1986 Annual Report
The Ecosystems Center

MARINE BIOLOGICAL LABORATORY
WOODS HOLE, MASSACHUSETTS
High vacuum pump used in stable isotopes workshops.

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INTRODUCTION
TO THE
ECOSYSTEMS
CENTER

The Center was founded in 1975 as a year-round program of the Marine Biological Laboratory, a private research institution located in Woods Hole, Massachusetts. The goals of the Center are to investigate the interactions of organisms with their environment and to apply the resulting knowledge for wise management of natural resources. The Center is organized as an association of scientists under a director, John E. Hobbie; most decisions are made collegially. Funding for the Center comes mostly from competitive government grants but vital support for salaries, administration and research also comes from a reserve fund created by awards from private foundations.

We believe the research goal can best be met by studies organized around an ecosystem. An ecosystem, which can range in size from a square meter of a coastal sediment to an entire forest, is the smallest ecological unit that contains all of the processes, organisms, and interactions necessary to reflect the complexity of nature. Ecologists who study ecosystems may make measurements of a large-scale process which integrates a number of reactions, such as the release of carbon dioxide from a forest floor, or may measure a single process (such as nitrogen fixation) or a population (such as the numbers of a single type of planktonic algae). Ecosystem ecologists make decisions about what to study according to whether or not an important ecosystem population, species, or flux of elements or energy are affected or controlled. This criterion for judgement, that is, based upon the importance to ecosystem structure or function, distinguishes ecosystem ecologists from species, population, or community ecologists who may often make some of the same types of measurements.

It is difficult for one person to have all of the skills necessary to study ecosystems. Accordingly, the skills of the Center's ten scientists include terrestrial and aquatic ecology, microbiology, chemistry, remote sensing, botany, zoology, physiology and modeling. Each has his own project but also works with the others on various grants and in various combinations. One of the strengths of the Center is the ability of those scientists to interact closely over the years; the constant challenge and stimulation is invaluable.

The offices of the Ecosystems Center staff are located in the Homestead Building; the adjoining Environmental Sciences Building contains the aquatic, terrestrial and chemical laboratories. The aquatic and terrestrial labs are shared by all the projects and are used for experiments, sample preparation, radioisotope experiments, and microscopy. The chemistry lab contains such shared instruments as an Auto-Analyzer for nutrients, gas chromatographs, an ion chromatograph, an emission spectrometer for $^{15}N$, and other spectrometers. In 1986, construction was completed on the Center's mass spectrometer facility for analysis of the ratios of isotopes of carbon, hydrogen, oxygen, nitrogen and sulfur and the lab became fully operational.

The research projects at the Center are mostly funded by the National Science Foundation; there are also grants from the Department of Energy and NASA. Almost all of the projects involve multiple investigators. That is, on every grant there are at least two scientists from the Center or a Center scientist and a scientist from outside the MBL. One grant, the NSF carbon project, includes four scientists from the Center and one from the University of New Hampshire while the Arctic project includes two scientists from the Center and six from other institutions. Finally, the realities of the granting process dictate that each of the Center's staff members have on three or more grants at any given time. While this arrangement means the staff is continually involved in writing proposals and reports, there are great benefits to the investigators through learning about many aspects of ecosystem ecology.

The second goal of the Ecosystem Center, that of application of knowledge to the management of natural resources, is approached in a number of ways. Some of the Center's research, such as that on acid rain and on groundwater quality, will provide answers immediately useful to managers and governments. Some of the time of Center scientists is spent in consulting with government agencies, such as the EPA, or with environmental groups and in serving on committees of the National Research Council and the National Science Foundation.
In recent years there has been an abrupt turnaround in the way ecologists view ecosystems. Previously ecosystems were thought of as dynamic but basically unchanging. That is, while forests did change as a result of harvest or disease, these changes were relatively short term; eventually the forest would return to a predictable configuration as determined by the natural conditions of soil type, climate, or topography. Over the past two decades, ecologists have realized that chronic low level human perturbations are having an impact; virtually all ecosystems are being changed and over the long term. The challenge of the 1990’s will be to recognize the early signs of change and to predict the consequences.

Recent studies by Center scientists and by others across the country provide the example of the interactions of forests and the chronic addition of nitrogen in acid rain. The following explanation of these interactions is a working hypothesis drawn from discussions with Center scientists (see section of this report on Predicting the Long-Term Ecological Effects of Acid Deposition) and with Richard Waring, a visiting scientist during 1986-1987. Although this hypothesis explains seemingly unrelated events in a very reasonable way, it still must be tested.

In undisturbed forests, nitrate nitrogen is found in low concentrations. In part this is because trees and their roots remove most of the nitrate from the soil water as soon as it becomes available. This nitrate is then transported to the leaves where it is reduced, at great metabolic cost, to form amino acids and proteins. Usually there is not enough nitrate to provide all the nitrogen the forest trees could use and so the forest is nitrogen limited.

The record of the chemistry of precipitation, preserved in Greenland ice cores, reveals that the amount of nitrate in precipitation has increased more than 250% since 1960. What is the forest response to this chronic addition of nitrate? At first the forest trees respond by additional growth. Eventually, as the trees continue to remove nitrate from the soil they form excess amounts of amino acids and proteins. The results are: 1) energy is wasted in unnecessary nitrate reduction, 2) the 200-300% increase in amino acid content of the leaves makes them more palatable to insects and may allow outbreaks, and 3) root mass is reduced relative to foliage and the absorption of other nutrients and water may be reduced, especially in times of drought.

