1979
Annual Report
The Ecosystems Center

Marine Biological Laboratory
Woods Hole, Massachusetts
Pierce, Pierce, and Kramer's design for the new Ecosystems Center building. Construction will begin in fall of 1980.
Science And The Surge Of Conservatism

The industrialized nations have entered a new era of scarcity of all resources. This scarcity breeds inflation and the predictable reaction: a surge of conservatism, a return to basics, a look back at the old days and an attempt to restore them, an emphasis on the narrowest individual interests, on short-term profits, on private as opposed to public interests. The academic community, always the first to feel such swings, has been forced by the progressive restriction of budgets over a decade to prune, even to fell, whole programs. The net effect has been a retreatment parallel to the shift in political and economic perspectives, toward the traditional, the narrower interests, toward what worked in the past. Advice for the younger, the active mind, the vigorous intellect, anxious for approval and promotion, rules out the new ventures appropriate to the transition: “Shoemaker, stick to your last”.

The most important cause of the squeeze on resources is the unrelenting growth in numbers of people. This growth alone assures continued intensification in demand for all resources, an intensification that requires ever better management, better knowledge and more effective government. The alternative to intensified management was set forth lucidly by Garrett Hardin in 1968 in his essay The Tragedy of the Commons: pervasive impoverishment caused by the uncontrolled pursuit of individual profit at public expense.

The problems are immediate and global, a series of changes in the earth as a whole that can only make man’s lot more awkward. A man-caused increase in the CO₂ content of the atmosphere promises a global warming, with shifts in climatic zones over the next decades and a rise in sea level of 20 feet over a century or two; significant changes in the global circulation of nitrogen and sulfur will have biotic implications; toxic substances accumulate in the oceanic biota to the point of changing the biota itself; a global increase in the extinction of species with other parallel changes must be considered a trend toward the biotic impoverishment of the earth as a whole; the acidification of rain over large areas of the U.S. and Europe is having untold effects on plants and animals. The old shoes are clearly not good enough, comfortable though they may be.

The earth’s resources have limits that are now being pressed, even exceeded. The principles and processes that define these limits are the subject matter of ecology, the study of the “home” of life, the biosphere. To speed the development of this segment of science the Marine Biological Laboratory, with help from the scientific community and with financial support from major foundations and friends of the Laboratory, established a new institute of ecology, The Ecosystems Center, on January 1, 1975. Now, five years later, the Center has a staff of about 45, an annual budget of $1.3 million, and a vigorous program of research and education that is in the tradition of the MBL.

The special emphasis of the Center has evolved from the thesis that the biosphere can be interpreted as a set of interacting units. The units are segments of the surface of the earth: forests, lakes, streams, estuaries, oceans, islands, farms, cities or the earth as a whole. Each of these units is, above all, a biotic system. The subject of study is the structure, function, development, and interaction of these units. The approach includes the study of processes that are common to all such units — such as the fixation of carbon, the cycling of nutrients, the decay of organic matter.

The fact that the earth is unique in the solar system, confirmed by the remarkable data from the Space Program, reemphasizes that life is the dominate process in both the formation and continued maintenance of the biosphere. The concept that the biosphere is not only a past product of life but a continuing product of biotic processes whose function is now affected globally by man requires new approaches to science and to government. The Center is the Laboratory’s response to this new challenge.

The program has three segments: basic research, education, and, in recognition that basic science must not only be available to but systematically introduced into public affairs, a program on policy in management of resources. Details of this work are set forth below.

Despite the conservative mood of the nation and the retrenchment of academic enterprise, the Laboratory in 1980 is expanding in response to increased year-around activity, increased support for its programs, and continued vigor in the summer program. To accommodate our needs for space, the Fleischmann Foundation has recently granted funds to renovate the Homestead House and to construct a new two-story laboratory building adjacent to it on the MBL Quadrangle. Plans are developing rapidly and construction will begin in the fall of 1980.

The wave of conservatism that has engulfed us all is reason enough to reject the advice to the shoemaker, to ask new questions, and to build new lasts. Special strength will be required in the academic community in the next years to keep sufficient insights flowing, sufficient innovation before us all, and sufficient vigor to lead aggressively in the extraordinary advancements that must come in basic knowledge and in use of that knowledge in human affairs. The MBL, now in its 93rd year, is rapidly gaining additional strength in its new role as a year-around center of research and teaching and seems especially well poised to meet the demands on science that this era of scarcity promises. We have summarized in the following pages some of the questions the staff of the Ecosystems Center is asking at the moment and how we go about answering them.

December, 1979
George M. Woodwell
Director
Figure 1. The biotic systems that have built and now maintain the biosphere also influence the cycles of carbon, nitrogen, sulfur, and other elements. The general pattern of movement is a series of exchanges between the atmosphere, the land, and the sea. Human activities worldwide have mobilized significant additional quantities of biotically important substances, including toxins, and have modified the natural cycles.
I. The Ecosystems Center

What are the limits of resources? How can predictions be developed that offer a reasonable basis for anticipating the rate of accumulation of CO₂ in the atmosphere? What are the changes in nutrient content of streams and estuaries following disturbance and the effects of these changes? What are the limits of biotic systems? What are the processes that unify these systems? How can these processes best be interpreted for use in management? What are the elements of the scientists’ model of environment?

These are some contemporary challenges for ecology — urgent, complex and demanding. They are obviously beyond the reach of any single scientist or institute, but they are real, and they have strongly affected our choices in developing the program of the Ecosystems Center.

The Center was founded in 1975 to encourage basic research in ecology, to strengthen the educational program of the Laboratory, and to seek ways to improve the application of science to human affairs. The activities often blend these three objectives. For instance, the role the biota plays in affecting the CO₂ content of the atmosphere is a major topic of research, was the subject of a week’s attention in the January Course of 1979, and is the subject of two sets of Congressional hearings and other governmental activities in which the Center’s contributions have been important.

The research demands detailed knowledge of major processes, including the cycling of carbon and other elements in both the terrestrial and marine systems. Forests are sufficiently important in the world carbon cycle that any policy designed to mitigate the effects of increased CO₂ in the atmosphere must be based in part on a program of management of the world’s forests. The work is being expanded through a joint proposal with General Electric Corporation, now before the U.S. Department of Energy, and the National Aeronautics and Space Administration (NASA). The proposal is for detailed measurements by satellite imagery of current and recent changes in the vegetation of the earth as a whole, a study that will have ramifications beyond the work on carbon. Those processes that control the photosynthetic fixation of carbon not only affect the carbon cycle but determine the water quality of rivers and the rates of forest regrowth or other vegetation following disturbance.

