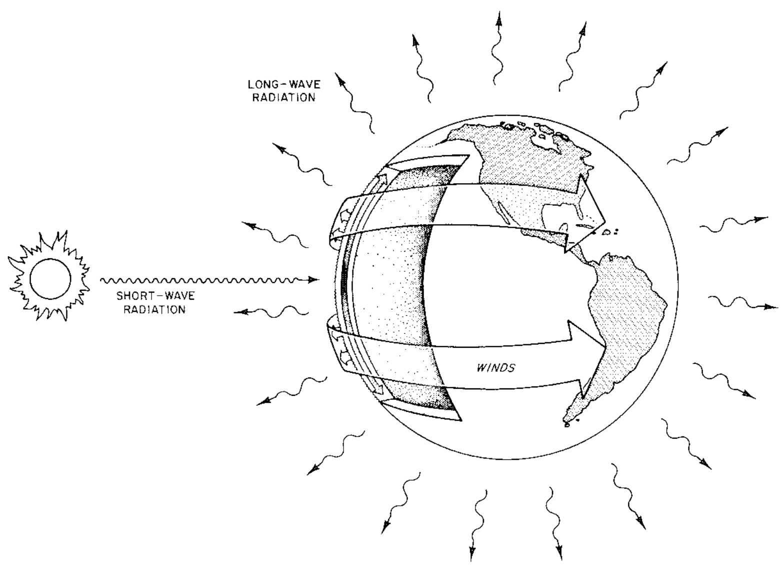
In 1966 the international *Joint Air-Sea Interaction Project* (JASIN) was proposed on aspects of the problem, particularly the air-sea transfers and the vertical mixing processes. After several trial and developmental field programs, the main field experiment was held from July to September 1978 about 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

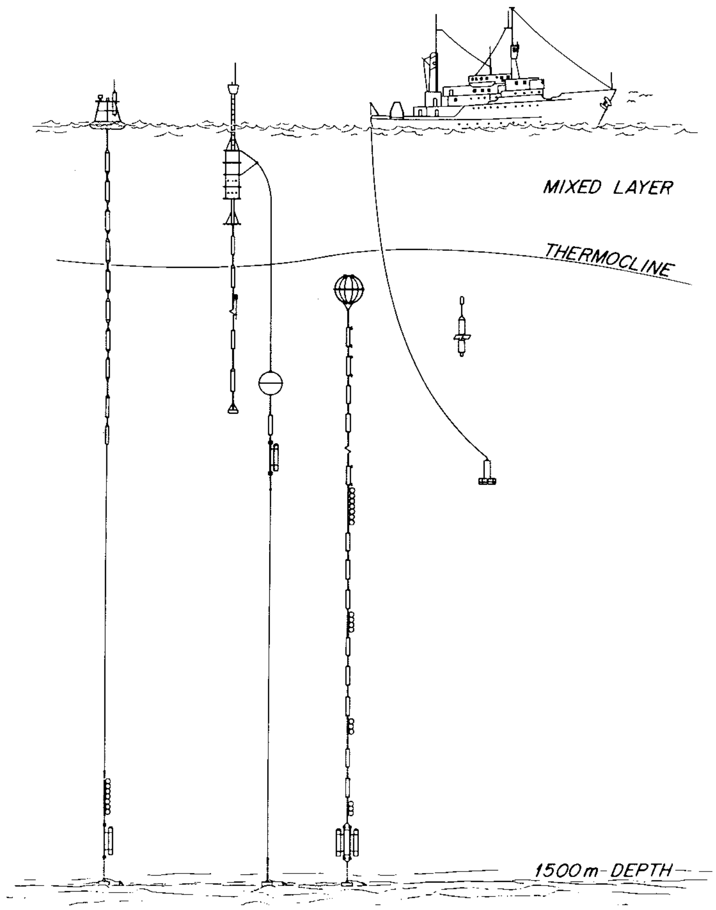


VICKY CULLEN

Mel Briscoe teaches Joint Program class.



Schematic of the global heat balance and the buffering effect of the oceans indicates how short-wave radiation from the sun heats primarily the equatorial regions, while long-wave radiation is lost to space fairly uniformly from the earth's surface. This results in a poleward heat flux that is transported partly by the atmosphere and partly by the ocean. In essence, the cooled polar seas sink and flow equatorward, while the warmed tropical seas rise and flow poleward. Rotation of the earth and the blocking effect of the land masses greatly modify this simple picture. The surface temperature is what is seen by the atmosphere as a heat source and is therefore a driving force for winds, including hurricanes. The winds, on the other hand, are a source of energy to mix the ocean, especially the upper ocean, and therefore contribute to changing the surface temperature as the warm surface water is combined with the cooler deeper water. The net effect depends on how the waters mix vertically, especially near the surface. Understanding these processes is one of the main goals of upper ocean variability research today.



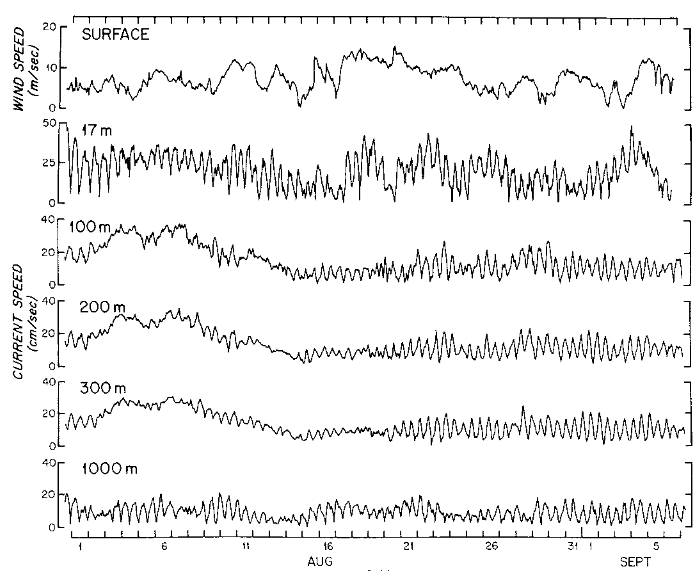
Artist's conception shows the Woods Hole Oceanographic Institution's contributions to the Joint Air-Sea Interaction Project (JASIN), a nine-country, 14-ship, international study of the response of the ocean to the motions of the atmosphere. The field experiment took place July – September 1978 northwest 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 II* 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 ½ 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 sea. They have periods of hours, lengths of kilometers, heights of tens of meters, and exist at all depths in all oceans.

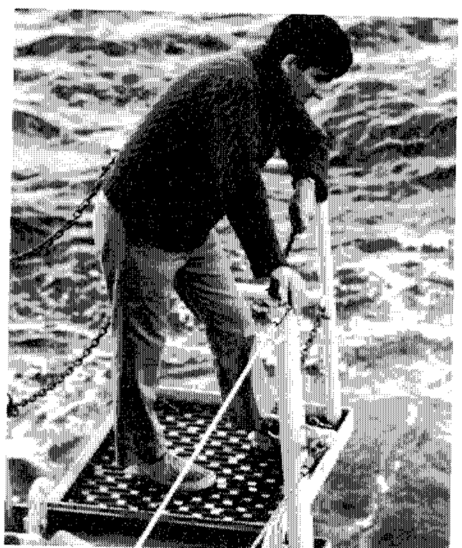


Surface wind speed (at 3½m height) and water current speeds from five depths; measurements are from the JASIN project. The approximately twice-daily current fluctuations are inertial oscillations forced by the wind and maintained by the rotation of the earth; also twice-daily are tidal currents. The 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.

Transport of Larvae by Ocean Currents and the Geographical Distribution and Evolution of Benthic Organisms

Rudolf Scheltema

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.

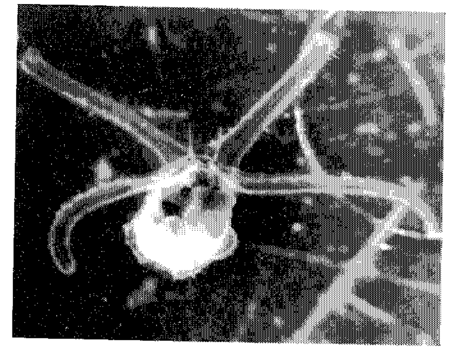


PETER WIEBE

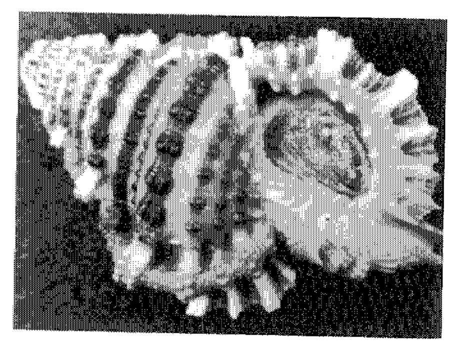
Rudy Scheltema

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-



Living veliger larva of a gastropod taken from the Gulf Stream and belonging to the genus *Bursa*, the frog shells, is shown above. The long extended structures, called velum, have cilia which allow the larva to swim and feed. This teleplanic larva (Gr. *teleplanos* far wandering: Aeschylus, *Prometheus Bound*, line 576) may drift on ocean currents for thousands of miles over a period from six to 10 months. An adult frog shell is shown below. Larva is about 1½ mm, adult about 4 cm.



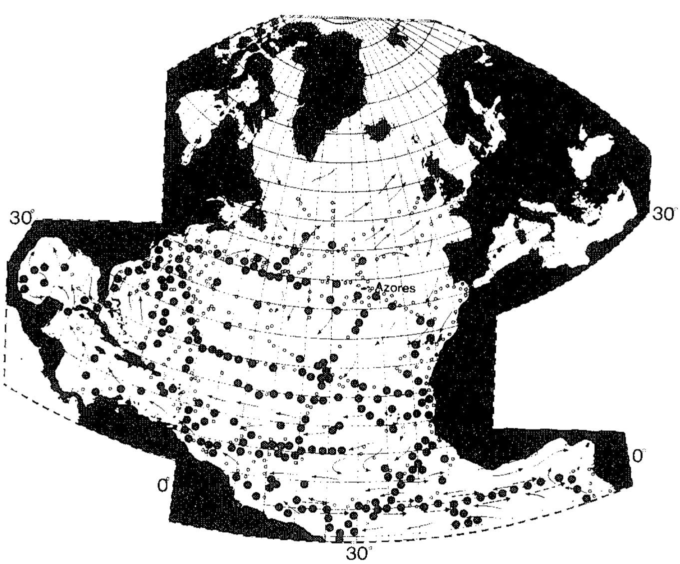
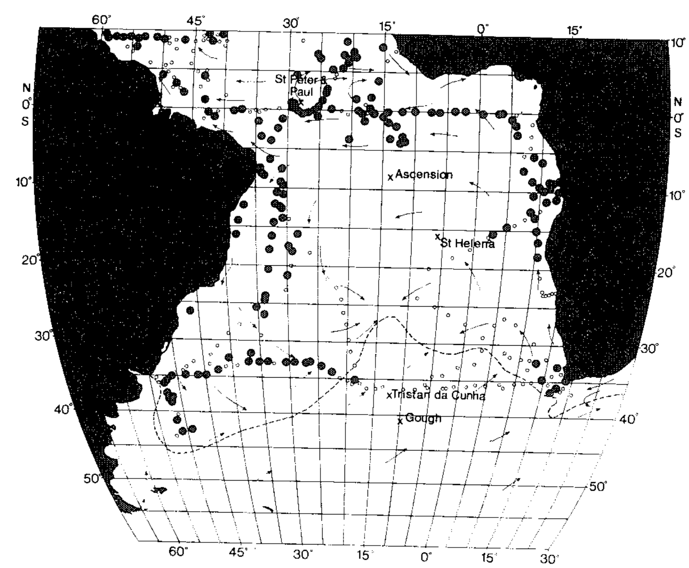


Chart shows North Atlantic distribution of veliger larvae belonging to the gastropod family Architectonicidae, the sundial shells. Members of this family of snails are extensively distributed on the continental shelf throughout the tropics. Ten species are known from both the eastern and western Atlantic Ocean. Filled circles indicate locations where larvae were present; open circles show points where samples were taken but no larvae were found.



South Atlantic distribution of veliger larvae belonging to the family Architectonicidae is shown on this chart. Symbols are as in the North Atlantic chart. The dashed line shows subtropical convergence.

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.

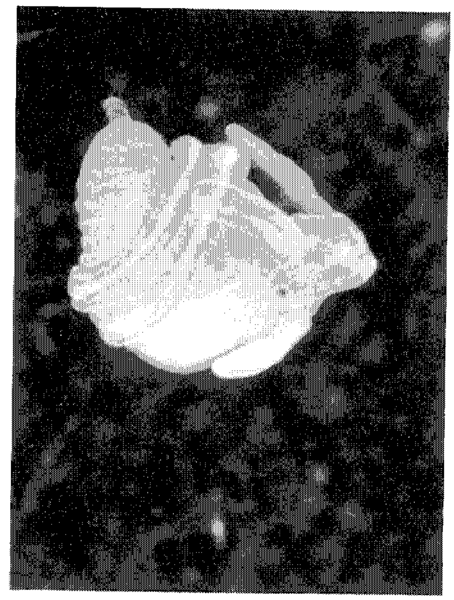
The duration of the planktonic larval stage may be modified by seawater temperature and, in some species, by a settlement response induced by some attribute of the adult environment. In the absence of such a cue, the settlement of the larva may be delayed. The kind and quantity of food available may 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 on 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 of a 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 mesotroch larva of the polychaete worm *Chaetopterus variopedatus* taken from a plankton tow in the Gulf Stream. The two ciliated metatrochal bands help propel the larva. Yellow to green in color, the mesotroch 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 mesotroch 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.