Thus, the chronic addition of nitrate to forests probably leads to stressed trees and even to a change to species better able to handle the excess nitrogen. This important conclusion came about only because of measurements made before 1960 of soil and phloem concentrations of nitrate and because of present day measurements of the nitrate reduction of trees in undisturbed ecosystems such as those in northern Scotland. Ecologists today must study ecosystems which are constantly changing in many and subtle ways.
There is no doubt that acid deposition has lowered the pH of some lakes in the eastern United States. We are not able, however, to predict the long-term effects of continued acid deposition on lakes which are not now acidic, on forests, or on the release of trace gases to the atmosphere. Because acidic deposition consists of a mixture of nitric and sulfuric acids, prediction requires a thorough understanding of nitrogen and sulfur cycles in ecosystems.

In most forests the amount of mineral N made available in soil is less than the N uptake or assimilation capacity of vegetation. As a result, N cycling between soil and vegetation is tightly coupled and almost no nitrate is exported to surface waters. However, acid deposition may alter the amount and forms of N cycled in forests and may increase nutrient exports from forest ecosystems to streams and lakes. Recent studies in Europe and New England have shown that streams draining some high elevation forested watersheds have unusually high nitrate concentrations — sometimes in excess of 20 ppm nitrate-N. These large exports of nitrate anions to surface waters suggest that chronic N additions in acid deposition may result in “N saturation”, a condition in which soil N availability gradually increases beyond the N assimilation capacity of forest vegetation.

Researchers at The Ecosystems Center (Melillo, Nadelhoffer, Steudler) and the University of New Hampshire (John Aber) are looking for patterns of forest ecosystem response to chronic N additions. The overall goal is to predict when N saturation will occur in different forest ecosystems receiving various levels of N inputs. Normally, forests balance their very low inputs of nitrate and ammonium with outputs of nitrogen dissolved in flowing waters or as a gas. At this stage (Figure 1, Stage 0), nitrate (and associated H⁺ and Al³⁺) exports to surface waters are very close to zero.

When conditions change and acid deposition begins to add nitrate, there will be little change in cycling patterns for a number of years (Stage 1). This added N increases the N supplied to trees by 10 to 40%. They respond to this extra N by increasing N uptake, by allocating more N to green leaves, and by increasing the production of leaf litter.

As the nitrogen cycling rate gradually increases, exchangeable ammonium levels in soil increase and nitrifying bacteria are better able to compete with microbes and plant roots for ammonium, which they oxidize to nitrate. Eventually, nitrification provides more nitrate than plants can economically assimilate (Stage 2) and nitrate is leached to surface waters.

If the vegetation becomes further stressed by other factors associated with acid deposition (lowered soil solution and fol-
Table 1.

CARBONYL SULFIDE AND CARBON DISULFIDE EMISSIONS FROM EUROPEAN TEMPERATE AND BOREAL FOREST SOILS

<table>
<thead>
<tr>
<th>Location</th>
<th>COS (µg S m(^{-2}) h(^{-1}))</th>
<th>CS(_2) (µg S m(^{-2}) h(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOLLING, WEST GERMANY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>130 yr-old Beech</td>
<td>2.87</td>
<td>2.39</td>
</tr>
<tr>
<td>95 yr-old Spruce</td>
<td>2.40</td>
<td>0.89</td>
</tr>
<tr>
<td>JÄDRAÅS, SWEDEN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40 yr-old White Birch</td>
<td>0.18</td>
<td>0.00</td>
</tr>
<tr>
<td>130 yr-old Scots Pine</td>
<td>1.37</td>
<td>1.05</td>
</tr>
<tr>
<td>GÄLLIVARE, SWEDEN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>60 yr-old White Birch</td>
<td>0.13</td>
<td>0.28</td>
</tr>
<tr>
<td>150 yr-old Scots Pine</td>
<td>0.57</td>
<td>0.12</td>
</tr>
</tbody>
</table>

iar pH, ozone, SO\(_2\)), the productivity of the forest may decline (Stage 3); the capacity for nitrate assimilation may be lowered while nitrification proceeds. The end result of chronic N additions could then be very high rates of nitrate export to ground and surface waters or high rates of conversion to gaseous nitrogen forms.

Forest ecosystems also exchange large amounts of trace gases containing carbon, nitrogen, and sulfur between the soil and vegetation of forests and the atmosphere. These gases may have a much influence on future climate as the loading of the atmosphere with carbon dioxide. For example, carbonyl sulfide (COS) and its precursor carbon disulfide (CS\(_2\)) are two trace gases that play important roles in the energy budget of the earth and the chemistry of the stratosphere. Biotic sources, especially upland soils covered by forests, are currently believed to dominate the global emissions of these gases. Globally, many of these forests are receiving large inputs of sulfur and nitrogen from acid rain.

Steudler and Melillo have developed and are testing two hypotheses: 1) that the amount of COS and CS\(_2\) emitted from forests is directly related to the amount of the acid rain inputs of sulfur and nitrogen; and 2) that the amount of the gaseous sulfur emissions from forest stands is controlled, in part, by nitrogen inputs.

The first hypothesis was tested by measuring COS and CS\(_2\) emission in sites with different amounts of acid rain (Table 1). Forests in Solling, West Germany, receive the high amounts of 80 kg SO\(_2\) and 34 kg NO\(_3\) ha\(^{-1}\) yr\(^{-1}\) while two sites in Sweden receive much lower S and N inputs. The Gallivare sites have the lowest S and N deposition rates—about 2 kg ha\(^{-1}\) yr\(^{-1}\) for both SO\(_2\) and NO\(_3\). In agreement with the hypothesis, the COS and CS\(_2\) emissions at the Solling sites were between 4 to 20 times larger than the emissions measured at the Gallivare sites. Similar patterns of COS and CS\(_2\) releases were also observed along a North American transect.