The staff of the Ecosystems Center has made progress recently in defining the cycle of nitrogen in salt marshes and in temperate zone forests. Work in such dissimilar communities as New England forests, Arctic tundra, and Cape Cod marshes has demonstrated the competition for nitrogen between the primary producers of organic matter and the microbes that decompose that material and provide the source of energy for detritus food chains.

Studies of the cycling of sulfur in coastal marshes have shown that transformation of sulfur compounds absorbs a major fraction of the energy budget of a salt marsh. The products of the oxidation of organic matter by sulfate ions are reduced sulfur compounds rich in energy. Research at the Center is currently examining the importance of these compounds in marsh metabolism. The extent to which coastal marshes are sources of gaseous sulfur compounds is also important in defining the sources of acid precipitation. The biotic processes that are significant in the functioning of such ecosystems are those that determine under many circumstances the quality of air and water. The global cycling of carbon, nitrogen, sulfur, and other biologically important substances is shown diagrammatically in Figure 1. Research at the Center is concerned with measuring, or determining the factors that control, these cycles.

The Program in Policy draws on staff members from the Center, on other scientists from the Woods Hole scientific community, and on other persons to address issues in management of resources with special emphasis on the coastal zone. The program has been supported over the past year with two special grants, one from the Schermer Foundation and one from the Ford Foundation.

The Program in Education is in the longstanding tradition of the Marine Biological Laboratory that research and education proceed together.
II. The Research Program

The Global Carbon Cycle

The CO₂ content of the air reached about 334 ppm during 1979. The rate of increase is about 1.5 ppm annually and this rate appears to be increasing at 3 to 4% per year. The continued increase is expected to lead to a warming of the earth over the next decades. The warming will cause a poleward migration of the climatic zones of the earth, a displacement of agriculture, and a rise in sea level of as much as 20 feet over the course of a century or so. Such climatic changes are expected to be apparent within the next 20 years, certainly early in the next century.

The source of the CO₂ that is accumulating in the atmosphere is a combination of the combustion of fossil fuels and the destruction of forests (Figure 2). The extent to which the transformation of forests is contributing to the CO₂ problem has been the subject of considerable work within the Center over the past several years. The approach has been through a very detailed review of the world literature on changes in the area of forests. Forests are important because they contain approximately the same amount of carbon in their standing crop as is contained in the atmosphere. If we add the organic matter held in soil humus, the total carbon associated with forests is three or four times the amount held in the atmosphere.

The transformation of forests into agricultural or grazing lands is occurring worldwide but is especially important in the tropics. It results in a release of carbon into the atmosphere that may be as large as the approximately 6 billion metric tons released annually through the combustion of fossil fuels. The analysis is sufficiently complex that progress depends on use of mathematical models. An extensive review of the literature combined with modelling has confirmed that there is a significant release of carbon from the biota (Figure 3). Efforts are continuing to bring a higher degree of resolution into the analysis.

During the spring of 1979 the Center arranged and held in Woods Hole an international conference on the world CO₂ problem. The objective was an examination of the question of how remote sensing can be used to measure changes in the vegetation of the earth. The conference was supported by the Department of Energy, the Exxon Corporation and the Center, and was arranged under the auspices of SCOPE, the Scientific Committee on Problems of the Environment of the International Council of Scientific Unions. The conclusion was that satellite imagery is most appropriate and that a pilot study should be conducted.

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Research on Coastal Ecosystems

Staff of the Center has made a series of advances in the past several years in defining the role of estuarine marshes as units of the biosphere. Special attention has been given to the primary productivity of marshes and to various aspects of the carbon cycle in marshes. This work has led to still further questions with special emphasis on transformations of sulfur, nitrogen and dead organic matter or detritus. The work on sulfur is especially important because transformations of sulfur account for a large fraction of the total energy flux in salt marshes and because the releases of sulfur-containing compounds into the atmosphere contribute to the acidification of rain. The nitrogen cycle is both compli-
icated and important, since it is intimately involved in virtually all aspects of plant and animal growth. Finally, detritus is the basis of complex food webs in marshes and supplies energy for many of the biotic and chemical functions of estuaries. Staff of the Center currently has several complementary research projects covering aspects of these topics underway in marshes. These are described below.

**Sulfur in Estuarine Marshes**

The research has two parts. The first is a detailed investigation of sulfate reduction in marsh sediments and of the movement and chemical transformation of reduced compounds within the marsh. The second is a net input-output budget for the ecosystem, including exchanges of both oxidized and reduced forms of sulfur with the ocean and with the atmosphere (Figure 4).

![Figure 4. The Global Sulfur Cycle. The role of the biota in this cycle is typified by the transformations of sulfur that occur in a salt marsh. Sulfate enters the marsh on flood tides, is reduced, and leaves the marsh through atmospheric or tidal exchanges.](image)

The annual cycle of sulfate reduction in the *Spartina alterniflora* peat has been measured by a 35/S-sulfate radioactive tracer technique. Sulfate-reducing bacteria use the low molecular weight organic compounds produced by fermentative bacteria, and the net overall reaction is the breakdown of 2 moles of organic carbon for each mole of sulfate reduced. The amount of sulfate reduced is about 2400 grams of sulfur per square meter per year, an amount sufficient to account for the decomposition of the total annual below-ground production of roots and rhizomes of Spartina.

Much of the sulfate that is reduced becomes pyrite. However, the pyrite does not accumulate and substantial quantities of soluble or volatile sulfides (hydrogen sulfide, thiosulfate, polythionates, organic sulfides), sulfate, or other sulfur compounds must be leaving the peat.

The sulfur released to the atmosphere is being measured in wind tunnel chamber experiments. The measurements are in their first year, so an annual total cannot be estimated, but the major forms of sulfur emitted are dimethyl sulfide, hydrogen sulfide and several other volatile organic sulfur-containing compounds. The fluxes to the atmosphere have decreased dramatically from August through October, perhaps because of decreasing temperature or the senescence of the higher plants.