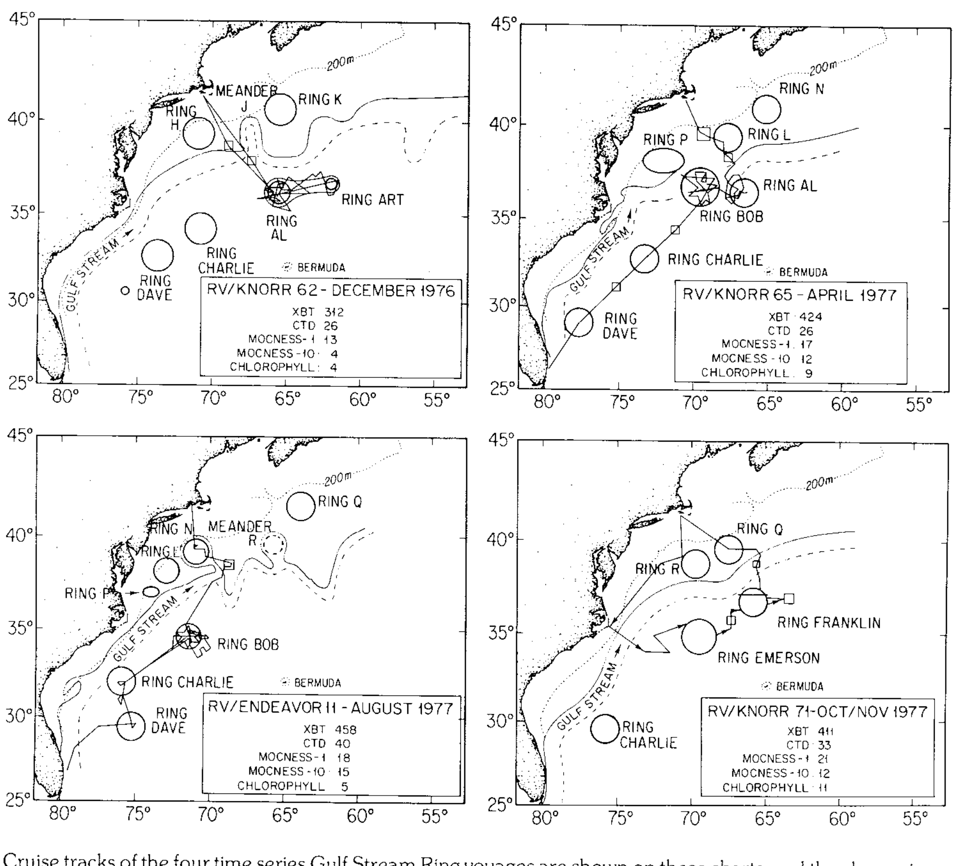
Gulf Stream cold core rings have been the focal point for these studies for the past six years. Large unstable southward meanders of the Gulf Stream break away to form rings of swiftly flowing Gulf Stream water around cores of cold Slope Water normally found to the north of the Gulf Stream. Following 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.

VICKY CULLEN

Peter Wiebe

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



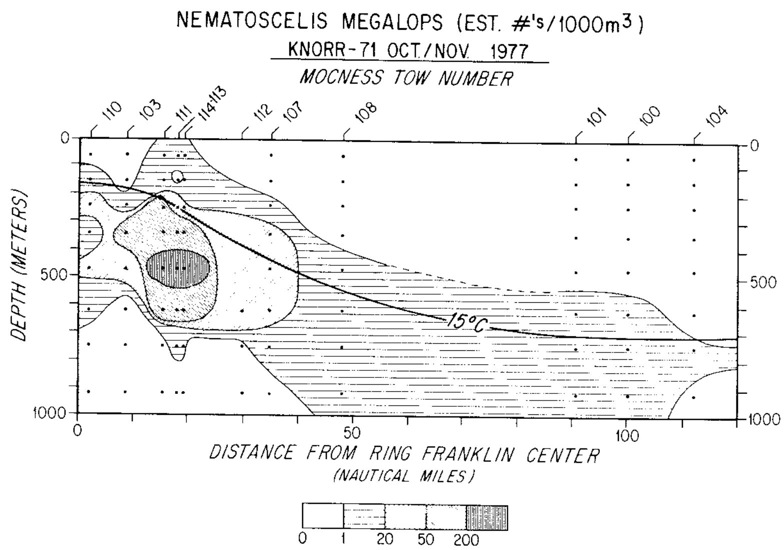
Cruise tracks of the four time series Gulf Stream Ring voyages are shown on these charts, and the change in the ring picture can be clearly seen. Tallies are listed for each voyage of expendable bathythermograph (XBT) measurements, lowerings of a conductivity-temperature-depth (CTD) sensor, zooplankton tows (MOCNESS 1 and 10), and chlorophyll readings on a flurometer 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.

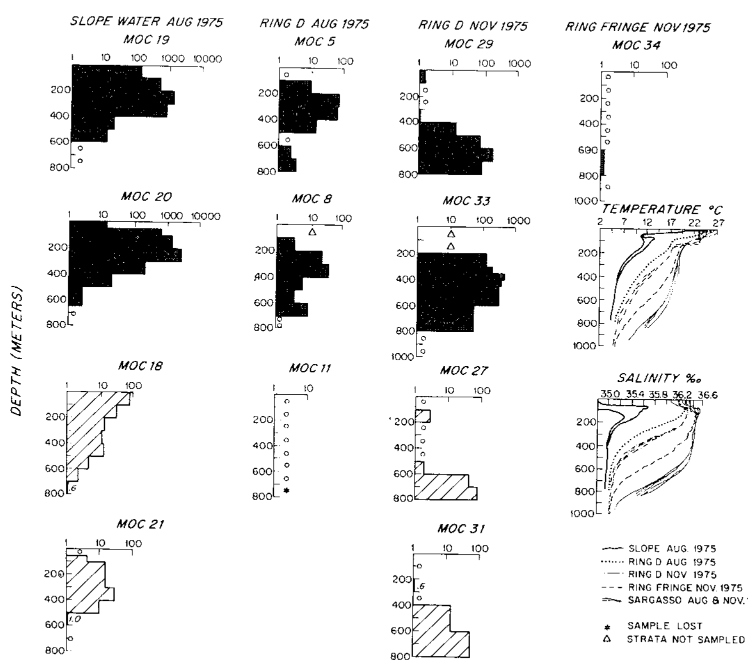
The biological effort included the collection of samples for the assessment of phytoplankton, zooplankton, and midwater fish populations at various locations within the rings as well as in the surrounding Sargasso Sea and in the Slope Water. Samples for analysis of the vertical distribution and abundance 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.



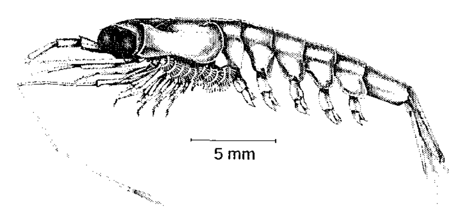
Changes in the vertical distribution of *N. megalops* in a ring through time compared to normal distribution in Slope Water.

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 advected 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.



Nematoscelis megalops

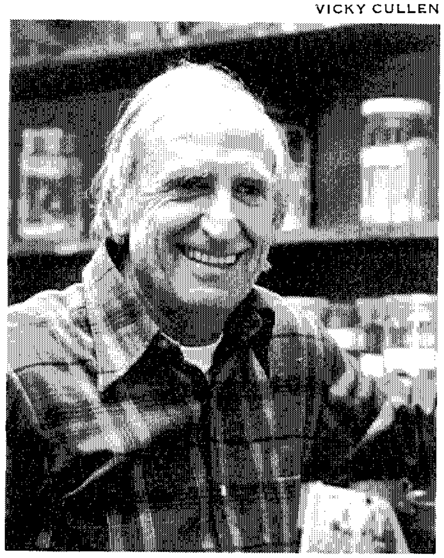
Our new awareness that such large-scale mechanisms as Gulf Stream rings move large segments of oceanic communities away from the home range area and into areas of quite different environmental conditions has only just begun to be translated into ongoing research activities. As open ocean experimental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

Distribution of Atlantic Mesopelagic Fishes

Richard Backus

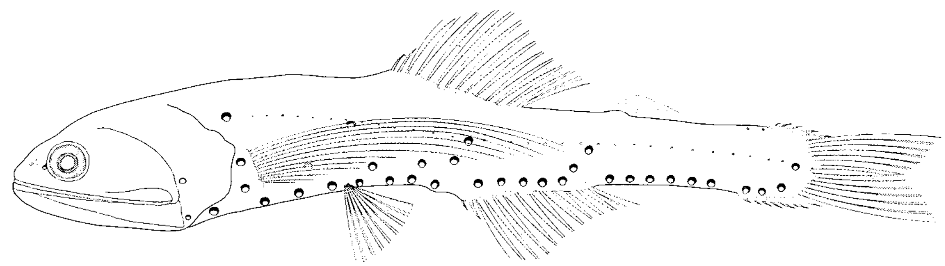
The Atlantic-wide distribution patterns of the small fish species of the upper 1,000 meters of the deep ocean have been an object of study at the Institution for about 15 years. So-called "mesopelagic" fishes are, for the most part, small (one to a few inches long at maturity), black or silvery, luminescent, 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.

VICKY CULLEN


Dick Backus

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 circum-global 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 gaussi,* is one of several distributed according to the *subtropical* pattern. Furthermore, like many lanternfishes, *L. gaussi* 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 pelagial environment.



Lepidophanes gaussi

The heavier lines approximately coinciding with the limits of the black circles, which signify catches of *Lepidophanes gaussi*, 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. gaussi* and the physical limits of the Atlantic's subtropical seas shows that *L. gaussi* 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. gaussi* is a positive "bioassay" for those parts of the Atlantic that are subtropical.

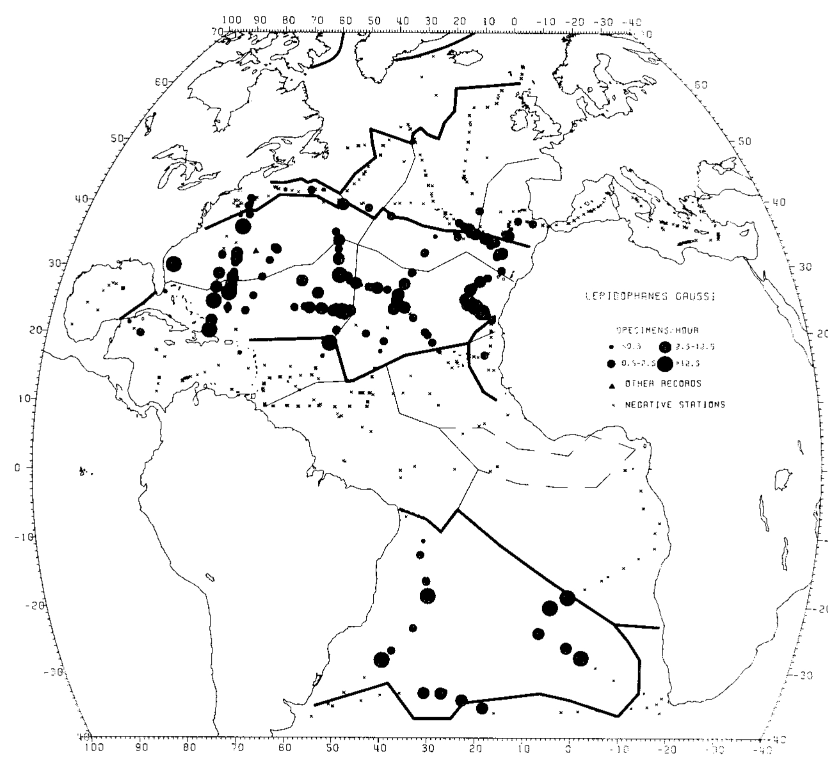
Thus, the study of the distribution of mesopelagic fishes together with the kind and scale of physical change that accompanies faunal change in the upper waters of the deep ocean tells us not only about the biology of the fish, but also may help delimit areas that are relatively homogeneous physically.

The unoccupied region between the North Atlantic and South Atlantic populations of *L. gaussi* (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-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-



Distribution of *Lepidophanes gaussi.*

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 Bokandretok, a small uninhabited island near Eniwetok Atoll, Marshall Islands, in the northwestern Pacific; and Tutuila 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

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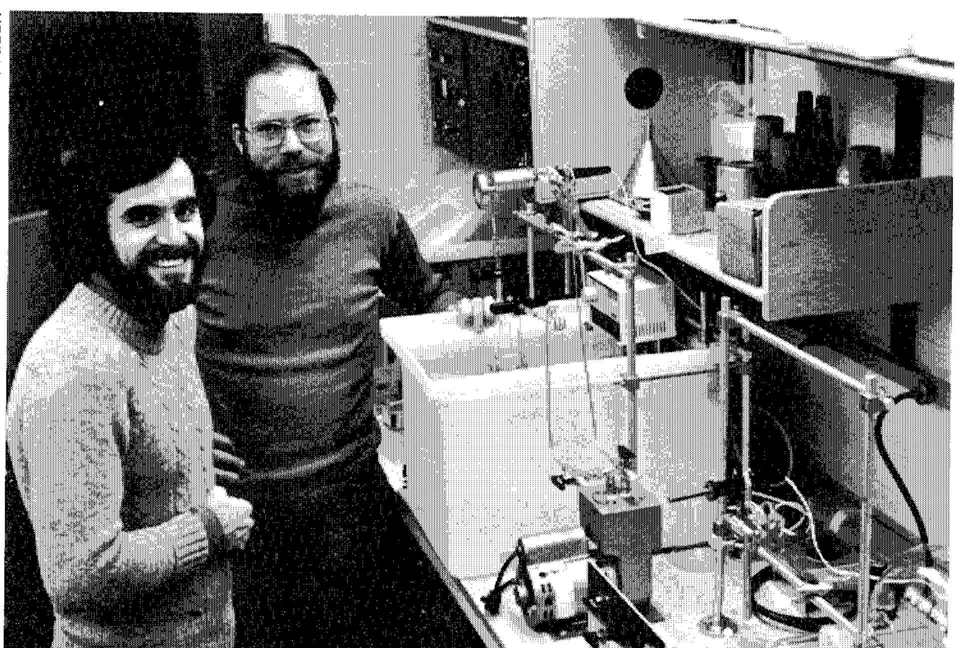


Bob Gagosian, left, and Ollie Zafiriou

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 tha 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.

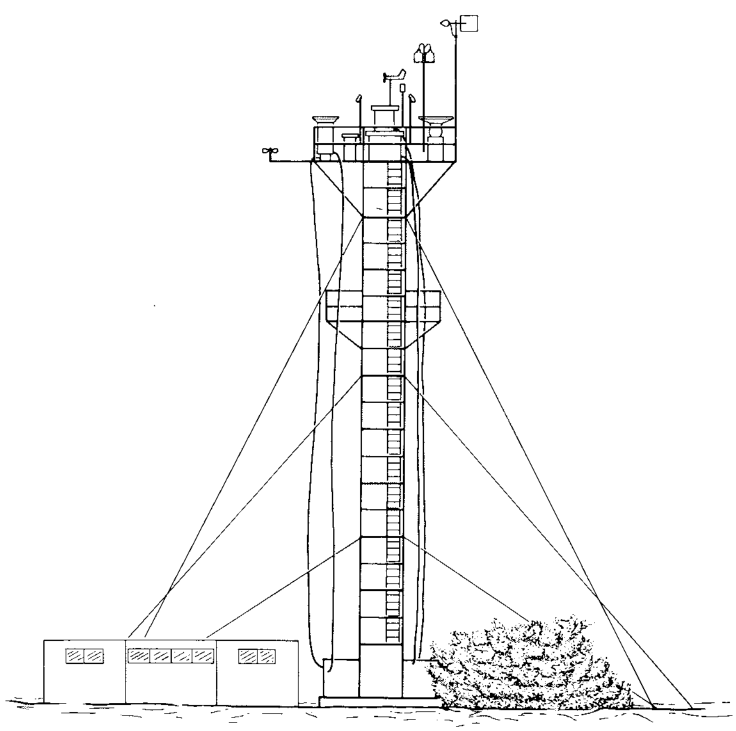
In preparation for this effort, a test program was run at Pigeon Key, Florida, in early 1978 to test equipment, detect potential interferences, and gain experience with the automated sampling system. This system permits sampling to be controlled according to wind direction and speed and various indicators of local contamination, such as condensation nucleus counts. The Bokandretok (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 land 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.