The second hypothesis, that nitrogen additions to forest soils cause increases in the net flux of the sulfur gases from the soil to the atmosphere, was tested by establishing fertilized and control plots in two forest stands at the Harvard Forest in central Massachusetts: an 85-year-old mixed hardwood stand, and a 55-year-old red pine plantation. The fertilized plots received a total of 10 g N m\(^{-2}\) yr\(^{-1}\) of nitrogen in the nitrate form during 1985 (May-October). Measurements of COS and CS\(_2\) fluxes between the soils of the forest plots and the atmosphere were made in May, 1986.

Nitrogen fertilization increased the combined COS and CS\(_2\) emissions from the soils in both stands (Table 2), the
combined emissions were increased by a factor of four in the hardwood stand and were almost doubled in the pine stand. The nitrogen fertilization, however, did not affect COS and CS₂ emissions in the same way in the two stands. The added nitrogen caused a dramatic increase in COS emissions from the hardwood stand (a factor of five increase), while CS₂ emissions from this stand were not affected. The opposite response was observed in the pine stand; that is, nitrogen fertilization had no effect on COS emissions, but did stimulate CS₂ emissions (a factor of almost nine increase). The conclusion was that nitrogen appears to limit the microbially mediated production of COS and CS₂ but the mechanism is still unknown.

The understanding of the sulfur cycle is also necessary for the prediction of effects of acid precipitation. A portion of the acid which enters some lakes is neutralized via the biological reduction of sulfate to sulfide. This process, which takes place in the anaerobic zones of sediments, is an effective neutralizer only if sulfide reacts with iron or organic matter and is stored in the sediments. If the sulfide escapes to aerobic waters it is reoxidized to sulfate and the alkalinity is lost (Figure 2).

To predict the long term ability of lakes to retain sulfur by this mechanism, it must be determined whether sulfur is being stored as organic-S or as inorganic ferrous sulfide minerals. Anne Giblin and collaborators Bob Howarth (Cornell) and Gene Likens (Institute of Ecosystem Studies) have found that substantial quantities of sulfur are being stored in some lakes, such as Ice House Pond, Massachusetts, as inorganic sulfur. In other lakes, such as Lakes of the Clouds, New Hampshire, organic sulfur forms dominate (Figure 3). In a wider study of a number of lakes, it was found that iron is very abundant in the sediments of many lakes, but that some lakes have low stores of iron (Figure 4). It appears that the ability of a lake to store sulfur in inorganic forms could become exhausted. The next step in this research is to experimentally manipulate lake sediments to identify the controls on reduced sulfur accumulation. Anne Giblin, Bruce Peterson and Brian Fry of the Ecosystems Center have begun a series of intact core experiments where iron, sulfur, organic matter, and oxygen concentration may all be manipulated independently.

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**Figure 3.**
Forms of sulfur in two New England lakes. In Ice House Pond nearly half of the total sulfur is present in organic reduced forms (elemental S, FeS and pyrite-FeS₂). In Lakes of the Clouds, more than 80% of the total sulfur is in organic forms.
<table>
<thead>
<tr>
<th>STAND</th>
<th>TREATMENT</th>
<th>COS (µg S m(^{-2}) d(^{-1}))</th>
<th>CS(_2) (µg S m(^{-2}) d(^{-1}))</th>
<th>Σ COS + CS(_2) (µg S m(^{-2}) d(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>HARDWOOD</td>
<td>CONTROL (12 May 1986)</td>
<td>3.41</td>
<td>1.96</td>
<td>5.28</td>
</tr>
<tr>
<td></td>
<td>FERTILIZED (13 May 1986)</td>
<td>19.5</td>
<td>1.71</td>
<td>21.20</td>
</tr>
<tr>
<td>PINE</td>
<td>CONTROL (16 May 1986)</td>
<td>21.5</td>
<td>2.21</td>
<td>23.7</td>
</tr>
<tr>
<td></td>
<td>FERTILIZED (15 May 1986)</td>
<td>23.9</td>
<td>19.1</td>
<td>43.0</td>
</tr>
</tbody>
</table>

* Difference between control and fertilized treatments was significant at 0.05 level, n=4.

f. Harvard Forest, Massachusetts.

**Figure 4.**
Distribution of oxidized and reduced iron in two New England lakes.
The climate of the earth may already have begun to change as a result of increased concentrations of CO₂ and other trace gases in the atmosphere. These changes in temperature and rainfall may move the location of agricultural lands with consequences for economic and political well-being. They may cause increased melting of glaciers and ice caps and so change sea levels. How successfully mankind manages these changes depends in part on how fast the climate changes; this rate of change depends to some degree on the response of natural ecosystems whose response could either speed up or retard the rate of change. Increased levels of atmospheric CO₂, for example, might enhance photosynthesis, reduce the rate at which CO₂ builds up in the atmosphere, and reduce the rate of climate change. On the other hand, a small warming of the earth might enhance respiration more than photosynthesis, increase the rate of build-up of CO₂, and increase the rate of warming.

Two projects at the Center are investigating these possible ecosystem effects of climate change. In the first project, Richard Houghton and Tom Stone are using the natural short-term response of ecosystems to year-to-year variations in climate to try and predict the longer-term (5-25 years) response of ecosystems over large regions of the earth. The project is based on the record of terrestrial metabolism provided by the continuous measurements of CO₂ concentrations in the atmosphere (Figure 1) begun by C. D. Keeling at Mauna Loa, Hawaii, and the South Pole in 1957 and expanded by NOAA to include more than 20 stations worldwide. Highest concentrations of CO₂ occur in spring, after the winter when the respiration of ecosystems has exceeded net primary production. Lowest concentrations occur in fall, after the growing season when plants have removed carbon from the atmosphere. This pattern agrees with results from studies of single ecosystems; one example is the gross primary production (GPP) and ecosystem respiration (Rs) for an oak-pine forest in Brookhaven, New York (Figure 2). In other ecosystems the amplitude of the seasonal high and low concentrations would vary as a function of the amount of overlap of GPP and Rs throughout the year.