The other major exchange of sulfur is caused by the tidal waters that flush the marsh daily. The water is high in sulfate, assuring that sulfate does not limit decomposition. As the tide retreats, a fraction of the interstitial pore waters from the Spartina zone drains out of the peat and mixes with the receding waters. These pore waters are high in reduced sulfur compounds such as H₂S and thiosulfate, and on each tide there is a measurable export of these energy-rich substances. In contrast to the atmospheric releases, the tidal exports have increased by several-fold during the period from August through October.

The sulfur brought in by both precipitation and groundwater appears to play a minor role in the marsh sulfur cycle.

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**Decomposition of Organic Matter**

Most of the energy or carbon that is fixed in photosynthesis is not consumed directly by animal populations but enters a complex and poorly known series of decay processes sometimes called the decay food chain. When decomposition is slow, organic matter and nutrients accumulate and have profound effects on the physical, chemical and biotic processes in any ecosystem. In this work we are attempting to learn more about the factors that control the processes of decay in nature. The work is being done in Greater Sippewissett Marsh because the decay food chain is extremely important in marshes and because much is known about this marsh from previous studies. The salt marsh offers an additional advantage in that the principal source of fixed organic matter is a single plant species, *Spartina alterniflora*, a grass.

The research is being done jointly with scientists from Boston University, the Woods Hole Oceanographic Institution and the Ecosystems Center. Staff of the Center is especially concerned with the influence of microbial populations on decay.

The first step was to develop a technique to determine the bacterial mass. The technique used was direct counts with acridine orange and the epi-illuminated fluorescent microscope. The measurements showed that bacterial populations increased rapidly on litter in the marsh, up to 4 x 10¹⁰ cells per gram dry weight of litter, and then remained constant for the next ten months.

There is a clear need for direct measurements of metabolic activity as well as counts of bacteria in the field, but any such measurements must apply to both aerobic and anaerobic conditions and must be accurate under the full range of field conditions. The measurement of biomass appears not to be a good index of metabolic activity, because the metabolism obviously varied over the ten-month period. Parallel measurements of fungal hyphae are difficult,
but the evidence available indicates that biomass of fungi is also an inadequate basis for appraising rates of decomposition. One method that shows promise for measurement of activity is a determination of the turnover of glucose using $^{14}$C (Figure 5). Tracer quantities of $^{14}$C glucose are incubated with sediment and the rates of removal of the labeled glucose are determined. Our early studies show changes in activity that were not reflected in the measurements of microbial mass. We are now exploring the implications of the new technique, which appears to be very sensitive, for measurement of metabolic activity in sediments.

The evidence at the moment is that, while microbial populations may remain large over long periods, their presence does not reflect continuous metabolic activity or effectiveness in decay. We are continuing the search for indices of activity that will be useful under field conditions.

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Nitrogen Uptake and Growth

*Spartina alterniflora* is the dominant vascular plant of salt marshes on the Atlantic coast and contributes the largest fraction of fixed carbon and energy that is available to higher trophic levels. The highest growth rates of Spartina occur nearest creek banks. The differences in growth are due to environmental factors; no genetic differentiation has been found within the marsh. Spartina plants farthest from the creek banks are normally dwarfed, but when nitrogen fertilizer is added their growth increases. Creekside plants show little or no response to fertilization. Inorganic nitrogen is abundant in the pore water in all areas of the marsh and we have observed a net export of inorganic nitrogen to the coastal waters during the growing season at the time when marshes might be expected to be absorbing nitrogen if plant growth were nitrogen-limited. These observations led to an experiment designed to allow measurement of the efficiency of nitrogen uptake by Spartina.

Rates of nitrogen uptake were measured in cultures of Spartina growing outdoors in continuously-flowing nutrient solutions. A Michaelis-Menten model described the nitrogen uptake rates of Spartina better than several other models tested (Figure 6). The half saturation constants were determined as $0.057 \pm 0.016$ mg N for ammonium NH$_4^+$ and $0.124 \pm 0.034$ mg N per liter for NO$_3^-$. Although Spartina growth is enhanced by fertilization with nitrogen in the field, the natural concentration of inorganic NH$_4^+$ in the marsh pore water is very high in comparison to the half-saturation constants measured in this experiment and would be sufficient to support the maximum production of hydroponically grown plants. This suggests that the N-uptake kinetics of Spartina in the marsh may be modified by factors common to the marsh and uncommon to the hydroponically grown plants. Edaphic conditions in the marsh that can modify nutrient uptake kinetics include a depletion of oxygen in the soil, the presence of metabolic poisons like H$_2$S, or competition with NH$_4^+$ for membrane carriers from cations such as Na. Any of these conditions could increase the half-saturation constant and reduce the efficiency of nitrogen uptake by Spartina in the field.

A model of photosynthesis was developed and used to examine mechanisms by which nitrogen supply affects plant growth. The model was used to predict the rate of photosynthesis on the basis of several independent variables: temperature, sun angle, nitrogen content of leaves, fraction of leaf tissue living, light intensity, total aerial biomass, and total live biomass. Model predictions of total plant production were within one standard error of those observed in all cases and indicate that the leaf-weight-specific assimilation rates were not sensitive to the range of leaf-nitrogen concentrations, 1 to 4% by dry weight, observed in this work.

The distribution of photosynthetic between photosynthetic and non-photosynthetic tissue was the most important process affecting net production. Nitrogen supply did not affect rates of photosynthesis per se, but affected the relative production of roots and shoots. As nitrogen became more limited, shoot production became more limited as well.

This work is opening several new channels for examining the complex of processes that jointly affect the structure and metabolism of salt marshes.

Investigator:
James T. Morris
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Drainage Basins

The long-term challenge is the development of a systematic approach toward the prediction of water quality based on the sum of activities in the drainage basin.

The staff has addressed this series of problems in the North River drainage, a 100-square-mile basin north of Plymouth, Massachusetts. The North River is attractive because it has been the site of an extensive series of studies of land use and population distribution by staff and students of the Graduate School of Design at Harvard University. The Center's work is basic to a larger study of the entire drainage basin and is designed to provide information on the biotic transformations of nitrogen in freshwater marshes. This emphasis is based on the recognition that changes in land or water use in the basin will appear early as changes in the nitrogen budget of the aquatic system.