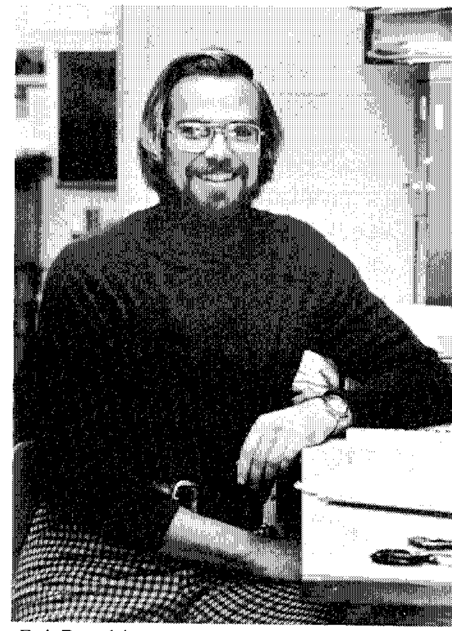
Shelf Circulation

Robert Beardsley

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 southwestward flow of slope water.



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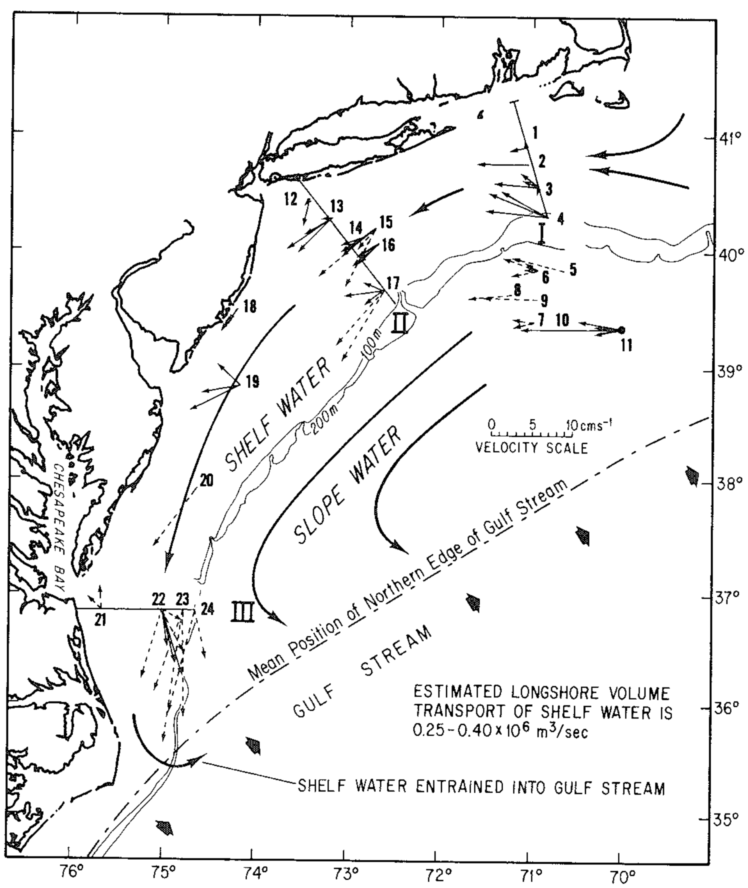
Bob Beardsley

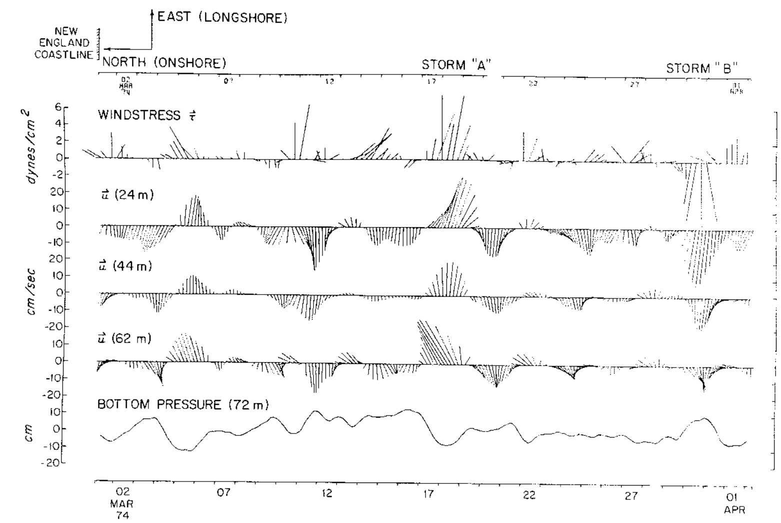


Mean velocities as measured by moored current meters in the Middle Atlantic Bight region. Winter measurements are indicated by solid arrows, summer velocitiies by dashed arrows. Individual station numbers are circled. Measurements depths, in meters, are shown near heads of arrows.

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 longshelf 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 offshelf flow near the surface and onshelf flow near the bottom; storm "B" drove equally strong westward longshelf currents, with now offshelf 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.



Time series of wind stress (top panel), subtidal currents at 24 m, 44 m, and 62 m depth, and bottom pressures at 72 m observed in March 1974 at a mid-shelf site on the New England shelf.

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 1.4×10^{-7}, or 1.4 centimeters in 100 kilometers. This result was based on a one-month-long data set and was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subject to error due to short-term sea-level response to wind stress variations.

An alternative estimate of the magnitude 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 coming in via the Labrador current and the St. Lawrence, for example? Or is it imposed on the shelf waters from offshore by the dynamics of the massive deep-water gyres of the North Atlantic?

We found the answer to these questions 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 importantly on the air-sea temperature difference. 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 continental 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 principle 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 centimeter 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 column. As this impinges on the upper continental 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 circulation 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 continental shelves, where electric power stations discharge their cooling waters and dissipate 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 variation. The longshore flow driven in shallow water by this sea-level slope is substantial enough to remove expeditiously 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.

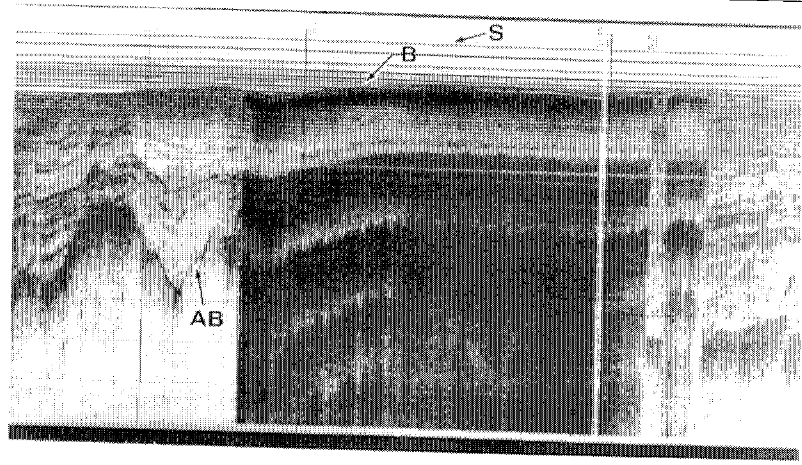
Source and Fate of Urban Estuarine Sediments — Boston Harbor

Michael Fitzgerald and John Milliman

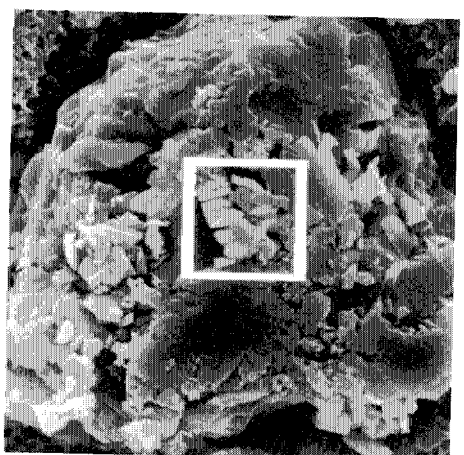
The urban estuary is a fragile resource subjected to a variety of human pressures. The estuary's sedimentary regime both influences and records the environmental response to these pressures. Understanding estuarine sedimentary processes, therefore, is necessary for wise coastal management.

Boston Harbor is perhaps an extreme example 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 considerable portion of the outfall material moves directly or indirectly into the harbor. As a result, parts of the harbor bottom are covered with organic-rich (three to five percent organic carbon) polluted sediment. The organic-rich sediment produces considerable quantities of methane gas, which in turn facilitates charting of these sediments by remote sensing (figure right above). Cores in these sediments show a major increase in pollutant influx (including trace metals such as cadmium, lead, nickel, and copper) and sedimentation rates of 0.5 centimeter per year during the past 80 years (when outfalls have grown in size and use).

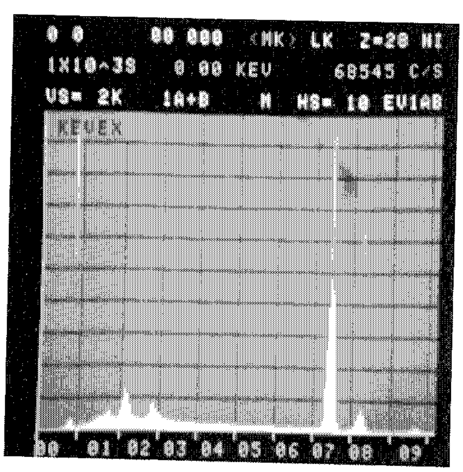
We have documented the movement of these anthropogenic contaminants with suspended matter and water column measurements that delineate spatial, tidal, diurnal, and seasonal variations within the system and outline the imprint of sewage upon the estuarine regime. Particulates come from three main sources: 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



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 1/16 second or 93 meters; Horizontal distance is approximately one kilometer.



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.



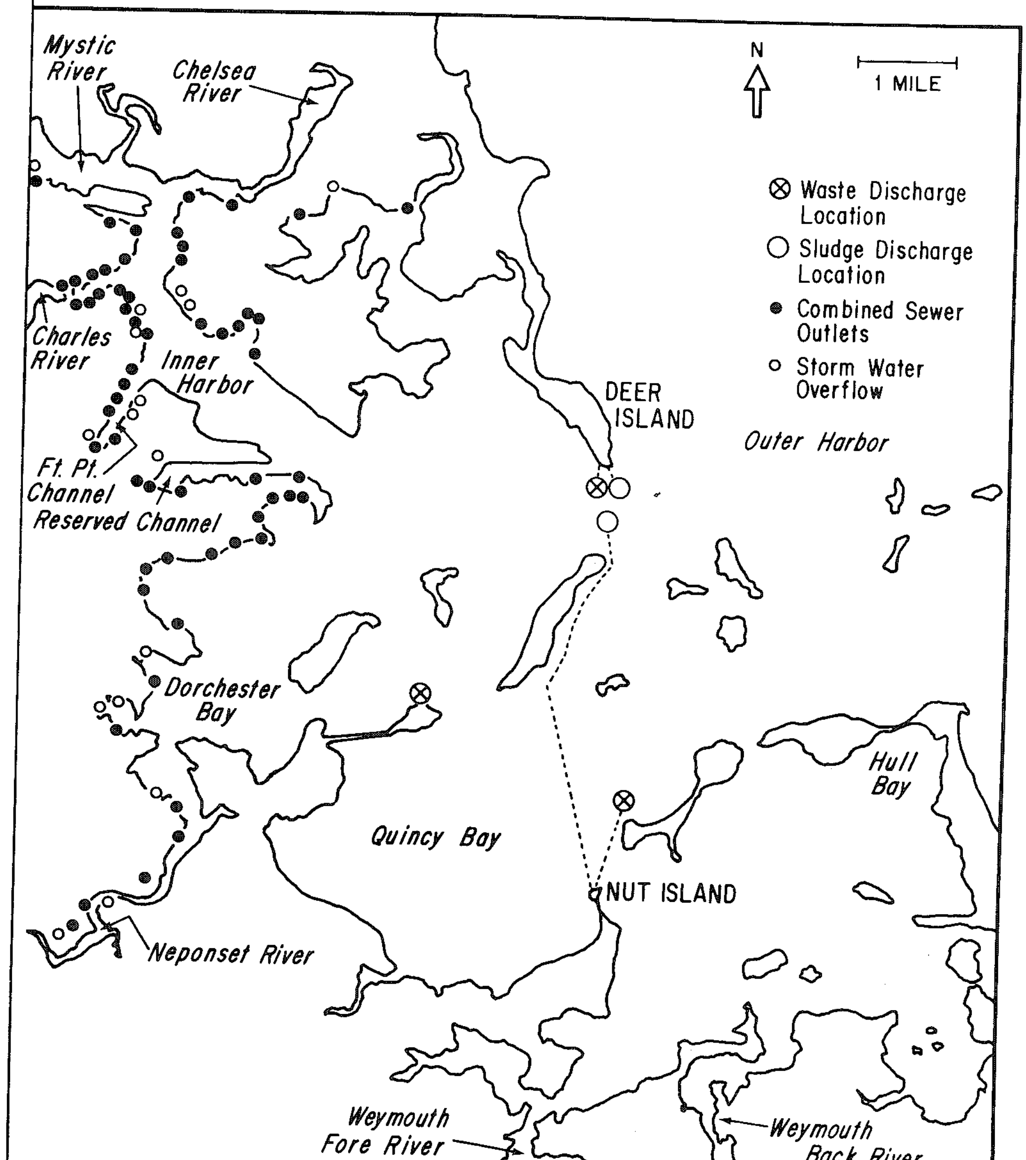


Chart of Boston Harbor shows locations of sewer outfalls and storm sewer overflows (after Hydroscience, Inc., 1973).

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.

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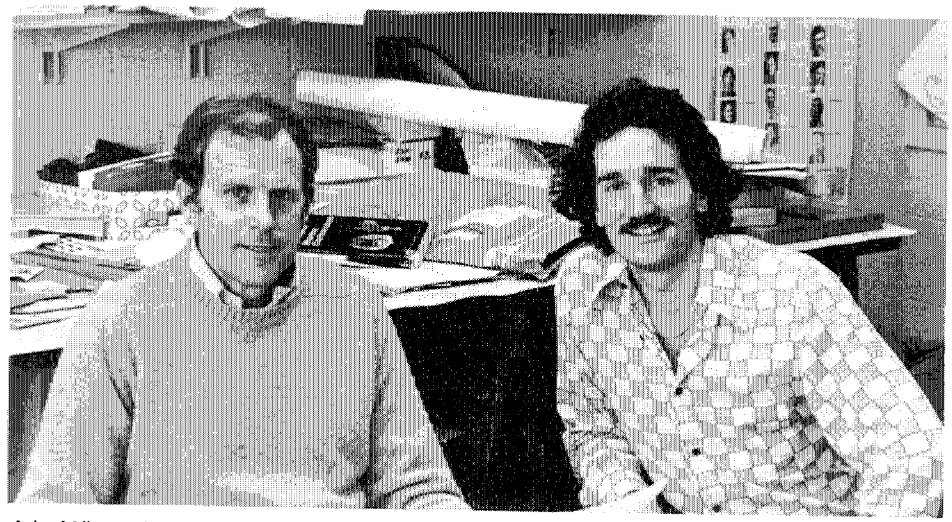

John Milliman, left, and Mike Fitzgerald

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 *(Artica 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.