Anomalies in the seasonal or year-to-year patterns of the CO₂ concentrations in the atmosphere may thus suggest the location and, with weather records, the cause of the metabolic variations. These variations, in turn, may offer insights into the integrated short-term response of terrestrial ecosystems to changes in the global environment.

The first results of our analysis illustrate the factors that must be considered. The analysis begins with the fact that the seasonal amplitude of CO₂ concentrations at Mauna Loa has increased by 0.7% yr⁻¹ between 1957 and 1982. If all the biota reacted as did the Brookhaven Forest, this change in amplitude could be produced by an increase of the GPP of about 0.4%. While such an increase in GPP is not large, it is 2 to 4 times larger than what would be expected from the increased levels of CO₂ in air over the same period. Similarly, the increase in winter Rs needed to produce the observed 0.7% yr⁻¹ increase in the seasonal amplitude of CO₂ concentrations is 3 to 4 times higher than can be explained on the basis of the observed warming of winter temperatures. We conclude that neither the increase in CO₂ concentrations nor the increase in air temperature can account for the changes observed in the seasonal amplitude of atmospheric CO₂ concentrations. However, the information on the effect of high concentrations of CO₂ on photosynthesis is mostly greenhouse based. Large scale experiments with whole ecosystems are needed.

In the second project, Ed Rastetter is constructing a model with the help of John Hobbie, Gus Shaver, Knute Nadelhoffer, and Ske Houghton. The long-term goal is to predict the 10-100 year response of various forests and grasslands to changes in CO₂ and climate. The problem is that little is known about how whole ecosystems respond to these changes but a good deal more is known about how the parts of ecosys-
Figure 1.
Seasonal and latitudinal variations in atmospheric concentrations of CO₂ as measured by the National Oceanic and Atmospheric Administration's Geophysical Monitoring for Climatic Change.

Figure 2.
Top: monthly rates of gross primary production (GPP) and ecosystem respiration (RsE) for the Brookhaven Forest in New York. Middle: monthly net flux of carbon from the forest (positive values indicate a net release to the atmosphere). Bottom: cumulative net flux of carbon between the forest and atmosphere. The shape of this cumulative flux resembles the shape of seasonal CO₂ concentrations in the atmosphere. The units of 10¹² g C on the right of the Figure are the calculated flux of carbon for all non-tropical ecosystems in the northern hemisphere.

...tems respond. The challenge, of course, is to predict how these parts are going to respond as a complex, interacting aggregate. One way to improve our guesses about the responses of whole ecosystems is to incorporate what is known about their parts into a mathematical model that will allow us to explore the consequences of interactions among the ecosystem components.

The model, which can be applied to forests and grasslands (Figure 3), integrates responses at three scales. On a fine scale, changes in atmospheric CO₂ concentrations and associated changes in climate will affect the rates of enzymatically mediated processes such as photosynthesis and nutrient uptake. At a larger scale, whole plants are likely to acclimate to environmental changes by altering the patterns of carbon and nutrient allocation to their tissues in a way that maintains their metabolic balance. At the ecosystem scale, environmental changes associated with elevated CO₂ concentrations will probably change the balance between production and decomposition processes (represented here as the CO₂ leaving the litter) thereby affecting the rates of nutrient cycling. The responses at these three levels of organization will not be simultaneous and may work counter to each other. This point can be illustrated best by examining what might happen under a hypothetical scenario of an instantaneous doubling in the atmospheric concentration of CO₂.

If CO₂ in the atmosphere were to double, the photosynthetic rate of the plants would increase immediately because of the greater substrate availability to carboxylating enzymes in leaves. Thus, based on the enzymatic response alone, it might be predicted that the productivity of terrestrial ecosystems would increase and the biomass in these ecosystems would increase. By tying up carbon in biomass, such a response would be expected to reduce or even reverse the accumulation of atmospheric CO₂.

Whole plants, however, may acclimate in such a way that the magnitude of the enzymatic response is reduced. To maintain a metabolic balance, the plants will...
have to match, at least partially, any increase in the rate of carbon fixation with an increase in the uptake of nutrients. Plants should therefore regulate the allocation of resources to their tissues so that the nutrient capturing mechanisms in the fine roots are increased relative to the carbon fixing mechanisms in the leaves. This might result in fewer, less nitrogen rich leaves relative to fine roots and thereby decrease the rate of photosynthesis relative to the rate of nutrient uptake and reduce productivity. Predictions of biomass increases in terrestrial ecosystems based on information about whole plant responses to increased CO$_2$ concentrations might be substantially lower than predictions made on enzymatic considerations alone.

The responses of whole ecosystems are more difficult to unravel. If, for example, the tissue chemistry of the plants changes substantially, then the rates of decomposition of the litter derived from these tissues might change. If leaf litter has a lower nitrogen concentration, then it is likely to decompose more slowly, thereby tying up nitrogen in soil organic matter. The microbes decomposing this material are also likely to be nitrogen deficient and therefore may remove more inorganic nitrogen from the soil solution. The net effect of this would be to place the plants under greater nutrient stress thereby decreasing productivity. Predictions based on a whole ecosystem response, therefore, might be that the biomass in terrestrial ecosystems will actually decrease if CO$_2$ concentrations increase.