Sewage treatment facilities in the drainage basin now provide the largest input of dissolved inorganic nitrogen, a major plant nutrient that, when present in excess, leads to the degradation of aquatic habitats. A study by staff of the Center has shown that most of this dissolved inorganic nitrogen is removed from the river as it flows past a freshwater marsh. The objective of our current work is to determine the fate of this nitrogen and to measure the capacity of the marsh for removing it. We are studying several processes that dominate the nitrogen cycle in the North River: nitrogen assimilation by the marsh plants, decomposition of organic matter, nitrogen transformations within the sediments, and the exchange of nitrogen across the sediment-water interface (Figure 7).

The study site has been carefully chosen to offer the greatest possibility for resolving this central question. It contains over 60 species of higher plants, including a zone dominated by Zizania aquatica (wild rice), a zone dominated by Typha latifolia (the cattail) that includes Carex sp. (a hedge) and Calamagrostis sp., (a grass) and a zone in which the shrubs Rosa sp., Spiraea tomentosa, and Viburnum dentatum share dominance (Figure 8).

Approximately eight tons of dissolved organic nitrogen enters the head of this marsh during the summer months while about 0.9 ton leaves the marsh. Nitrogen uptake by the plant community accounts for most of the seven tons of nitrogen lost from this section of the river. The annual net aboveground plant production in the marsh is about 800 grams of dry organic matter per square meter per year or $2.9 \times 10^2$ tons for the entire marsh.

The decomposition of organic matter in the sediments releases nitrogen in both organic and inorganic
The inorganic nitrogen can be assimilated directly by higher plants or may diffuse from the sediments into the river where it is used by phytoplankton. The organic nitrogen can also be assimilated, following its mineralization to inorganic nitrogen, or can diffuse from the sediments and be exported downstream in the river. The retention of nitrogen within the sediments and exchanges with the flood water is a function of sediment type, time, and the magnitude of the flow of water.

These studies will be used as the basis for a far more comprehensive approach to the biogeochemistry of the drainage basin.

Investigators:
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The Cycling of Nutrients on Land

Severe disturbance of terrestrial plant communities has been shown to produce a rapid release of nutrients into the ground water or into surface runoff. Losses of nitrate are especially conspicuous because they cause eutrophication downstream.

A study of the processes that control nitrogen retention in disturbed ecosystems was carried out in 20 forest sites throughout the United States. Forest floor, soil, and lysimeter leachate samples were collected in well replicated trenched (all roots cut, vegetation regrowth prevented) and control plots in each site. The samples were analyzed for ammonium, nitrate, and organic nitrogen. Responses to trenching ranged from sites having no detectable differences between trenched and control plots (soils or lysimeters) to sites having nitrate losses from trenched plots of up to 2150 µeq per liter (See Table 1).

Four processes were identified as being capable of either delaying or preventing solution losses of nitrate from the trenched plots: nitrogen uptake by regrowing vegetation, nitrogen immobilization, lags in nitrification, and a lack of water for nitrate transport. The net effect of all these processes, except uptake by regrowing vegetation, is insufficient to prevent or delay losses from relatively fertile sites, and hence such sites have the potential for very high nitrate losses following disturbance.

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* Trenched plots were placed in several different communities within one watershed, and responses to trenching differed in the different communities.

Decomposition of Leaf Litter

Factors controlling leaf litter decomposition were studied in three sets of experiments. In the first experiment we examined the effects of initial nitrogen and lignin contents of six species of hardwood leaves on their decomposition dynamics using litter-bag techniques in the field. Rate constants (k values) for annual weight loss ranged from 0.08 to 0.47, and were highly correlated \( r^2 = -0.89 \) with the ratio of initial lignin to initial nitrogen concentrations (Figure 9). Decomposition dynamics were described by an inverse-linear relationship between the percentage of original weight remaining and the nitrogen concentration in the residual material. Initial lignin concentration was highly correlated \( r^2 = 0.93 \) with the slope of the inverse-linear relationship for each litter type, an expression of the efficiency of substrate utilization by mi-
In the second experiment, we examined the influence of initial nitrogen concentration and various levels of exogenous nitrogen on the decomposition of *Spartina patens* using a batch culture technique in the laboratory. Treatments were: (1) different initial nitrogen concentrations without emendations, (2) same initial nitrogen concentration with three levels of nitrogen emendation. The rate of decomposition is positively correlated with initial nitrogen concentration. Enrichment of the batch cultures with ammonium produced a significant increase in decomposition rate. As with the forest leaf-litter, the decomposition of Spartina litter can be described as an inverse-linear function with correlation coefficients ranging from -0.85 to -0.99.

In the third experiment, we examined the influence of various combinations of exogenous nitrogen and phosphorus on the decomposition of *Typha latifolia* leaf litter. Nitrogen was shown to control decomposition dynamics except when nitrogen was present in very high concentrations relative to phosphorus. By pooling the results of experiments 2 and 3, the decomposition rate \( k \) can be predicted from the initial lignin to nitrogen ratio.

### Wood Decomposition in the Forest Ecosystem

The nutrient dynamics of wood decomposition in forest ecosystems remain largely unstudied despite the fact that the large size of the woody component, with its wide carbon-to-nitrogen ratio, would suggest an important role for decomposing woody material in the organic matter and nutrient budgets of forests.

Two experiments were performed to investigate whether woody residues serve as a substrate for the microbial immobilization of external nitrogen during their decomposition. In the first experiment, the bulk densities sampled from a forest in central Massachusetts were determined. While an inverse linear relationship between original biomass remaining (\%) and nitrogen concentration of the remaining residue (\%) has been demonstrated with high correlation for a variety of plant tissues, our birch data yielded an \( r^2 \) of 0.32. A comparison of our data with a power equation representing no net change in total nitrogen content through time \( (Y = 18.20X^{-1}) \) and another hypothetical equation \( (Y = 11.48X^{-1}) \) suggests that with the exception of an initial nitrogen loss phase, probably due to retranslocation or leaching, the total nitrogen content of birch logs does not change over the course of the decomposition process studied. Pin cherry samples from a northern hardwood stand in New Hampshire yielded nearly identical results.