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Roger Mann

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 mollusc 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 relatively uniform 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

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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 approaching.

Some of the stresses that phytoplankton encounter are man-made chemical stresses — pollutants. Pollution is not just characteristic of coastal water; 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/1) 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/1 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-

Judy Capuzzo

tion as to the actual toxicant concentration to which an organism was exposed.

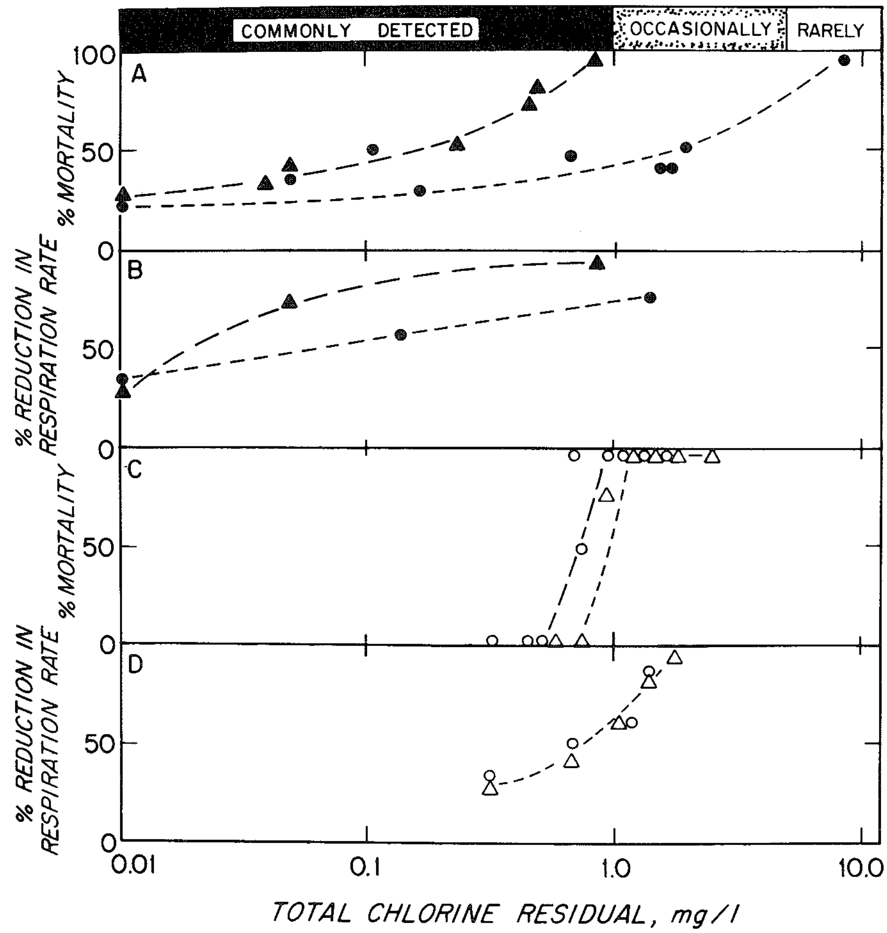
To test the potential responses of marine phytoplankton and zooplankton to entrainment conditions, continuous flow bioassay units were designed to allow short term toxicant and/or thermal stress, rapid elimination of these stress conditions, and subsequent long term observation of the test organisms. The comparative effects of free chlorine and chloramine combined with thermal stress were evaluated for each organism investigated, and both applied and residual toxic levels were determined.

Chlorination effects on marine phytoplankton at power plants appear to be minimal compared to effects on larval zooplankton. With both laboratory-cultured and natural populations of phytoplankton, no permanent adverse effects were observed with exposure to chlorine and thermal stress. Although some mortality may occur, phytoplankton not killed by stress conditions exhibited rapid recovery and no change in growth rate when compared to control populations. Because of the intermittent chlorination schedules used in the United States, entrained phytoplankton exposed to chlorinated seawater would represent only a small fraction of the standing crop, and therefore no change in primary production as a result of power plant operations would be anticipated in coastal waters.

The abundance of larval and juvenile organisms in the plankton is intermittent because many marine animals spawn during restricted periods in their annual cycles. Since young animals lost to chlorination 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/1), whereas less than 10



● ○ chlorine applied as free chlorine ▲ △ chlorine applied as chloramine

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/1 but may occasionally reach higher levels – approximately 5 mg/1 to ensure removal of mussels and barnacles and approximately 12 mg/1 to deter eels 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 $\mu l\ O_2/h/mg$) 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 $\mu l\ O_2/h/mg$) 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/1 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 killifish 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/1 total residual chlorine, applied as free chlorine, and less than 0.8 mg/1 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 killifish 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/1 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 killifish to the toxicants probably reflect differences in uptake and metabolic regulation. Juvenile killifish are apparently unaffected by short term exposure to toxicant concentrations less than 0.3 mg/1, while lobster larvae experience significant metabolic stress even at the lowest toxicant concentrations tested (0.01 mg/1).

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 entrainments or in 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 chlorine on marine 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 increases 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

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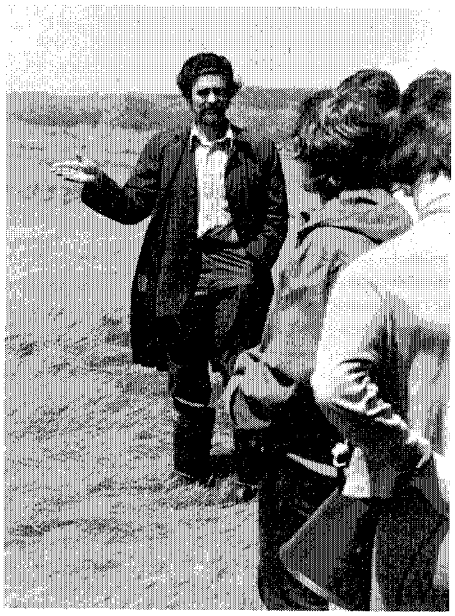


John Teal describes salt marsh on field trip.

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 naturally 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.

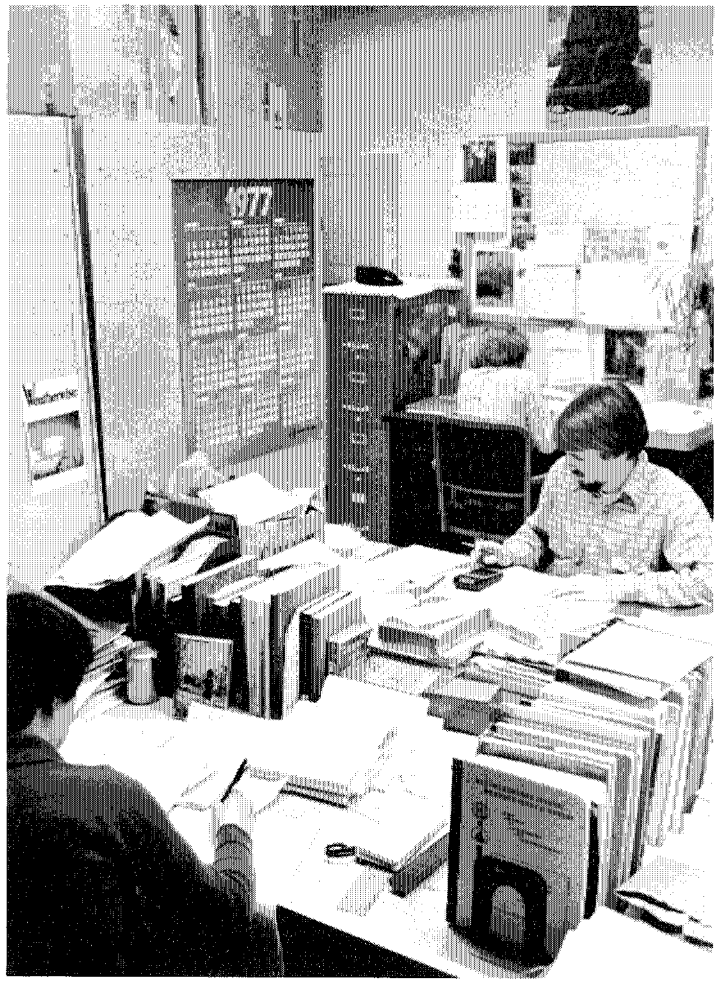
VICKY CULLEN

Students explore the salt marsh.

WENDY WILTSE

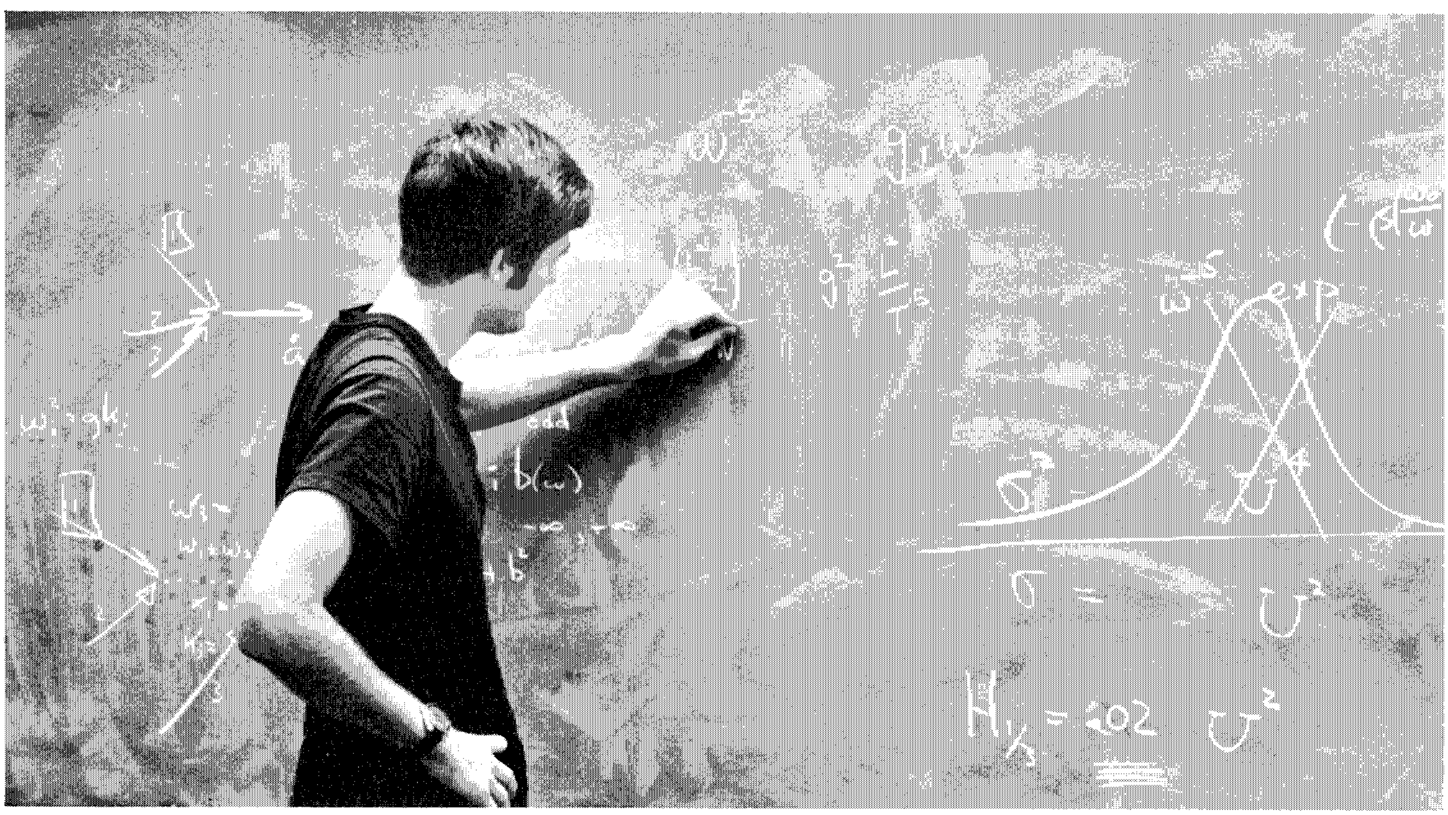
Trainee Paula Randolph records measurements during summer work in the salt marsh.

VICKY CULLEN



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

VICKY CULLEN



Bruce Cornuelle applies chalk to board during class in Surface and Internal Gravity Waves.

Dean's Report

THE year 1978 marked the tenth anniversary of the Joint Graduate Program in Oceanography between the Woods Hole Oceanographic Institution and the Massachusetts Institute of Technology. By the end of the year, a total of 76 doctoral degrees and 12 ocean engineer degrees had been awarded under the program. Fall enrollment was 89.

Establishment of the Joint Program followed several years of debate by the staff and Trustees of the Oceanographic Institution and culminated an intensive search for a way by which the Institution could conduct graduate education without compromising its traditional commitment to research. A special Education Committee appointed by the Trustees in 1964 consisted of Dr. James S. Coles, Professor Arnold B. Arons, and Professor Carroll L. Wilson. The following year the Committee was reinforced by Dr. Jerome B. Wiesner and Dr. Detlev W. Bronk.

In their Interim Report of January 1965, the members of this committee made plain their conviction that the Institution should have a degree-granting program. Drawing on national studies concerning the inadequacy of doctoral training in oceanography and reflecting the view that graduate education and basic research belonged together, the central conclusion of the Education Committee was that "... the establishment at Woods Hole of a graduate studies program leading to the Ph.D. offered the best promise for insuring the intellectual vitality of the Institution and for discharging its responsibility in the field of education."

Models discussed for educational arrangements ranged from a wholly independent degree program to a program sponsored by a consortium of universities. The Education Committee's final recommendation was for joint degrees to be administered with both MIT and Harvard under separate agreements with the two universities. It was envisaged that "the curriculum in the basic sciences in each of the joint programs would be selected from those appropriate courses provided at the university, while the curriculum in oceanography would be selected from seminars and advanced courses available at both the university and at Woods Hole. Thesis research could be done at the university or at Woods Hole, or at both."

An agreement creating such a joint program with MIT was signed in 1967, and Dr. H. Burr Steinbach was named the first dean. Harvard chose to retain cooperative status rather than share in a joint degree program, and Brown and Yale have since been added as cooperative universities, a status which allows their students to take courses and do research at Woods Hole in the pursuit of their degrees. In return, Woods Hole students may take courses at these universities.