There are, of course, many other equally plausible scenarios that can be constructed suggesting very different responses of terrestrial ecosystems to elevated CO$_2$ concentrations. Our model is sufficiently flexible that it should allow us to explore most of these. In this sense, the model is a means of posing quantitative hypotheses about the responses of terrestrial ecosystems to elevated CO$_2$ concentrations and related climate changes. The utility of the model, however, is more than a vehicle to explore "What if" types of questions. Building the model helps to identify what we don’t know about these ecosystems. The model, therefore, is a valuable tool that can help guide future field and laboratory experiments and observations. The model is also a convenient means of organizing large-scale ecosystem studies. Finally, the model should help us recognize the correct explanation for our observations once the responses of terrestrial ecosystems to CO$_2$-induced changes in the global environment become detectable.
Patterns of element cycling vary widely among ecosystems. For example, some ecosystems depend primarily on external element inputs to support biological activity. Others generate most of their required elements in situ, through fixation, weathering, and decomposition processes. The basic pathways of element cycling are the same in all cases: what differs is the relative importance and efficiency of each pathway. Similarly, some ecosystems are “leaky,” losing large portions of their biologically active element capital each year; they must rely heavily on new inputs for maintenance of essential processes. Other ecosystems are conservative, with highly efficient recycling of elements both within vegetation and between vegetation and soils.

What are the implications of this variation in element cycling patterns? This is a central question of ecosystem-level ecology, with relevance at local, regional, and global scales. The answers are important to understanding the variability in response of diverse ecosystems to disturbance, to management of ecosystems for human purposes, and to understanding the role of terrestrial ecosystems in regulating the chemistry of lakes, streams, and the atmosphere. In research in northern Alaska, Gus Shaver and Bruce Peterson are taking a landscape-level approach to this question, asking more specifically: “How do elements cycles of adjacent ecosystems interact to determine overall landscape patterns?”

Their current work includes studies of biogeochemical variation in terrestrial arctic ecosystems, and studies of nutrient limitation in arctic rivers and lakes. The terrestrial and aquatic components of this research have evolved mostly independently over the past 10 years; the components will be more closely linked in the future with the help of a long-term ecological research project (LTER) recently funded. Altogether, the arctic research projects involve over half the senior staff of the Center in collaboration with about a dozen scientists from other laboratories.

The Center work on terrestrial arctic ecosystems is focused on a series of six strikingly different vegetation types (ecosystems) that occur in a consistent and predictable sequence along topographic gradients from upland tundra to the floodplain of a large arctic river (Figure 1). Ecosystems like these should differ sharply in the relative importance of internal recycling processes versus external exchanges of elements. This sequence of contrasting ecosystems is thus an ideal place to answer such questions as:

1. How do these ecosystems act to control the rate of nitrogen and phosphorus movement over the landscape, from uplands to the river floodplain? Which ecosystems are the greatest bottlenecks?

2. What is the relative importance of element inputs from “uphill” ecosystems as element sources to each ecosystem including the river?

3. Do the same processes limit the rate of element movement in all ecosystems, or are the limiting processes and forms of element availability different in each?

The six study ecosystems differ strongly in the relative availability of nitrogen versus phosphorus, and in the availability of the major forms of nitrogen (Figure 2). For example, the ratio of available N to available P varies by more than an order of magnitude among sites. This result suggests significant variation in the relative rates and importance of various N and P cycling processes, and thus in the factors that limit productivity of these ecosystems. Fertilization experiments support this conclusion.

In laboratory incubation experiments, a similar variability was found in the release of N and P from these soils over a range of temperatures. Thus the same temperature change applied to all six ecosystems should have very different effects on N and P losses from each. Keeping in mind that losses from one ecosystem represent inputs to another ecosystem, the focus now is on quantifying the amounts of N and P carried between ecosystem types across the tundra landscape and into streams.

The Center’s research in the ecology of arctic rivers includes fertilization and other experiments designed to elucidate the importance of nutrient inputs from terrestrial ecosystems as controls on the river’s trophic structure and productivity.
Earlier work on nutrients, hydrology, and primary productivity of the Kuparuk River showed that phosphorus was the primary nutrient limiting the growth of algae in the river.

During 1983 to 1986 we have studied the changes that phosphorus fertilization produces in the river. One fascinating aspect has been that the biological response to the fertilization has changed markedly over time. In 1983 and 1984, the first two years of phosphorus addition, the algal biomass on river bottom rocks increased greatly. In contrast, during 1985 there was little algal buildup and we hypothesized that nitrogen was limiting. However, when we added both phosphorus and nitrogen in 1986 we still found little increase in algal biomass on the river bottom and we were forced to seek an alternate explanation.

We currently feel that grazing insects are controlling algal biomass in the fertilized reach whereas algae are nutrient limited in the control reach. Growth rates of all four dominant insect species have increased in response to the fertilization. The populations of the two grazers, the mayfly (Baetis) and the omnivorous caddis (Brachycentrus), have increased dramatically. Perhaps at these high densities the insects prevent the large algal biomass accumulations that were observed in 1983 and 1984. The response was delayed for two years because the life cycle of the insects is one to three years for Baetis and Brachycentrus, respectively. In contrast to the grazers, the filter feeding blackflies have experienced a population decline in the fertilized reach even though their growth rates are stimulated by the fertilization.

The abundance of grazing insects has greatly stimulated fish growth and reproduction. Adult grayling from the fertilized river reach grow faster, achieve better condition prior to the overwintering migration, and produce more eggs for the following spring spawning than fish from the upstream control reach. Larval and young-of-the-year grayling grow 40 to 100% faster in the fertilized reach than in the control reach.

The experiments in the Kuparuk River have shown that river metabolism is closely coupled to and regulated by nutrient inputs from the watershed. The cycles of phosphorus and nitrogen interact strongly. When phosphorus inputs are high, inorganic nitrogen in the river water is taken up and export of nitrate is decreased. Over several years of high phosphorus input, the stream community has evolved and we anticipate that these changes will continue in the future. These observations call into question the utility of short-term experiments on bioassays in predicting long-term ecosystem responses and argue strongly for long-term ecosystem research.