In a second experiment, the organic matter and nitrogen dynamics of decomposing, fragmented wood in mesh bags are being examined in a field study. The effects of increased nitrogen availability (induced by a trenched plot), soil horizon (litter layer, forest floor), fragment size (four classes), and time on these processes will be determined. Data from the first eight months of this study does not allow us to discern the individual effects of each of these variables, but all groups of bags showed significant increases in total nitrogen content and decreases in weight, indicating a net immobilization from the soil environment during decay (Figure 10).

The combined results of these experiments suggest that the physical size, structure, and spatial orientation of decomposing birch logs in forest systems may all be important factors in preventing the immobilization of external nitrogen sources during early stages of decay, while the incorporation of fragmented, woody residues into the soil in later stages (20% biomass remaining) may result in a substantial net quantity of nitrogen immobilized.

### Investigators:

**J. M. Melillo**
The Ecosystems Center
**K. N. Eschlen**
**J. D. Aber**
The Ecosystems Center
University of Wisconsin
Studies of Arctic Ecosystems

The Arctic, with its short growing season, limited flora and fauna, wide range of physical and chemical conditions, and apparent simplicity of biotic structure offers opportunities that do not exist elsewhere for analyses of questions in ecology. Most biotic activity is compressed into a short period of three months or less on the North Slope of Alaska. Simultaneously the area is being exploited for oil and other resources, and there is a new series of questions about how renewable resources can best be preserved. These most practical objectives combined with the unusual opportunities for examining the details of structure of nature under conditions that are not encountered elsewhere have given impetus to detailed studies of Arctic ecosystems. The staff of the Center have been involved in these studies over more than a decade and continue to find new insights into ecology through this work.

Arctic Ponds and Streams

Two studies of freshwater systems in the Arctic are a part of a large study called ALPS (Arctic Lake Process Studies) that draws on investigators from six universities. A station has been established at Toolik Lake, 120 miles south of Prudhoe Bay in the foothills of the Brooks Range, Alaska. While the overall goal of the project is a detailed examination of freshwater systems in the Arctic, the simplicity of the biotic systems of these waters offers some advantages in the general study of aquatic processes. For example, the lake contains a very low number of animals capable of grazing on bacteria. When an experimental measurement of bacterial growth is made, the interference from grazers will be at a minimum compared with what occurs in waters near Woods Hole.

One objective of the study of Toolik Lake has been determination of the seasonal distribution and numbers of bacteria in the water. Samples were collected, preserved and later counted in Woods Hole. A nucleic acid dye, acridine orange, was used to see the bacteria under epifluorescence. Beneath the ice at the beginning of the spring thaw there were about 0.5 x 10^6 bacteria per milliliter, with an even distribution from top to bottom of the 25-m deep water column. As soon as the stream started to flow, large numbers of bacteria were introduced into the lake, and by the time the ice left the lake at the end of June there were 1.5 to 2.5 x 10^9 bacteria per milliliter, a three-fold increase.

The next question is how rapidly the bacteria grow within the lake. The techniques available are not totally satisfactory but a minimum value can be obtained by following the transfer of 14C from photosynthesizing algae into bacteria and into dissolved organic carbon. In these experiments a water sample incubated for 24 hours with 14CO2 under natural light. The plankton are then collected onto filters. The fraction of the plankton that passes a 1-μm filter and is trapped on a 0.2-μm filter is assumed to be the bacteria, and the fraction that passes through the 0.2-μm filter is the dissolved organic carbon by definition.

The data (Figure 11) are presented as percentages of the total uptake at six different depths. Most of the photosynthesis is in the upper 5 meters. If the 14C in the 0.2- to 1.0-μm size fraction is bacteria and if the bacteria respire half the organic carbon they take up, then the bacteria sometimes cycle 30 to 40% of the 14C taken up in photosynthesis. The next step is to determine by autoradiography whether the 14C is really in the bacteria or if it is all in the small fragments of algae that have been broken during filtration.

Streams are extremely vulnerable to oil spills in the Arctic, and during the summer of 1979 we observed the effects of a break in the oil line on a stream about 30 miles from our study area. The effects of this spill are a continuing subject of study. Details are still being developed.

Investigators:
J. E. Hobbie
B. J. Peterson
The Ecosystems Center

Terrestrial Studies in Alaska

Nutrient availability is a major factor in determining the characteristics of vegetation, its productivity, stature, distribution, and stability. In the Arctic nutrient availability is limited by low rates of decomposition, by the fact that inputs through precipitation or dust accumulations are small, and by the fact that nutrients in the soil are relatively immobile.

We are engaged in a series of studies designed to determine how nutrient availability controls the productivity, composition, and response to disturbance of two major types of tundra vegetation. Although the focus is on Alaska, each study has been conceived as a general example of how plant nutrition affects the structure and function of vegetation.

Two new projects were started in 1979. One is an investigation of metabolic interactions between mobile carbon and nutrient pools within plants. The second is a study of how disturbances of the tundra affect nutrient cycling rates and therefore the rate and pattern of revegetation. Both projects are centered at Toolik Lake, Alaska.

The work on carbon-nutrient interactions is of general importance because it attempts to separate controls on utilization of carbon and nutrients in growth from their acquisition by photosynthesis and nutrient uptake.
This step will help to clarify relations between different processes that limit primary production. Our hypothesis is that in the tundra photosynthesis per se is not a limiting process but that nutrient supply to growing points controls the plants’ ability to use fixed carbon. Results from the first summer of work support the hypothesis.

Detailed biochemical analyses of experimental plants will provide a further, more rigorous, test.

Our research on disturbance and recovery of tundra vegetation has both basic and applied aspects. For management, our work has shown that removal of organic soils during construction and exploration also removes both the principal source of seed for revegetation and over 80 percent of the nutrient content of the system. The exposed mineral soil is a very poor seed bed that then must be both seeded and fertilized intensively.

Less severe disturbances to tundra change nutrient cycling patterns in a way that allows us to investigate nutrient effects on the growth form composition of vegetation. In concert with long-term fertilization studies to undisturbed tundra, this work will help to explain why low-nutrient sites in many parts of the world are dominated by evergreen species. In general, evergreens appear to cycle nutrients internally more efficiently than deciduous species. However, deciduous species that grow in low-nutrient sites may compensate through higher uptake rates, higher root/shoot ratios, or specialized rooting patterns.