A student's entering summer is usually spent on a fellowship working directly in some research activity so that he or she may be quickly involved in laboratory and field research activities of the Institution. In recent summers, an informal seminar has been presented to expose the new students to a wide range of Woods Hole staff. This orientation is followed by an academic program of advanced courses in the basic sciences at MIT or the other universities, while graduate level oceanography survey courses and specialized seminars are taught by Woods Hole staff. Student reactions to the oceanography courses have been varied, some good, some not so good, and it is fair to say that one of the more troublesome areas over the years with the graduate program has been the teaching of formal courses at Woods Hole. In the long run, I believe the problem will be eased as younger staff members who have worked closely with students gain seniority in the Institution.

It is interesting to note that of the facilities the Trustees' Education Committee thought would be required (a student center, classrooms, laboratories, student housing, and educational ships), only the Student Center, which has proved most useful for summer student seminars and for providing visitor accommodations, came to be designated exclusively for the educational program.

The Quissett Campus development and the building of the Clark Laboratory clearly were heavily motivated by the new educational program; indeed, the title "campus" suggests an educational rather than a research center. Wisely, however, these developments proceeded with educational activities fully integrated with the research activities of the Institution. Thus, students share the laboratories of the staff, and classrooms double as departmental seminar rooms.

While student housing often has been a subject of discussion, no sensible and affordable plan has ever been put forth. The basic difficulty stems from the seasonal nature of the local housing market with rental property reasonable and plentiful ten months of the year, but expensive and scarce in the summer. It has not seemed reasonable to construct housing in order to meet a two-month requirement, and student housing needs are being met by a combination of Institution-owned housing and the local market.

The original budget proposed by the Education Committee included some \$150,000 per year for educational ship time. Interestingly, this need has never materialized, but not because students do not go to sea — Joint Program students, in fact, go to sea extensively, occasionally even as chief scientists of cruises. In every case, however, ship costs have been carried by the Institution's research programs. Indeed, certain students have engaged in thesis research requiring ship costs exceeding the \$150,000 estimated by the Committee as needed for the whole program. Again, the integration of education and research has proven mutually supportive.

The Trustees' Educational Committee estimated a financial need of \$2.5 million

VICKY CULLEN

Assistant Dean Jake Peirson, Dean Robert Morse.

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 1965 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.

JAY DEAN

Biology student Nick Staresinic on *Knorr* voyage.

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.

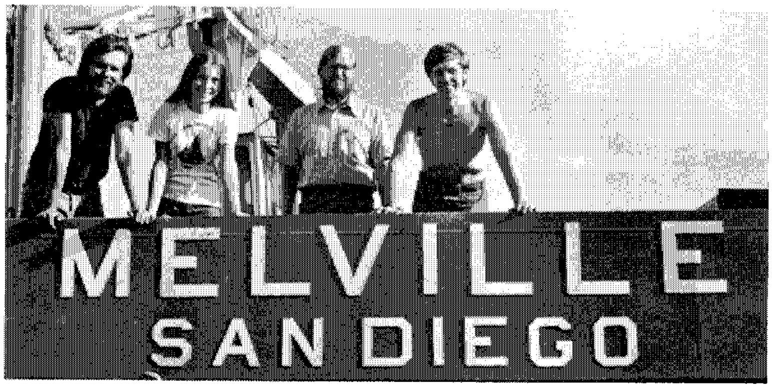
In 1975 the Educational Assembly, a faculty-like forum, was created. One of its first debates concerned a proposal that the official policy on participation of staff in the education program statement be changed from a statement that staff are "encouraged" to participate to a statement that they are "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

VICKY CULLEN



G&G graduates Ed Laine, Roger Flood, and Wilf Gardner and student Mary Jo Richardson worked together on R/V *Melville* voyage.

BRUCE TRIPP

Biology students Mike Connor and Bob Howarth aboard *Oceanus*.

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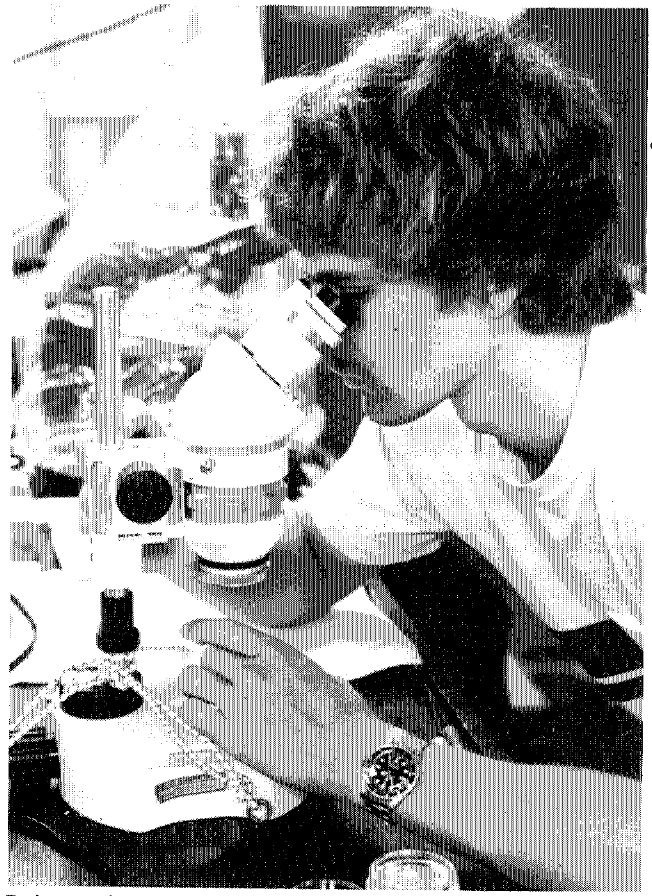


Biology student Neil Swanberg uses microscope in *Atlantis* II lab.

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
Dissertation: *Studies of Deep-Sea Sedimentary Microtopography in the North Atlantic Ocean*

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, Sepiapterin, in* Drosophila Melanogaster

GEORGE RODENBUSCH
B.S., M.M.E., Rice University
Special Field: Oceanographic Engineering
Dissertation: *Response of a Pendulum Spar to 2-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*

KEVIN M. ULMER
B.A., Williams College
Special Field: Biological Oceanography
Dissertation: *Rate Zonal Density Gradient Ultracentrifugation Analysis of Repair of Radiation Damage to the Folded Chromosome of* Escherichia Coli

Ocean Engineer

HAROLD DAVID LESLIE
B.S.E., Princeton University
M.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*

Ashore & Afloat

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 oceanographics 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


FRANK MEDEIROS

Oceanus Master Paul Howland greets Chinese visitors.

Presidential appointment as Assistant Administrator for Research and Development for the National Oceanic and Atmospheric Administration. Dr. Derek W. Spencer was appointed Associate Director for Research in August to replace Dr. Webster.

Among the many individuals and groups to visit the Institution in 1978 was Dr. Evelyn Murphy, Secretary for Environmental Affairs in Massachusetts. Dr. Murphy met with the Directorate and marine policy staff 13 July to discuss fisheries problems, coastal zone management, the Law of the Sea, and the effects of the national oceans policy upon New England.

Nine countries were represented when the 12th class of the Naval Staff Course, Naval War College, visited in March for lectures, laboratory, and ship visits. In April, an 11-member marine sciences delegation from the People's Republic of China spent two days in Woods Hole studying research vessels and scientific equipment. A second Chinese delegation of 13 oceanographers arrived in May. The delegations were sponsored jointly by the National Council for U.S.-China Trade and the Council for Scholarly Communication with the People's Republic of China. Senior Scientist John Ryther accepted an invitation to join a U.S. oceanographic delegation to China in October.

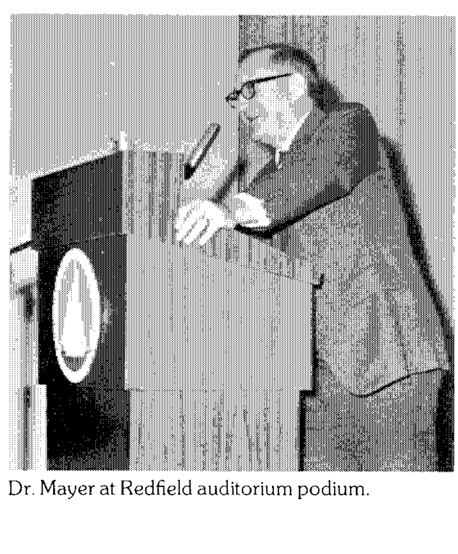
M. Gerard Piketty, President of the French Centre National Pour L'Exploitation des Oceans (CNEXO) and members of his staff met with the Directorate in June to discuss scientific exchange programs and other oceanographic matters. Among other groups visiting the Institution in 1978 were: the New England 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


FRANK MEDEIROS

Dr. Mayer at Redfield auditorium podium.

VICKY CULLEN

Fisheye view of part of Dick Haedrich's fish collection.

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 aircraft in a North Atlantic study. Following a study of the feasibility of repow-

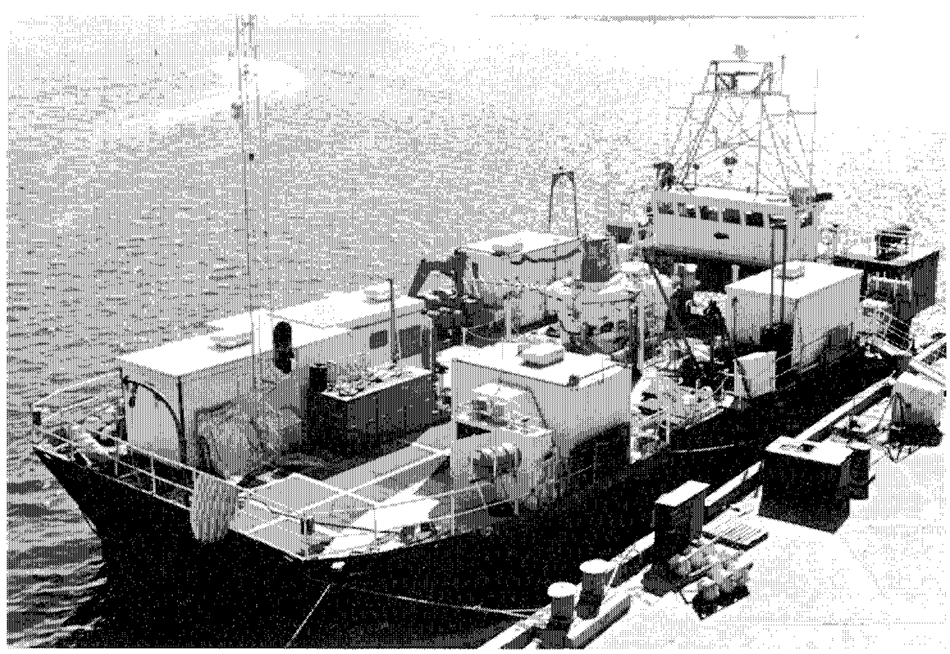
Ocean Industry Program attended two major seminars in 1978. "Chemical Environment of Marine Sediments" in May focused on the geological aspects of benthic boundary layer mixing in the deep ocean and on several research programs in the low energy and high energy benthic boundary layer. On 14 and 15 September "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,

VICKY CULLEN



R/V *Lulu* and DSRV *Alvin* at Woods Hole pier.

DAVID GRAY

Dr. Steele with 35-year veterans Bill von Arx and Jimmy Gifford, seated left and right, and, standing from left, Dick Dimmock, Ralph Vaccaro, and Bob Walden.

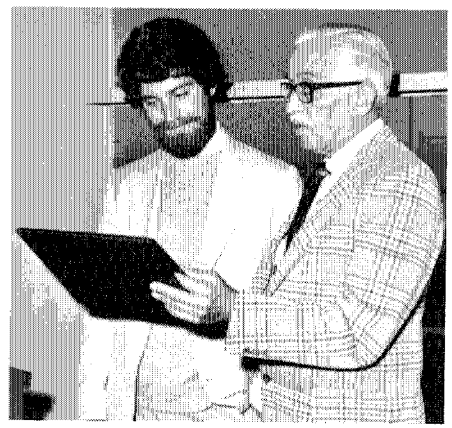
ering the *Atlantis II*, it was recommended that the ship be converted from steam to diesel power in early 1979 to reduce operating costs and increase the ship's speed, range, and selection of ports. The $1.8 million overhaul is being funded by the National Science Foundation and specially allocated Institution funds. The Office of Naval Research is furnishing the diesel engines and other auxiliary machinery.

R/V *Oceanus* 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 *Oceanus* returned to Woods Hole in December.

The 24th Annual Associates Day of Science attracted some 225 persons to Woods Hole 6 October for lectures, luncheon, and a tour of facilities. 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 15 December. Eleven employees who had reached retirement age in 1978, with a total of 195 years of service, were also honored.

FRANK MEDEIROS

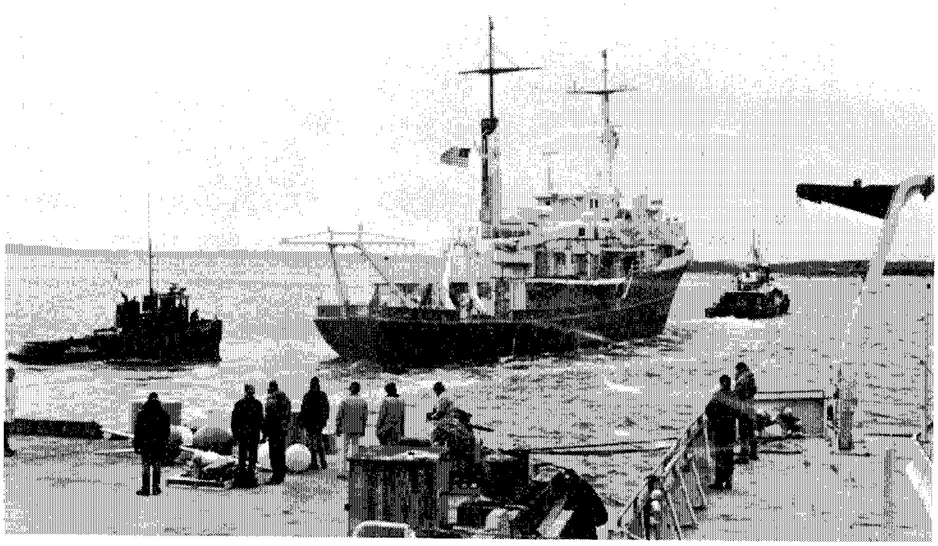


Dr. Fye presents WHOI degree to Peter Ortner.

Oceanus, 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 minicomputer for the entry, editing, and printing of manuscripts and technical reports.

VICKY CULLEN



Tugs take *Atlantis II* out of Woods Hole for diesel installation in New Bedford yard.