Figure 1. Schematic drawing of study sites and soil profiles along the mesotopographic gradient at the Sugavairnarkot River. Diagonal lines in the soil profiles represent organic horizons. Horizontal lines represent permafrost. Profile depths are in centimeters. Vertical relief from the willows (Site #1) to tussock tundra (Site #6) is about 30m. Horizontal distance of the transect is about 350m.

Figure 2. "Available" nitrogen and phosphorus in soils of six ecosystems along the riverside toposequence in the summer of 1986. The nitrogen data are seasonal averages of KCl-extractable ammonium and nitrate. Because early-season KCl-extractable phosphate levels were extremely high, results from the first extraction in early June are shown separately from the average phosphate availability in four later extractions.
The carbon and nitrogen transferred from plants to animals in food chains is a key to the growth and survival of animals. But the transfers are not always one-way, for there are many complex interrelationships between animals and their foods. Thus animal grazing removes plant biomass, but animal excretion provides nutrients for new plant growth. Recent ecological thinking has emphasized these complex relationships in formulating theories of food web regulation. In some cases predators or grazers effectively control production of lower trophic levels, while in other cases the level of primary production limits the production of animals. This has been termed "top-down" versus "bottom-up" control of productivity and animal populations. In practice, it is often difficult to separate the effects of predation versus primary production in controlling food web structure. A simple averaging or integrating technique for measuring animal diets and overall energy flow in food webs would be extremely helpful.

Measurements of the stable isotopes of carbon ($^{13}$C/$^{12}$C) and nitrogen ($^{15}$N/$^{14}$N) provide one such averaging technique for tracing energy flow in food webs. In animals, the amount of the heavy isotope of nitrogen, $^{15}$N, rises in food chains by 3-4%o with each trophic transfer such as when fish feed on zooplankton. This increase is due to a faster loss of $^{14}$N than $^{15}$N in excreta, leaving animals...
enriched in $^{15}$N. Simple measurement of the $^{15}$N content of animals provides a quick way to estimate the average food chain length and trophic positions of individual animals. Carbon stable isotope measurements record a different aspect of food web structure, indicating which primary producers provide the energy used by consumers in food webs. For example, fish feeding on stream algae may have different $^{13}$C contents than fish that feed on decaying leaves.

In 1986, we began $^{13}$C and $^{15}$N stable isotope studies of fish feeding ecology in two different environments: the Georges Bank fishery off New England, and the Kuparuk River of Alaska's North Slope. The marine Georges Bank studies show how $^{15}$N increases in food webs while the freshwater Kuparuk results show how the $^{13}$C contained in the fish records changes in algal production.

Georges Bank Fisheries

On a July 1986 cruise aboard the National Marine Fisheries' vessel, Delaware II, Brian Fry collected fish and their stomach contents from Georges Bank (Figure 1). Nitrogen measurements showed that fish are, on average, $3.5\%$ enriched in $^{15}$N relative to their invertebrate prey (Figure 2). This average relationship holds in spite of some exceptions. For instance, one silver hake ate squid whose $^{15}$N content was higher than the hake's (Figure 2, silver hake B). This exception shows that fish diets are very broad; they sometimes include animals who occupy an apparently higher trophic position than themselves.

A preliminary estimate of the Georges Bank trophic structure can be made using the $^{15}$N analyses. The total $^{15}$N range for plants and animals from Georges Bank is $+5$ to $+14\%$ (Figure 3), with most common fish averaging $+12\%$. These fish are about $7\%$, or two trophic levels ($2 \times 3.5\%$), higher than plants. This $^{15}$N estimate of average fish trophic level agrees well with existing fisheries models. More extensive use of $^{15}$N measurements may allow an easy way to monitor and compare fish feeding between seasons and years.

Kuparuk River Fertilization Study

Freshwater studies in the Kuparuk River of Alaska have led Bruce Peterson to focus on $^{13}$C measurements as recorders of stream algal production. This production is greatly increased when phosphorus and nitrogen fertilizer is dripped into the river. The rocks become covered with filamentous algae in the stream equivalent of a plankton bloom. This algal bloom is recorded in increased $^{13}$C contents of fish and their insect foods (Figure 4). The four insect species of the Kuparuk (Figure 4) seem to consume plant foods that differ in $^{13}$C content. But all insect species shift in synchrony to higher $^{13}$C contents downstream of fertilizer inputs, suggesting that new algal production is generally enriched in $^{13}$C. Fish also grow to larger sizes in the fertilized stretch of the Kuparuk, so that monitoring changes in fish $^{13}$C may be a way to monitor both changes in algal production and fish growth rates.

Stable isotope measurements promise a new way to understand how primary production and fish feeding are connected. Combined use of these C and N natural isotopic tracers enables us to describe energy flow in food webs and follow changes that occur in response to human or natural perturbation.
Figure 4.
Increases in fish and insect $^{13}$C contents in the Kuparuk River, Alaska, downstream of fertilization sites with phosphorus at 0.5 km and nitrogen at 1.8 km. The downstream $^{13}$C increases are due to increased algal $^{13}$C contents that are propagated through this stream food web to insects and fish.

Brian Fry and Bob Michener preparing gas samples for stable isotope studies in the Mass Spectrometer Laboratory.
Forests as Wastewater Filters

The problem of disposal of man's wastewater has many wrong answers and few right ones. It is possible that one virtually unexploited disposal method, the spraying of treated sewage onto forests, can be made use of with the aid of ecological data.

As recently as 1974, 84% of municipal wastewater was discharged into surface waters; widespread eutrophication and pollution of rivers and coastal waters resulted. In an attempt to encourage alternative treatments, the Federal Water Pollution Control Act of 1972 called for zero discharge by 1985. In 1986 most wastewater still enters surface waters but there are now more than 1500 land treatment sites nationwide. Of these, only about 20 utilize forested lands.