Investigators:
G. R. Shaver
The Ecosystems Center
F. S. Chapin
University of Alaska

Figure 12. Typical Alaskan cottongrass tundra, with experimental fertilization plots, into which nitrogen, phosphorus, and potassium were introduced.
III. Ecology And Policy In Management Of Resources

The continued intensification in use of resources and in use of the biosphere as a whole is placing special demands on governments and on the scientific community. Demands range from those emerging from the threat of climatic change from the increase in CO₂ in the air to the persistent and increasingly frequent surprises from unintended effects of drugs and other toxins on people. The scale of the problem is illustrated by the upward-flowing, sine curve of CO₂ concentrations on Mauna Loa, a curve that reflects in its upward sweep the spread of industrialization and in its sinuous oscillation the power of the biota for affecting, even controlling, conditions for life on earth. The curve records a man-caused change in the earth as a whole. And it threatens further change. In a rational world the information would be used to improve man’s prospects, but how?

The issue is one of a thousand similar issues, not all global, that are with us at the moment and a thousand more that are imminent. They are the result of growth, and part of the cost of more intensive use of all resources. The issues can be addressed successfully from basic principles, not simply from compromise. Politicians, economists, and many others are surprised to find choices limited by laws of nature; there are an increasing number of issues that are not open to intermediate solutions. These issues can be resolved completely and satisfactorily in one way only, or remain festering, spreading sores.

Ecologists find themselves drawn, even pressed, into considering these issues, examining their own knowledge, experience and objectives in the framework that the issues themselves establish. The demands are two-fold: the need for data to address almost every issue, from standards of water quality to predictions of the effects of CO₂ on climate, and a continuing need for longer term policy management of resources. How can we arrange our activities in the coastal zone to assure that the sum of these activities does not destroy the very resources we need most?

Both of these needs were incorporated into the Center’s activities at the time the Center was established but experience has made them even more important in the eyes of the staff.

The interest of the staff has been recognized formally through a series of grants made specifically in support of the Program in Policy. The first of these enabled the appointment of a Senior Fellow, Dr. Richard Burroughs, now on leave to the Department of the Interior. Subsequent grants have continued the program. Activities within this program have incorporated all of the scientific staff of the Center, have drawn heavily on the larger scientific community of Woods Hole, and to a lesser degree on colleagues elsewhere. An explicit attempt has been made to maintain a focus in all of these activities and to avoid becoming so embroiled in the immediate issues that the longer term questions of policy are ignored. At the same time the staff has recognized the need to limit its activities in this realm to preserve the basic research program of the Center. Activities have focused on two general topics, the coastal zone and global environmental issues.

The overriding issue in the coastal zone at the moment is the development of oil resources on the continental shelf. The staff has participated in the recent activities of the Department of the Interior in leasing tracts for drilling, has supplied scientific analyses for review of the Environmental Impact Statement on Georges Bank, and has participated directly in the various reviews of the leasing procedures precipitated by the Conservation Law Foundation and others. A one-day symposium on offshore oil has been arranged by the Center and will be held in Woods Hole in February, 1980 to provide a summary of the background of scientific information on the effects of drilling, a perspective of the industry’s analysis of the problem, and a review of the performance of the Federal Government in the recent leases on Georges Bank, a major East Coast fishing area. A summary of the proceedings will be prepared.

Staff of the Center is currently involved in discussions with officials of the Commonwealth of Massachusetts and with federal officials in an effort to see that the EPA regulations governing releases during the drilling operation are appropriate and effective in protecting the fishery.

Although the staff has had many exciting, important experiences in attempting to bring science more effectively to bear on government in recent years, one of the most interesting experiences also proved to reveal the limitations of science in this realm.

The staff of the Center was approached to offer a new appraisal of the elaborate scientific studies done in support of attempts to resolve the 20-year-long series of altercations over the use of the Hudson Estuary by the power plants needed by the New York Metropolitan area. Millions of dollars have been spent in research to determine the hazards to fisheries that are based in whole or in part on the estuary. Despite the availability of money, the intensity of the research, the fact that the studies have been long-term studies and have resulted in numbers that appear well-defined, the detailed studies do not offer an objective basis for resolving the issues. If the success of the fisheries is to be the criterion, then factors beyond the Hudson River Estuary must be considered.

A review of the issues led to the suggestion that the extent to which the estuary can be used by the power plants be based not on the effects of any power plant on the larval stages of fish populations, but on the vigor of the fishery as a whole. Such a broadening of the burden of responsibility would give the power companies a strong interest in efforts to manage the fishery. Presumably, the success of the fishery would result in a reward to the power company and the consumers of power in the form of an increased opportunity to use the estuary for cooling. The failure of the fishery would result in increasing restrictions on the use of the estuary.

While the suggestions may prove unacceptable, they arose from the recognition that the scientific studies carried out so
far were inadequate and that no intensification of those studies would change that circumstance if the studies were restricted to the estuary alone. This and much of the other work under the program has been carried out jointly with staff of the Natural Resources Defense Council.

The Center has prepared a variety of reviews of federal and state actions and proposals in regulating industrial or municipal activities in the coastal zone. These reviews have been solicited by the governmental agencies, who have sought outside advice from the scientific community. The reviews have been for the Commonwealth of Massachusetts, the President’s Council on Environmental Quality, the Federal Environmental Protection Agency, Department of Energy and the Department of the Interior.

A review of the carbon dioxide problem, prepared in draft form by staff of the Center and ultimately signed by Roger Revelle, David Keeling, Gordon MacDonald, and George M. Woodwell, went to the Council on Environmental Quality and has formed the basis for several reviews of the CO₂ problem by various agencies of the Federal Government, including two sets of hearings in the Congress.

The Center was approached by the Swedish Government for a review of a proposal for the handling of radioactive wastes emanating from the Swedish nuclear power industry. A review was prepared and became a part of the detailed documentation used by the Swedish government in making their decision as to how to proceed in the management of nuclear energy in Sweden.

The importance of the kind of activities and the need for a new level of intensity in addressing policies in the management of environment have been emphasized recently by the Carnegie Council on Policy Studies in Higher Education, “Three Thousand Futures: The Next 20 Years for Higher Education”, which will be published during 1980. The Council emphasizes the importance of new research on environmental issues and the importance of these issues to government. The issues are obviously gaining greater recognition and will certainly increasingly affect both government and science over the next years.