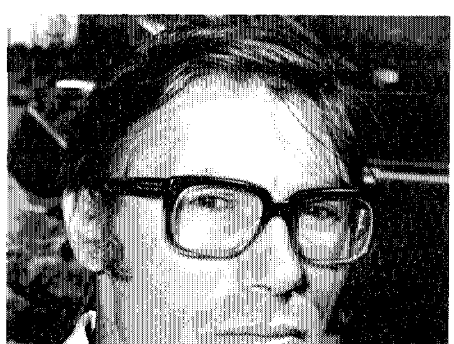
THE seventh Henry Bryant Bigelow Award in Oceanography was presented to Paleontologist Wolfgang Helmut Berger, Associate Professor at the Scripps Institution of Oceanography, University of California, at the winter meeting of the Trustees and Corporation 9 January 1979.

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.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Bigelow Medalist Wolfgang Helmut Berger.

Dr. Berger at sea.

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

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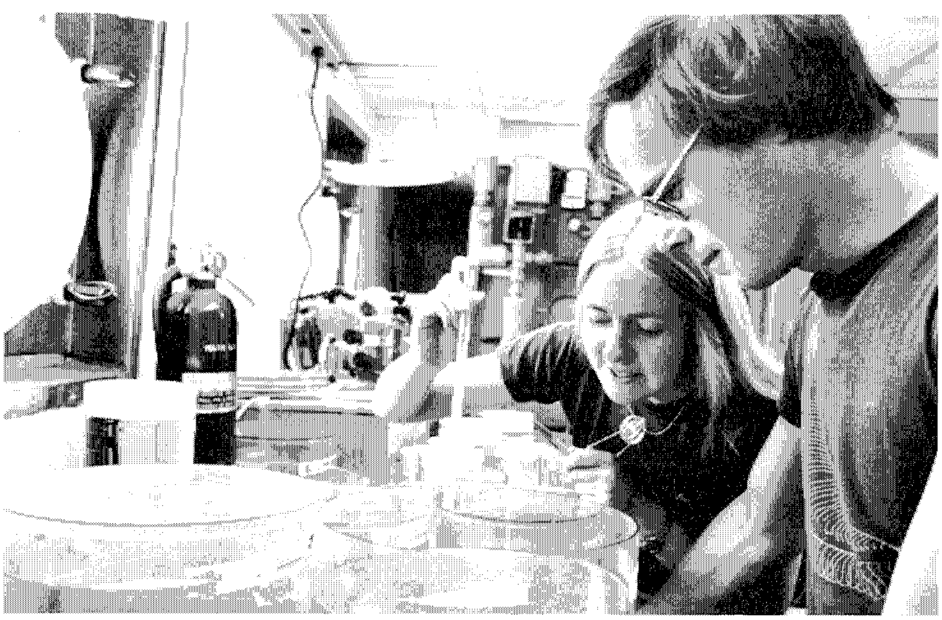

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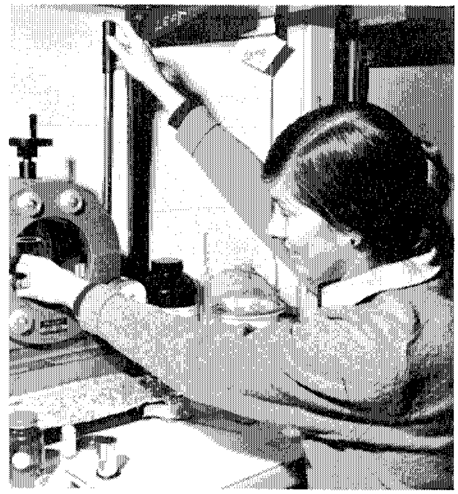
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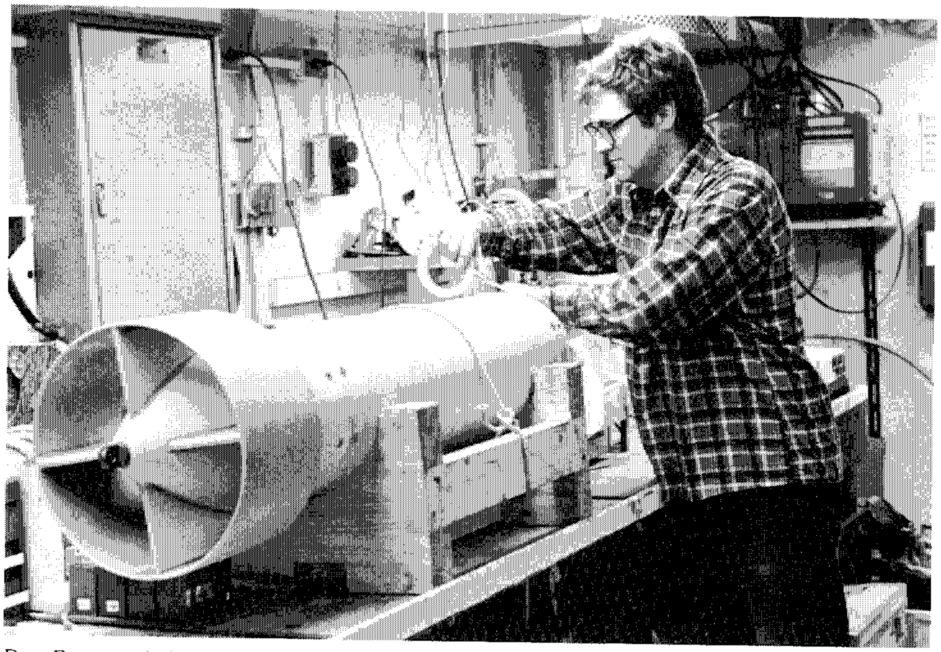

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Physical Oceanography

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VICKY CULLEN

The Physical Oceanography coffee ritual on this day included, from left, Andy Bunker, Val Worthington, Fritz Fuglister, Bruce Warren, and Gerry Metcalf.

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Alfred H. Woodcock, Oceanographer
nonresident

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Dave Simoneau loads ship.

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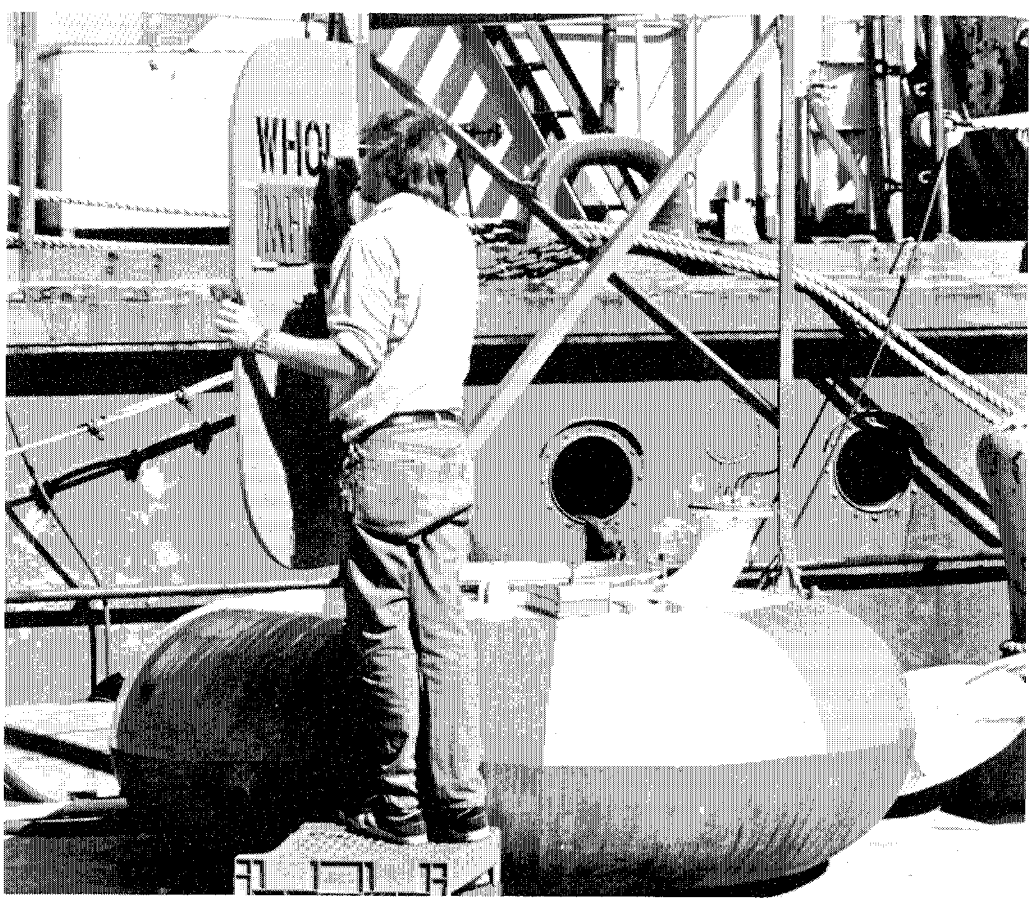

VICKY CULLEN

Matt Gould labels a buoy for JASIN voyage.

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Nancy E. Hazelton
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Ruthanne Molyneaux
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Cheryl C. Murphy
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M. Penelope Odom
Florence Pineault
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Ruth B. Spivey
Evelyn M. Sprague
Maurice J. Tavares
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Mary C. Thayer
Patricia A. Thomas
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Lynn T. Whiteley
Linda C. Wicks
Clarice S. Willert
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Facilities and Marine Operations Staff

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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. Casiles .... *Master, R/V ATLANTIS II*
Richard H. Dimmock .... *Port Engineer*
John D. Donnelly .... *Acting Manager, ALVIN/LULU Operations*
Richard S. Edwards .... *Marine Superintendent*
+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*
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Jonathan Leiby .... *Naval Architect*
Barrett H. McLaughlin .... *Chief Engineer, R/V KNORR*
Paul R. Mercado .... *Chief Engineer, R/V OCEANUS*
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Donald A. Moller .... *Marine Operations Coordinator*
David M. Owen .... *Diving Supervisor*
+Lawrence A. Shumaker .... *Manager, Deep Submergence Operations*
J. Paul Thompson .... *Assistant Facilities Manager*
Andrew L. Wessling, Jr. .... *Manager of Services*

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John A. Lomba
Ernest Mayberry
Anthony G. Mendousa
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Joseph F. Pucci
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John P. Romiza
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William R. Tavares, Jr.
Barbara M. Vallesio
David M. Ward
Robert G. Weeks
Haskel E. White
Carleton R. Wing
Martin C. Woodward
Carleton F. Young

*Deceased, December 5, 1978

BRUCE TRIPP

Gene Mysona on *Oceanus* bridge.

ALVIN/LULU Operations

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

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Kittie E. Elliott
Thomas Lyon
Carole R. Merson
Stephen G. Page

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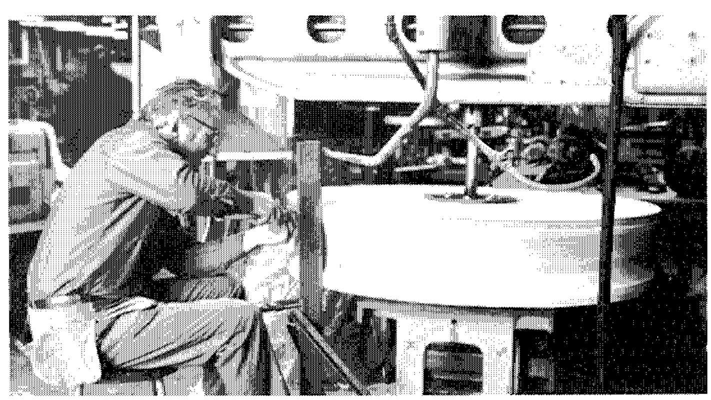
+Robert W. Baker
William R. Baker
#Kenneth E. Bazner
Edward J. Brennan
Edward R. Broderick
+Paul F. Carty
Harry F. Clinton
Arthur D. Colburn, Jr.
+Lawrence P. Costello
Jerome M. Cotter
John M. Daly
George A. Dunlap
Arthur J. Dunn
William A. Eident
+Peter M. Flaherty
#Eugene Fortes
John M. Gassert
+Robert A. Godfrey
Robert L. Gordon
Richard M. Hanley
David L. Hayden
Henry P. Hirschel
Albert C. Jefferson
John K. Kay
John J. Kennedy
+Bernard E. Kilbreth
Millard Klinke
+James E. Leahy
John T. Lobo
+Glen T. MacKinnon
#Thomas Marsland
+John W. Martin
Robert P. Martin
Robert G. Munns
George E. Murphy
Eugene J. Mysona
Conrad H. Ocampo
Thomas F. O'Neil
+Omer J. Palardy
Michael Palmieri, Jr.
George E. Pierce
Samuel F. Pierce
Joseph Ribeiro
Harry Rougas
+Arthur R. Shorten
Richard F. Simpkin
Martin G. Smith
Harry H. Stanton
John K. Sweet, Jr.
William L. Sylvia, Jr.
Frank D. Tibbetts
Joseph Warecki
Ernest C. Wegman, Jr.
Stephen T. Wessling
+Ronald White
+Arnold A. Whitehouse, Jr.
+Michael J. Zukovich

Safety

Cyril L. Fennelly
Ann C. Henry



VICKY CULLEN

Bob Davis finishes fiberglass mold for specially-built instrument.