In 1988 the town of Falmouth, near Woods Hole, will begin to spray half of its treated sewage into a forest. The Ecosystems Center has taken advantage of this very expensive experimental manipulation to begin a long-term study of the effects of the forest on the sewage, of the sewage on the forest, and of the treatment on the groundwater. Marilyn Jordan is in charge of the project.

Cape Cod is the most rapidly growing area in New England. Sewage disposal is mostly by infiltration to the groundwater yet Cape Cod uses the groundwater aquifer as the sole source of drinking water. Falmouth first began treating its sewage in 1986; 750,000 gallons per day are being disposed of by rapid infiltration in sand filter beds. In the spring of 1988 half of this wastewater will be disposed of by spray irrigation (1.5 inches of water per week) of 60 acres of forest and grassland. One-third of the 60 acres is a fertile oak-pine forest about 80 years old, one-third is an impoverished pitch pine forest about 25 years old, and one-third is grassland. Thus, this site provides the unique opportunity to compare the responses to the spray irrigation of sewage of three types of vegetation under similar conditions of soil and climate. Nearby unirrigated areas will serve as controls.

A two year baseline study has now been completed and permanent plots have been established in the control and irrigation areas. Species composition and biomass of trees, shrubs, and herbs have been surveyed. An array of 48 suction lysimeters have been installed at a depth of 0.5 meters in the soil to collect samples of soil porewater just below the rooting zone. Rain gauges near these lysimeters will record rates of wastewater deposition. Other baseline studies include the rates of litterfall and soil nitrogen mineralization as well as the soil density, pH, and organic matter content.

From these data, the nitrogen cycle in the oak and pine forest has been outlined (Figures 1 and 2). Nitrogen is a difficult element to remove, can cause human health problems in drinking water, and is often the limiting nutrient for forest growth. It is expected that major changes in the nitrogen cycle will occur when more than 100 times the normal amount of nitrogen is added in the irrigation water (annual deposition of 450 kg per hectare). The nitrogen will be taken up by the vegetation and stored in the biomass, will be lost as a gas through denitrification, and will pass through the soil into the groundwater. The relative importance and the rates of these processes must be followed before the rules for the optimal ecological operation of such a system can be determined.

Research at the Falmouth spray irrigation site should provide many benefits. At the regional level, a successfully functioning forest irrigation system could promote adoption of forest land treatment in southeastern New England. The data will also be valuable for development of design criteria for new sites in areas with similar vegetation and soils and will provide data on the processes involved. At the local level, the study will provide information for management to maximize nitrogen removal. Finally, this large experiment will provide a local site for the Center's research on nutrient cycling, microbial ecology, physiological ecology, and flux of trace gases from forest to the atmosphere.
Figure 1.
Nitrogen cycling in the pine woods. Vegetation stocks and uptake include both above and below ground plant parts. Litterfall includes only above ground contributions. Soil stocks include the litter and humus horizons plus the top 10 cm of mineral soil.

Figure 2.
Nitrogen cycling in the oak woods. Vegetation stocks and uptake include both above and below ground plant parts. Litterfall includes only above ground contributions. Soil stocks include the litter and humus horizons plus the top 10 cm of mineral soil.
The valuable tropical forests of the earth are being rapidly cleared because of a desire for short-term gain, because of population pressure, and because of geopolitics. Yet it is so difficult to measure the rate of this clearing by conventional techniques that it is not at all well known. Despite this, the rate estimates that do exist are used for policy decisions and to determine the release of CO₂ to the atmosphere. One solution is to remote sense by satellite.

Remote sensing of the environment has been largely carried out since 1972 with the Landsat satellites, which utilize the reflected radiance in the visible and near-infrared portions of the electromagnetic spectrum. The next step is to utilize other parts of the spectrum. One example of this is recent research by Tom Stone of the Center in which the microwave portion is used for analysis of tropical forests and deforestation.

The advantage of microwaves, or radar, is several fold. First, the waves penetrate clouds and so can both cover the entire region and operate day or night. Second, radar can give new information by sensing the large differences in biomass between a primary forest and a young secondary forest. This ability to sense the amount of biomass is different from Landsat which mostly sees leaves; once a canopy regrows a primary forest is indistinguishable from a regrowing secondary forest.

To test this radar method against Landsat, an area including intact and recently cleared forest was analyzed in Mato Grosso, Brazil. For analysis of the Landsat data, a vegetation index (NDVI) for each unit of area (pixel) was calculated. The NDVI is the ratio of the intensity in two different Landsat wavelength bands. For the same region, the radar data came from the Space Shuttle Imaging Radar-A (SIR-A) (Figure 1). When the NDVI data are plotted against the SIR-A data (Figure 2), there is an obvious increase in the radar values as the NDVI values increase. That is, the reflection increases (appears brighter) as the amount of vegetation increases. However, there are anomalies for when the data from the 25 sites are fitted to a regression, it becomes apparent that there is a significant drop in radar brightness at sites highest in NDVI, that is, the intact or primary forest. From this it appears that a three or five component model can be used to explain most of the variance seen when comparing the radar brightness signal and the Landsat NDVI.

One possible explanation for the very bright radar response of some areas is that these are forests which have been recently burned. Most of the cleared forest in this part of Brazil, Southern Amazonia, will become pasture for cattle. The land is cleared by cutting and burning which leaves a great deal of wood and litter intact. These are textural very rough and reflect the radar very well. Also, the absence of the canopy results in a brighter image for the intact canopy causes diffusion and attenuation of the radar signal. Over time, this wood and litter is destroyed, usually by the recurrent fires that are set every other year to control weeds. The result is less and less reflectance over the time the area is maintained as pasture.

If this hypothesis is correct and if NDVI is correlated with green leaf mass and leaf area, then radar and NDVI in concert will give the relative age of the cleared area and the amount of regrowth may be estimated. Areas with very low radar responses and low NDVI's may be old pastures very recently burned or otherwise devoid of vegetation. Areas with high radar brightness and high NDVI may be recently cleared with a significant amount of vegetative regrowth. Areas with intermediate radar brightness and high NDVI's are intact forest.