Measurements of atmospheric CO₂ made by Charles Keeling at Scripps Institution of Oceanography. The dots indicate monthly averages. The current rate of increase is one part per million per year (2.3 x 10⁻⁶ grams).
IV. The Education Program

The central program of the Laboratory throughout its 92-year history has been a series of summer courses offered to students selected from colleges and universities from around the world. The courses combine teaching and research. Staff of these courses also come from far and near; the staff is occasionally as large as the student body. Courses tend to address some particular aspect of biology that is of interest to the instructor, of general interest to the scientific community, and appropriate to a marine biological laboratory. In the establishment of the Ecosystems Center the Laboratory made a transition to year-round operation. The Center’s pattern of operation borrows heavily on that established for the famous summer courses. Staff of the Center participates in or operates the following:

The January Course in Ecology

This is a 4-week course designed for advanced undergraduates and beginning graduate students offered currently under the direction of Dr. G. M. Woodwell, Director of the Center, and Dr. J. E. Hobbie, Senior Scientist, with the assistance of the staff and others. There are usually 20 to 25 students, half undergraduates and the remainder graduate students and other advanced students. The course occasionally attracts post-doctorals, teachers from other institutions, and other senior scholars.

The course usually has more than 50 lectures given by 15 to 20 senior specialists from the Woods Hole scientific community and elsewhere. There are 20 organized laboratories.

The strength of this course lies in its staff, drawn from the scientific community at large and brought to Woods Hole to participate in a month-long examination of ecology.

The staff recognizes additional needs in education and is in the process of revising the Center’s course offerings with a special emphasis on the January course. The needs and objectives are summarized in the final paragraph of this section. It is probable that the January course of 1981 will be substantially different from the course offered previously.

The Year-in-Science Program

Undergraduates have an opportunity to spend a semester of research and study in the Center. For undergraduates the curriculum is the equivalent of an honors program at most universities. Credit is through the college or university where the student is enrolled. Total credit is normally 16 credit hours per semester.

Graduates are offered an opportunity to join staff of the Center in research. Credit and degrees are through the sponsoring university. Graduate students who have participated in this program recently have been from the University of Virginia, the State University of New York at Stony Brook, the University of North Carolina, and Yale University.

The recent emphasis of the Year-in-Science program has been on graduate work.
Interns in Science

A recent innovation has been the establishment during 1979 of a series of 6-month appointments for outstanding undergraduates or recent graduates in biology who have not had sufficient experience to compete effectively for positions as research assistants or to know whether they wish to enter science professionally as a career.

The program is an outgrowth of our recognition that one of the greatest failings in our educational system at the moment is the restriction of opportunities for practical training for talented undergraduates and recent graduates in science. The loss of opportunities has several causes. One is the restriction of all budgets. A second is the increased specialization in science with the need to hire more senior, experienced technicians whenever opportunities become available. These developments mean that chances for younger people to gain experience are disappearing rapidly as budgets are pared year by year and as research projects move into more and more complicated technical phases.

The problem has loomed large at the Center where we encounter talented undergraduates and recent graduates who wish to gain further experience but to whom we could give little encourage-

The Post-Doctoral Program

This is a post-doctoral program designed to aid young scientists in finding their way toward development of their own independent research programs in which they take advantage of the special opportunities available at the Center.

We have established these appointments to speed the development of new knowledge and its diffusion. The appointments are available to new holders of the Ph.D., either prior to their acceptance of their first position in a college or university or after they have taught for a few years. The appointments are considered an academic distinction, are normally held for two years and normally lead to a scholar’s movement to a teaching and research position in a university. We hope, of course, that our alumni will find an advantage in continuing to return to Woods Hole for their research and to participate in other activities of the Center.

The program is financed in part through incorporation of salaries and support money into federal grants for research. There remains, however, the need for a limited amount of money to be available at the discretion of the staff to invite outstanding candidates to join the scientific community from time to time.
Special Programs With Other Institutions

Staff of the Center seeks and enjoys collaborative relationships in both research and education with staff of other institutions, especially the Woods Hole Oceanographic Institution and the Boston University Marine Program.

The staff of the Center has a special relationship with Yale, where a grant from the Surdna Foundation has encouraged systematic exchanges of staff and students between the two institutions. The exchanges have included the offering of courses and seminars at Yale by staff from the Center, an annual field trip from Yale to the Center with a two-day symposium in science put on by staff of the Center for Yale students, and three summer assistantships under which Yale students are paid to work with MBL scientists on various field projects. During the past two summers the field projects have taken one student to Alaska in each summer and two students into the field on projects in Woods Hole.

The faculty of the Center accepts limited further responsibilities in education through lectures offered occasionally at other institutions.

NSF-DEB-78-11336
"Population dynamics and ecosystem processes: A new synthesis" (subcontract from University of California, Santa Barbara).
September 1978 — August 1980
Investigators: Melillo, Steudler, Bowles.
$76,767

NSF-DEB-78-11171
"An experimental and comparative investigation into the factors controlling nutrient losses from disturbed ecosystems" (subcontract from University of North Carolina).
September 1979 — August 1980
Investigator: Melillo.
$33,643

NSF-DEB-79-05127
"Decomposition processes in salt marsh ecosystems" (subcontract from Boston University).
May 1979 — April 1982
Investigator: Hobbie.
$296,740

NSF-DEB-79-08250
"Decomposition processes in forest soils: An analysis of organic matter and nitrogen dynamics" (subcontract from University of Wisconsin).
July 1978 — June 1980
Investigators: Melillo, Steudler.
$97,195

NSF-DEB-79-05842
"Effects of mineral nutrition and temperature on mobile carbon pools in arctic tundra plants" (subcontract from University of Alaska).
May 1979 — April 1980
$7,875

NSF-OCE-78-08247
"Microbial nitrogen assimilation in coastal marshes".
May 1978 — April 1980
Investigator: Bowden
$3,450