Services Personnel

Francisco D. Aguiar
Edgar L. Aiguier
Robert M. Alexander
Norman E. Anderson
James M. August
Karen H. Baker
Pamela R. Barrows
**Earle N. Black
Bruce A. Bowden
Richard J. Breivogel
Frederick V. Brown
Sandra J. Burt
Bernard J. Cassidy
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Porter A. Crouse
Judith O. Cushman
Frances L. Davis
Ruth H. Davis
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Catherine H. Ferreira
Steven R. Ferreira
David L. Fish
Victor F. Fontana
Elizabeth R. Fye
Irving A. Gaffney
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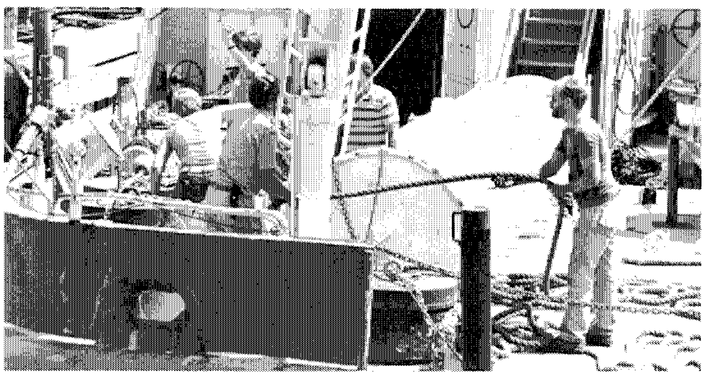
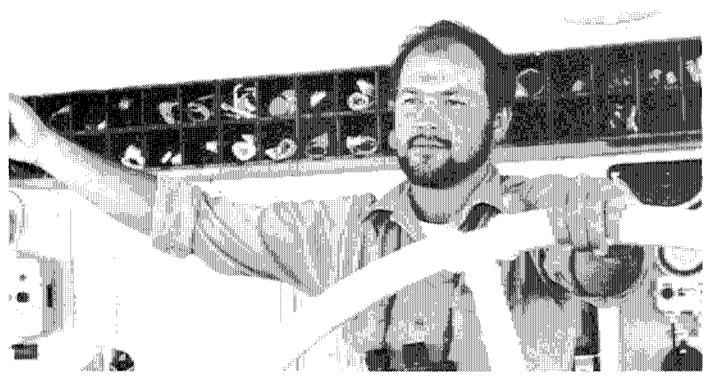
Eben A. Sage
Roland R. Simmons
Donald P. Souza
John W. Stimpson
James A. Swan
Jean D. Walker
Robert Wichterman
Ronald E. Woods
Jeffrey A. Zwinakis

#Disability Leave of Absence
+Leave of Absence
**Deceased, April 5, 1978



VICKY CULLEN

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



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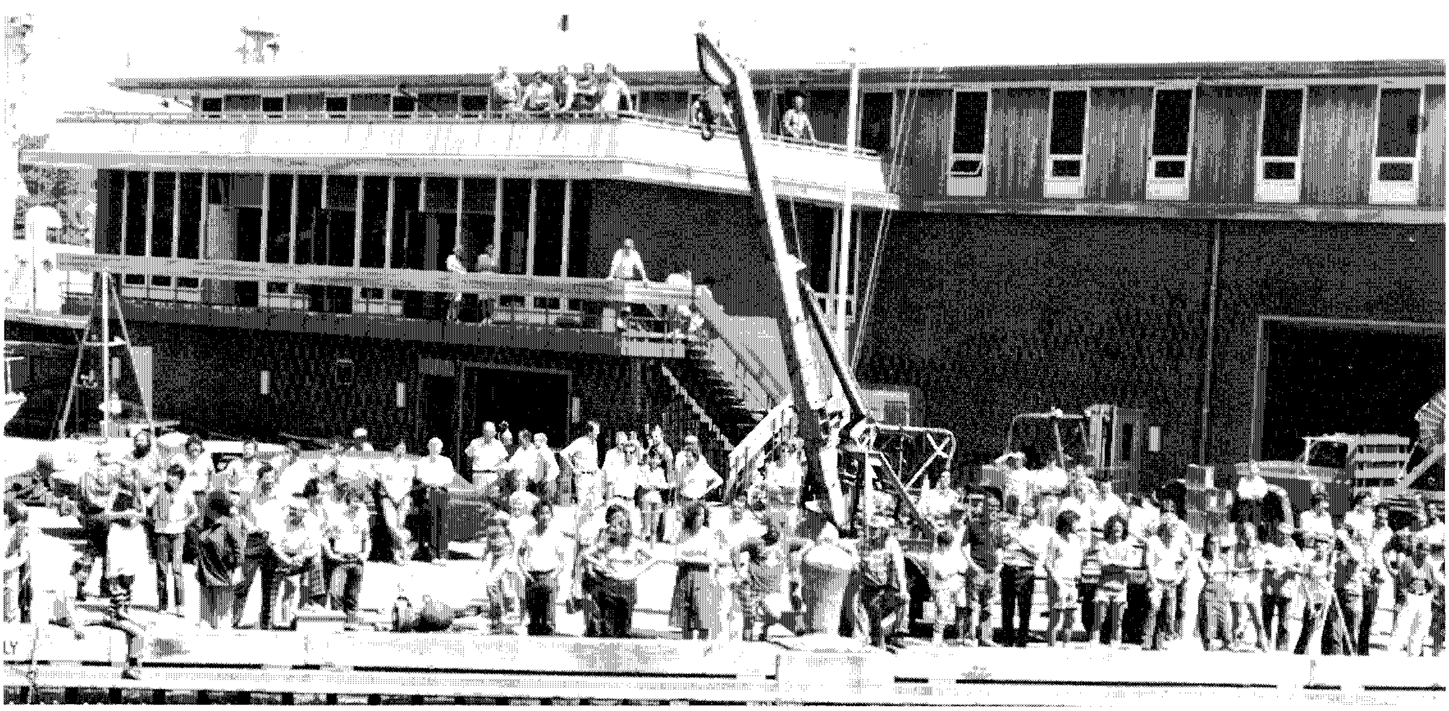
A.B. Larry Costello mans *A-II* wheel.



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Crowd gathered on pier in June to see *Atlantis II* off on Voyage #101.

Fellows, Students & Visitors

Postdoctoral Scholars 1978–79

Gayle A. Brenchley
Johns Hopkins University

James T. Carlton
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John J. Molongoski
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Anne M. Thompson
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Robert S. White
Cambridge University, England

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Marine Policy and Ocean Management 78–79

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University of Texas

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Per Magnus Wijkman
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James B. Zaitzeff
NOAA National Environmental Satellite Service

Woods Hole Doctoral Program 1978–79

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California Institute of Technology

M.I.T./W.H.O.I. Joint Graduate Program 1978–79

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Erika Faulk
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Alvin L. Jones
Elizabeth City State University
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David Hart
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Cynthia R. Wigley
Colby College

Kristina M. Wood
Boston University

R/V Atlantis II

Total Nautical Miles for 1978 — 27,650
Total Days at Sea — 226

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

R/V Knorr

Total Nautical Miles for 1978 — 34,813
Total Days at Sea — 278

Voyage	Cruise Period	Principal Objectives, Area of Operations	Port of Call	Chief Scientist
73-Ia	28 Jan–3 Feb	Dump site studies off Puerto Rico	San Juan, Puerto Rico	Meyer (NOAA)
73-Ib	4 Feb–10 Feb			
73-II	11 Feb–16 Mar	Organic chemical-biological studies in the Peru upwelling zone	Balboa, Canal Zone Callao, Peru	Gagosian
73-III	20 Mar–31 Mar	Study of nitrogen cycle in water and sediment in an upwelling area and microbiological studies in the Eastern Equatorial Pacific	Callao, Peru	Watson
73-IV	6 Apr–9 May	Study of a low geothermal heat flow region west of the East Pacific Rise	Honolulu	Von Herzen
73-V	15 May–13 Jun	Current and density structure measurements in the Gilbert Island area	Kwajalein Atoll, Marshall Islands	Eriksen (MIT)
73-VI	19 Jun–13 Jul	Artificial radionuclide studies around the U.S. Pacific Ocean nuclear test site	Kwajalein Atoll	Noshkin (L.L. Lab)

73-VII	19 Jul–30 Aug	Chemical studies in the Southwest Pacific including interstitial chemistry, photo chemistry, 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 73-X	18 Sep–9 Oct 13 Oct–5 Nov	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-XI	12 Nov–9 Dec	Study of the dynamics of eddies and of interleaving water masses and their effects on mean circulation in the Southern Ocean	Christchurch	Bryden
73-XII	15 Dec–(13 Jan)	Coring and *in situ* interstitial water studies in the South Pacific and Antarctic waters	Wellington, New Zealand	Sayles

R/V Oceanus

Total Nautical Miles for 1978 — 34,577
Total Days at Sea — 238

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

52-II	29 Oct–8 Nov	Biological studies and sampling in the Eastern North Atlantic and Equatorial Atlantic	Dakar, Senegal	Madin
52-III	10 Nov–23 Nov		Recife, Brazil	Madin
52-IV	28 Nov–21 Dec	Physical oceanography study of the movement of the Atlantic bottom water between North and South Atlantic in the Western Basin	Woods Hole	Worthington Whitehead

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.

Total Nautical Miles for 1978 — 15,830
Total Days at Sea — 173
Total Dives — 81

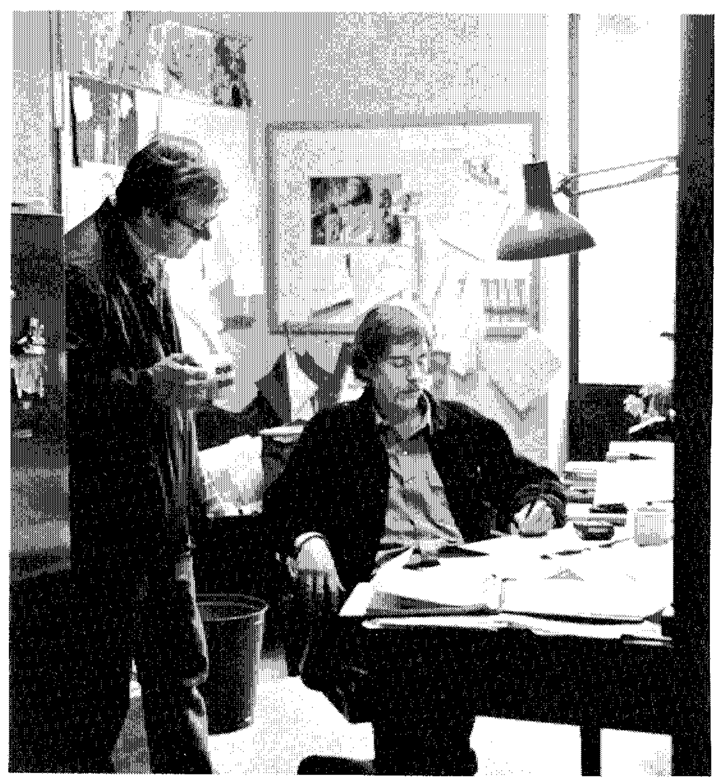
Lulu Voyage	*Cruise Period*	*Principal Objectives, Area of Operations*	*Port of Call*	*Chief Scientist*
97	6 Jan–24 Mar	Newport, RI, Shipyard		
	2 May	Test dive in Woods Hole Harbor		
98-I	5 May–14 May	Transit	Andros Island, Bahamas	
98-II	16 May–18 May	3 dives in Tongue of the Ocean for training, testing, and certification of *Alvin*	Andros Island	Shumaker
98-III	21 May–23 May	2 dives (#800 and #801, the latter for 4,000-meter certification) for training and testing in Tongue of the Ocean	Andros Island	Shumaker
98-IV	23 May–5 Jun	5 dives for shelf transport research off Cape Hatteras	Norfolk	Rona (NOAA)
98-V	6 Jun–15 Jun	5 dives to study slump physiography in Norfolk and Baltimore canyons	Woods Hole	Malahoff (NOAA)
99-I	20 Jun–1 Jul	6 dives for radioactive waste studies and waste drum recovery at New York Bight dump site	Woods Hole	Jannasch Dyer (EPA)
99-II	4 Jul–6 Jul	Deep Ocean Stations 1 and 2 (dives weathered out)	Woods Hole	Jannasch
100-I	13 Jul–25 Jul	Transit	Ponta Delgada, Azores	
100-II	27 Jul–5 Aug	5 dives to study tectonic structure of the FAMOUS Rift Valley	Ponta Delgada	Atwater (MIT)
100-III	10 Aug–28 Aug	10 geological and geophysical dives on the Mid-Atlantic Ridge	Ponta Delgada	Atwater (MIT)
100-IV	30 Aug–13 Sep	Transit	St. Georges, Bermuda	
100-V	14 Sep–19 Sep	2 dives to Deep Ocean Stations 1 and 2 to study boring and fouling molluscs	Woods Hole	Jannasch
101	22 Sep–1 Oct	6 dives in Oceanographer Canyon for biological and geological studies	Woods Hole	Cooper (NOAA)
102-I	21 Oct–25 Oct	Transit	Charleston	
102-II	26 Oct–30 Oct	1 dive on Continental Shelf for instrument recovery	Freeport, Bahamas	Webb
102-III	31 Oct–6 Nov	7 dives in the Northwest Providence Channel for deep carbonate bank margin work	Andros Island	Neumann (U. of N.C.)
102-IV	8 Nov–13 Nov	5 dives in Tongue of the Ocean to study benthic populations	Andros Island	Grassle
102-V	15 Nov–22 Nov	7 dives in the Northeast Providence Channel to study erosion and carbonate deposits	Nassau	Schlager (U. of Miami)
102-VI	25 Nov–10 Dec	9 dives in the Northeast Providence Channel to investigate benthic communities	Roosevelt Roads, Puerto Rico	Ryan (LDGO)
102-VII	13 Dec–14 Dec	1 recovery dive for U.S. Navy in St. Croix range	Roosevelt Roads	Williams
102-VIII	14 Dec–21 Dec	6 biology dives; establishment of new bottom station in St. Croix Channel	Roosevelt Roads	Turner (Harvard)


JOHN DUNLAP

Many willing hands haul in the absolute velocity profiler after data recording trip to the depths.


VICKY CULLEN

Nick Fofonoff in his Clark Laboratory office.


VICKY CULLEN

George Tupper, left, and Jim Luyten discuss buoy work.

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Listing as of 31 December 1978

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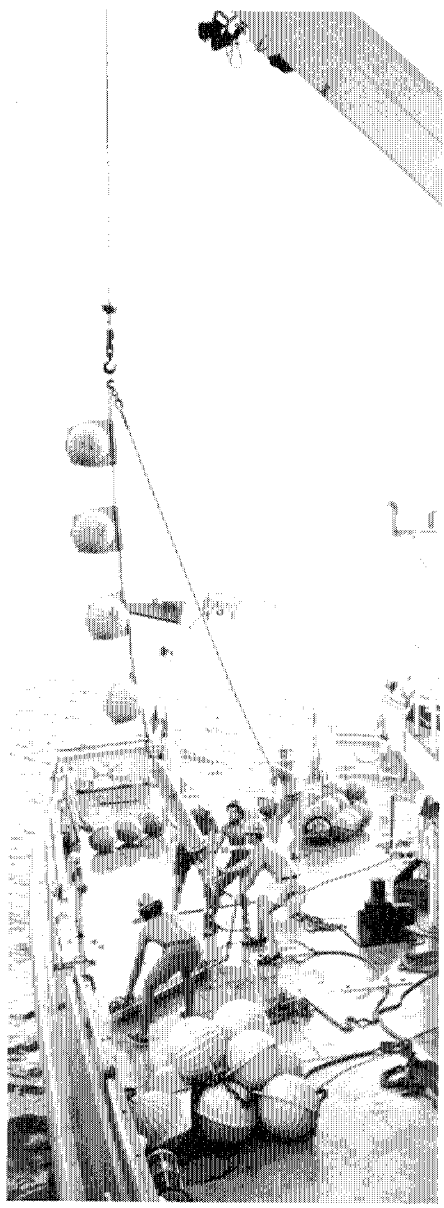
Night net haul comes aboard *Oceanus*.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Current meter string is hauled on *Oceanus* deck.