DOE-EY-76-S-02-2989
"Effect of oil on tundra ponds and streams".
October 1979 — October 1982
Investigators: Hobbie, Peterson.
$198,000
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<th>U.S. Army Research Office</th>
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<tr>
<td>DAA G 29-79-C-0112</td>
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<tr>
<td>&quot;Revegetation of Alaskan disturbed sites of native tundra species&quot; (subcontract from University of Alaska). June 1979 — May 1980</td>
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<td>U.S. Forest Service</td>
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<td>FS-NE-1601</td>
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<tr>
<td>&quot;Potential effects of intensive forest management on productivity and soils in northern hardwoods&quot; Investigator: Melillo</td>
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Pending Research Grants

**NSF-DEB-79-23329**
"The world carbon budget: An analysis through modelling". For 1.5 years Investigators: Woodwell, Melillo, Peterson, Shaver, Houghton. $329,332

**NSF-DEB-Unnumbered**
"Organic matter and nitrogen dynamics in forest ecosystems" (subcontract from University of Wisconsin). For 3 years Investigators: Melillo, Steudler. $213,505

**NSF-DEB-79-22894**
"An experimental and comparative investigation into factors controlling rates of decay and nitrogen dynamics of forest litter". For 1.5 years Investigators: Melillo, Steudler. $108,178

**NSF-DEB-79-22860**
"The effect of edaphic factors on the ammonium uptake kinetics of Spartina alterniflora and Spartina patens". For 2 years Investigator: Morris. $79,643

**NSF-DEB-80-12207**
"An investigation of the role of woody debris in northern stream and river ecosystems" (subcontract from WHOI). For 3 years Investigators: Melillo, Hobbie $93,797

**NSF-Renewal of DEB-78-11336**
"Population dynamics and ecosystem processes: A new synthesis" (subcontract from University of California, Santa Barbara). For 3 years Investigator: Melillo $178,701

**NSF-Supplement to DEB-76-17425**
"An experimental and comparative investigation into the factors controlling nutrient losses from disturbed ecosystems" (subcontract from University of North Carolina). For 1 year Investigator: Melillo $23,080

**DOE-P800014**
"The effect of changes in terrestrial carbon pools on the CO2-content of the atmosphere: A pilot study in the use of satellite imagery". For 2 years Investigators: Woodwell, Hobbie, Peterson, Melillo, Shaver, Bowles, Steudler, Houghton. $1,004,493

**Sea Grant-WHOI**
"The role of reduced sulfur compounds in the energy flow of a salt marsh". For 1 year Investigators: Howarth, Peterson. $40,220
V. Staff Of The Ecosystems Center

George M. Woodwell, Director
  B.A. Dartmouth College
  M.A. Duke University
  Ph.D. Duke University

John E. Hobbie, Senior Scientist
  B.A. Dartmouth College
  M.A. University of California
  Ph.D. Indiana University

Bruce J. Peterson, Assistant Scientist
  B.S. Bates College
  Ph.D. Cornell University

Jerry M. Melillo, Assistant Scientist
  B.A. Wesleyan College
  M.A.T. Wesleyan College
  M.F.S. Yale University
  Ph.D. Yale University

Gaier R. Shaver, Assistant Scientist
  B.S. Stanford University
  M.A. Stanford University
  Ph.D. Duke University

Francis P. Bowles, Research Associate
  B.A. Haverford College
  Ph.D. Harvard University

Richard A. Houghton, Research Associate
  B.A. Hamilton College
  Ph.D. SUNY, Stony Brook

Richard H. Burroughs, Senior Fellow (on leave 1979 - 1981)
  B.A. Princeton University
  Ph.D. MIT - WHOI

James T. Morris, Post-Doctoral Fellow
  B.A. University of Virginia
  M.S. Yale University
  Ph.D. Yale University

Robert W. Howarth, Post-Doctoral Fellow
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Paul A. Steudler, Research Associate
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  M.S. University of Oklahoma

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  B.A. Oberlin College

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  M.F.S. Yale University

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  M.S. Rutgers University

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  B.S. St. Mary's College of Maryland

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  M.S. School of Agriculture, Olsztyn, Poland.

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Joshua Schimel, Research Assistant
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Hedy E. Sladovich, Research Assistant
  B.A. Oakland College

Andrea R. Turner, Research Assistant
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James N. Fowles, Intern
  B.A. Dartmouth College

Judith A. Gale, Intern
  B.A. Chatham College

Julie K. Morse, Intern
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  M.S. North Carolina State University
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James P. Reed, Graduate Student
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  M.S. University of Cincinnati
  Ph.D. candidate, North Carolina State University

Mary Louise Montgomery, Assistant to the Director
  B.A. Mount Holyoke College

Joan M. Upton, Secretary
Suzanne Semino, Secretary
VI. Publications

1975


1976


1977


1978


1979


Woodwell, G. M. 1979. Address of the Past President to the Ecological Society of America. ESA, Natural History.


### 1980


VIII. Finances Of The Center

The Center is financed through a series of private grants made directly in support of the Center and through federal grants in support of specific research topics. Since its inception, the Center has received grants totaling $3,295,291 from the following foundations:

- Mellon
- Doherty
- Rowland
- * Rockefeller
- Clowes
- Culpeper
- ** Surdna
- Fleischmann
- Exxon
- *** Noyes
- * Ford
- Atlantic Richfield
- *** Robert Sterling Clark
- **** Hayden
- Lindbergh
- Davis
- G.E.
- Grace
- Grass
- IBM
- * Scherman
- * World Wildlife Fund - NRDC

* restricted funds for specific research
** restricted funds shared with Yale University School of Forestry
*** restricted funds for scholarship use
**** shared funds with Boston University Marine Program

1979 Financial Highlights

INCOME
Sponsored research $ 845,000
Private foundations 465,000
Interest earned on investments 126,000
Tuition for educational programs 12,700
Other 13,000

$1,461,700

EXPENSES
Personnel — salaries, stipends and employee benefits $ 555,000
Subcontracts to other institutions 127,700
Operating costs of research and education 245,300
Laboratory fees 132,000

$1,060,000

1980 Budget

INCOME
Sponsored research $1,115,000
Private foundations 230,000
Interest earned on investments 130,000
Tuition for educational programs 15,000

$1,490,000

EXPENSES
Personnel — salaries, stipends and employee benefits $ 750,000
Subcontracts to other institutions 150,000
Operating costs of research and education 310,000
Laboratory fees 180,000

$1,390,000