Financial Highlights

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:

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

Other statistics of interest are:

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

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

Report of the Certified Public Accountants

To the Board of Trustees of Woods Hole Oceanographic Institution:

We have examined the balance sheets of Woods Hole Oceanographic Institution as of December 31, 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

Balance Sheets: December 31, 1978 and 1977

	1978	1977
ASSETS		
Current Fund Assets (Note A):		
Cash	$ 188,742	$ 145,653
Short-term investments, at cost which approximates market	3,305,000	1,720,000
Reimbursable costs:		
Billed	1,410,323	1,956,027
Unbilled	1,486,109	1,583,865
Deferred charges supplies and prepaid expenses	704,333	708,800
Due to plant fund	(1,089,330)	(1,021,683)
Due (to) from endowment and similar funds	(1,622)	21,848
	6,003,555	**5,114,510**
Endowment and Similar Fund Assets (Notes A and B):		
Separately invested, at market	17,184,372	17,318,424
Pooled investments, at market	17,913,674	17,983,766
Accounts receivable – sale of investments	8,454	
Due (to) from current fund	1,622	(21,848)
	35,108,122	**35,280,342**
Annuity Fund Assets (Note A):		
Investments, at market (cost $73,654 in 1978 and $67,584 in 1977)	73,275	65,520
Cash	1,654	9,972
	74,929	**75,492**
Plant Fund Assets (Note A):		
Land, buildings and improvements	15,551,647	15,388,310
Vessels and dock facilities	7,176,910	7,105,346
Laboratory and other equipment	2,609,471	2,121,047
	25,338,028	24,614,703
Less accumulated depreciation	7,813,104	7,148,304
	17,524,924	17,466,399
Due from current fund	1,089,330	1,021,683
	18,614,254	**18,488,082**
	$59,800,860	**$58,958,426**
LIABILITIES AND FUND BALANCES		
Current Fund Liabilities and Balances:		
Accounts payable and other accrued expenses	$ 922,707	$ 864,787
Accrued vacation	787,962	706,179
Deferred revenue	601,184	54,967
Unexpended balances of restricted funds	1,519,715	1,414,750
Unrestricted balances designated for:		
Income and salary stabilization	1,941,446	1,786,141
Working capital and contingency	97,575	116,211
Ocean industry program	132,966	171,475
Total unrestricted balances	2,171,987	2,073,827
	6,003,555	**5,114,510**
Endowment and Similar Fund Liabilities and Balances:		
Accounts payable – purchase of investments	74,780	
Endowment:		
Income restricted	20,587,010	20,765,975
Income unrestricted	2,725,366	2,714,869
Term endowment	3,391,914	3,405,166
Quasi-endowment:		
Restricted	5,349,861	5,370,764
Unrestricted	2,979,191	3,023,568
	35,108,122	**35,280,342**
Annuity Fund Liabilities and Balance:		
Annuities payable	29,065	30,331
Fund balance	45,864	45,161
	74,929	**75,492**
Plant Fund Balances:		
Invested in plant	17,524,924	17,466,399
Unexpended:		
Restricted	176,056	195,219
Unrestricted	913,274	826,464
Total unexpended balances	1,089,330	1,021,683
	18,614,254	**18,488,082**
	$59,800,860	**$58,958,426**

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

Revenues	**1978**	**1977**
Sponsored research:		
Government	$22,411,236	$19,894,748
Nongovernment	2,512,083	1,673,916
	24,923,319	21,568,664
Education funds availed of	953,367	962,870
Total restricted	25,876,686	22,531,534
Unrestricted:		
Fees	194,291	257,272
Endowment and similar fund income	465,916	447,128
Gifts	420,028	606,401
Tuition	296,156	262,928
Other	517,382	305,493
Total unrestricted	1,893,773	1,879,222
Total revenues	**27,770,459**	**24,410,756**
Expenses and Transfers		
Sponsored research:		
Salaries and fringe benefits	7,525,727	6,574,110
Ships and submersibles	5,448,887	5,409,160
Materials and equipment	5,365,035	4,030,287
Laboratory overhead	1,545,853	1,336,920
Other	2,055,420	1,595,999
	21,940,922	18,946,476
Education:		
Faculty expense	257,790	224,779
Student expense	479,494	522,757
Other expense	109,235	116,524
	846,519	864,060
Unsponsored research and other activity	1,263,934	1,161,739
General and administrative:		
Allocated to sponsored research	2,982,397	2,622,188
Allocated to education	106,848	98,810
Allocated to unsponsored activity	192,279	99,196
	3,281,524	2,820,194
Total expenses	**27,332,899**	**23,792,469**
Nonmandatory transfers:		
To quasi-endowment fund	25,000	275,000
To plant fund, unexpended	314,400	275,000
Total expenses and nonmandatory transfers	**27,672,299**	**24,342,469**
Net increase in unrestricted current fund	**$ 98,160**	**$ 68,287**
Designated for:		
Income and salary stabilization	155,305	149,044
Ocean industry program	(38,509)	(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

	Current Fund						
1978	Restricted	Unrestricted	Total	Endowment and Similar Funds	Annuity Fund	Plant Fund	Total Funds
Increases:							
Gifts, grants and contracts	$24,701,796	$ 420,028	$25,121,824	$ 48,834		$ 75,000	$25,245,658
Endowment and similar funds investment income	1,280,268	465,916	1,746,184				1,746,184
Other		1,007,829	1,007,829		$ 703		1,008,532
Total increases	25,982,064	1,893,773	27,875,837	48,834	703	75,000	28,000,374
Decreases:							
Expenditures (including $501,863 of funded depreciation)	(25,876,686)	(1,456,213)	(27,332,899)			501,863	(26,831,036)
Depreciation (Note A)						(765,091)	(765,091)
Net decrease in realized and unrealized appreciation				(321,247)			(321,247)
Total decreases	(25,876,686)	(1,456,213)	(27,332,899)	(321,247)		(263,228)	(27,917,374)
Net change before transfers	105,378	437,560	542,938	(272,413)	703	(188,228)	83,000
Transfers — additions (deductions)	(413)	(339,400)	(339,813)	25,413		314,400	
Change in fund balance for the year	104,965	98,160	203,125	(247,000)	703	126,172	83,000
Fund balance December 31, 1977	1,414,750	2,073,827	3,488,577	35,280,342	45,161	18,488,082	57,302,162
Fund balance December 31, 1978	$ 1,519,715	$2,171,987	$ 3,691,702	$35,033,342	$45,864	$18,614,254	$57,385,162
1977							
Increases:							
Gifts, grants and contracts	21,453,339	606,401	22,059,740	186,588		50,000	22,296,128
Endowment and similar funds investment income	1,244,855	447,128	1,691,983				1,691,983
Other		825,693	825,693			7,544	833,237
Total increases	22,698,194	1,879,222	24,577,416	186,588		57,544	24,821,548
Decreases:							
Expenditures (including $441,737 of funded depreciation	(22,531,534)	(1,260,935)	(23,792,469)			441,737	(23,350,732)
Depreciation (Note A)						(704,965)	(704,965)
Other					(7,323)	(352)	(7,675)
Net decrease in realized and unrealized appreciation				(2,985,966)			(2,985,966)
Total decreases	(22,531,534)	(1,260,935)	(23,792,469)	(2,985,966)	(7,323)	(263,580)	(27,049,338)
Net change before transfers	166,660	618,287	784,947	(2,799,378)	(7,323)	(206,036)	(2,227,790)
Transfers — additions (deductions)	(5,143)	(550,000)	(555,143)	430,143		125,000	
Change in fund balance for the year	161,517	68,287	229,804	(2,369,235)	(7,323)	(81,036)	(2,227,790)
Fund balance December 31, 1976	1,253,233	2,005,540	3,258,773	37,649,577	52,484	18,569,118	59,529,952
Fund balance December 31, 1977	$ 1,414,750	$ 2,073,827	$ 3,488,577	$35,280,342	$45,161	$18,488,082	$57,302,162

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

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

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

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

Plant
Plant assets are stated at cost. Depreciation is provided at annual rates of 2% to 5% on buildings, 3⅓% on Atlantis II and 5% to 33⅓% on equipment. Depreciation expense on Institution-purchased plant assets amounting to $501,863 in 1978 and $441,737 in 1977 has been charged to operating expenses. Depreciation on certain government funded facilities (Atlantis II, Laboratory for Marine Science and the dock facility, amounting to $263,228 in each year) is accounted for as a direct reduction of the plant asset and invested in plant fund. Title to the research vessel Atlantis II is contingent upon its continued use for oceanographic research.

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

Reclassification of 1977 Balances
Certain balances in the 1977 financial statements have been reclassified to conform with the 1978 presentation.

B. ENDOWMENT AND SIMILAR FUND INVESTMENTS:

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

	December 31, 1978		December 31, 1977	
	Cost	Market	Cost	Market
Separately invested:				
Government and government agencies	$ 2,894,349	$ 2,652,250	$ 2,272,239	$ 2,213,000
Bonds	2,063,048	1,884,500	2,200,977	2,181,500
Common stocks	12,264,211	12,127,500	11,905,661	11,865,650
Savings deposits	524,267	524,267	1,052,200	1,052,200
Cash	46,099	46,099	6,074	6,074
Call options written	(41,225)	(50,244)		
Total separately invested	**$17,750,749**	**$17,184,372**	**$17,437,151**	**$17,318,424**
Pooled investments:				
Pool A				
Government and government agencies	2,079,711	1,957,250	1,598,363	1,575,000
Bonds	2,310,773	2,162,500	1,995,499	1,977,650
Preferred stocks	59,704	22,000	59,704	23,000
Common stocks	8,484,052	8,521,977	8,169,123	8,159,681
Savings deposits	28,115	28,115	970,295	970,295
Real estate	42,915	42,915	44,126	44,126
Cash	113,862	113,862	(385)	(385)
Other assets			7,000	7,000
Call options written	(29,112)	(36,006)		
	13,090,020	12,812,613	12,843,725	12,756,367
Pool B				
Government and government agencies	1,661,463	1,519,000	1,622,552	1,573,000
Bonds	1,370,298	1,253,200	1,070,448	1,040,000
Common stocks	2,299,094	2,310,100	2,202,812	2,162,650
Savings deposits	22,035	22,035	429,500	429,500
Cash	4,914	4,914	22,249	22,249
Call options written	(6,791)	(8,188)		
	5,351,013	5,101,061	5,347,561	5,227,399
Total pooled investments	**$18,441,033**	**$17,913,674**	**$18,191,286**	**$17,983,766**

C. POOLED INVESTMENTS UNITS:

The value of a pooled investment unit was as follows:

	Pool A	Pool B
December 31, 1977	$.8361	$.8373
December 31, 1978	$.8328	$.8147

The pooled investment income per unit was as follows:

	Pool A	Pool B
1977	$.0423	$.0426
1978	$.0410	$.0459

D. ENDOWMENT AND SIMILAR FUND INCOME:

Income of endowment and similar funds consisted of the following:

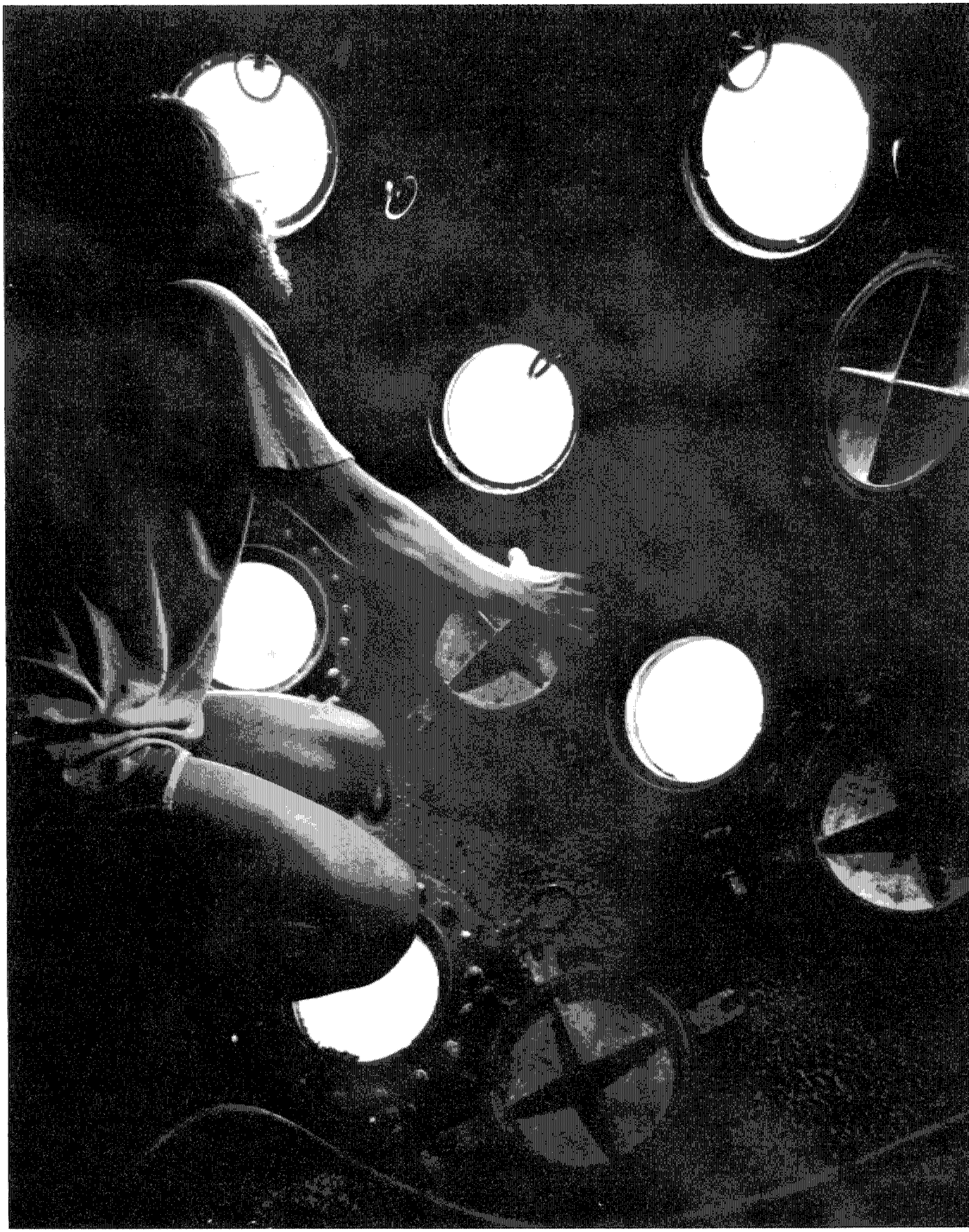
	1978	1977
Dividends	$ 866,912	$ 761,502
Interest	949,906	995,723
Other	2,994	3,479
	1,819,812	1,760,704
Investment management costs	(73,628)	(68,721)
Net investment income	$1,746,184	$1,691,983

E. RETIREMENT PLAN:

The Institution has a noncontributory trusteed retirement plan covering substantially all full-time employees. The Institution's policy is to fund pension cost accrued which includes amortization of prior service costs over a 30-year period. Retirement plan costs charged to operating expense amounted to $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.



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Bow chamber of *Atlantis II* provides marine life observation post.