The analysis of forests and land use in the tropics will improve greatly when the new Shuttle radar (SIR-C) becomes available within a decade. SIR-C will measure simultaneously two wavelengths of radar at the full range of polarizations and at several incidence angles to the ground. From these data it should be possible to define the stature and distribution of the tropical forests, the impact of man upon these forests, and the types of vegetation replacing the primary forest.
Figure 1.
Image of a portion of the Alta Floresta region of Mato Grosso, Brazil from the Space Shuttle Imaging Radar-A. The large clearing at the left of the image is the agricultural project Fazenda Mongo. At the time of this image (15 November 1981) about 140 km² of tropical seasonal forest had been cleared for the project. Note that the disturbed area at the lower part of the clearing is brighter than the surrounding undisturbed tropical forest. The image is about 45 km wide.

Figure 2.
Plot of Shuttle Imaging Radar-A brightness versus Landsat NDVI for the same sites near Alta Floresta. All sites with an NDVI above 0.50 are primary or undisturbed forest. All sites with an NDVI below 0.50 are partially or fully cleared since 1973 and planted to pasture, perennial or annual crops, or are abandoned.
The decomposition of organic matter (detritus) in sediments is essential to the maintenance of aquatic ecosystems. This process recycles nutrients bound in the detritus and fuels a complex, and often highly productive, benthic food web. While the major chemical pathways for decomposition have been well described and the rates at which detritus is processed along some of these pathways have been measured, we currently have little understanding of what controls decomposition rates. For example, we do not know whether rates are altered by the nature of the decomposition pathway.

Since the dominant anoxic pathways of lake and oceanic sediments differ (with methanogenesis in the former and sulfate reduction in the latter), fundamental differences in the cycling of organic matter may exist between these ecosystems. An indication that such fundamental differences indeed exist is the finding of much higher levels of organic matter in lake sediments than beneath the most productive coastal oceans. Furthermore, it has been found that for a given level of primary production, fish production in lakes is far less than in oceans.

In order to study causal relations in these complex ecosystems, experimental manipulations are necessary. David Rudnick, along with John Hobbie, Anne Giblin and Gary Banta, recently ran a laboratory experiment on decomposition processes in marine sediments. They tested whether oxic (using molecular oxygen) decomposition of phytoplankton detritus is faster than anoxic decomposition (via sulfate reduction) and whether decomposition is inhibited by the presence of metabolic byproducts, such as sulfides, that accumulate in sedimentary pore waters.

In these experiments, $^{14}$C labelled phytoplankton was injected into Buzzards Bay sediment cores and the chemical environment within these cores was controlled by continuously pumping four different types of water through the sediment. These treatments included aerated seawater, anoxic seawater, porewater from Buzzards Bay sediment, and porewater from an anoxic basin’s sediment (rich in sulfides and ammonium). The production of $^{14}$C-CO$_2$ from each core was measured for six months.

In Figure 1, it can be seen that metabolic byproducts in porewaters did not inhibit the decomposition of the labelled phytoplankton detritus. $^{14}$C-CO$_2$ production rates in the three anoxic treatments were nearly identical, despite a wide range in the concentration of potential inhibitors (e.g., a sulfide range of 0 to 3 mM). Furthermore, it can be seen that decomposition was faster in the presence of aerated seawater.

These results support the hypothesis that organic matter accumulates more rapidly in anoxic marine basins not only because the rate of detrital supply is faster, but also because of anoxia itself. Furthermore, these results indicate that marine benthic fauna stimulate decomposition rates because they maintain oxic conditions in subsurface sediments, but not because metabolic byproducts are flushed from sediments by their irrigation of porewaters.

This experimental approach will next be used in a direct comparison of decomposition in lake and marine sediments (in collaboration with Bob Howarth of Cornell University). Lake and marine sediments not only have vastly different chemistries (with different metabolic byproducts), but also receive different qualitative types of detritus and contain fauna that have substantially different burrowing behavior (Figure 2). How these factors affect decomposition rates will be compared in Lake Ontario and Buzzards Bay sediments. With such laboratory studies, some of the major similarities and differences of aquatic ecosystems may be identified.
Figure 1.
The cumulative production of $^{14}$C-CO$_2$ (dissolved inorganic carbon, DIC) in DPM from the decomposition of labelled algae in Buzzards Bay sediment. This algae was added to the sediment twice (days 0 to 75). The four types of water that were pumped through the sediment were aerated seawater (oxygen), deoxygenated seawater (nitrogen), porewater from Buzzards Bay mud (B. Bay), and porewater from an anoxic basin's mud (Orleans).

Figure 2.
Schematic diagram of the major aspects of detrital decomposition in lake and coastal marine sediments. Generally, lake sediments receive a larger variety of detrital types than marine sediments, contain smaller animals that do not mix the sediment and porewater as much as marine animals, and have anaerobic decomposers that predominantly utilize carbon dioxide (producing methane) while marine anaerobes largely depend on sulfate reduction.
Research is at the heart of the Center’s activities but the research results become valuable only when they are communicated to students, scientists, and policy makers. This communication takes place through courses, presentations at scientific meetings, visiting students and scientists, publications, and expert testimony and advice. At the present time, we give no formal courses but do lecture extensively at various universities and in the MBL Marine Ecology Course. The goal of these lectures is to present our understanding of how ecosystems function and how to approach the study of ecosystems.

It is equally important to the scientists at the Center to have information flowing in as well as out. Short courses and workshops help but even more stimulation and excitement come from visiting students and scientists. To foster this interaction, the Center supports two post-doctoral fellows, and encourages the visits of other scientists. In 1986, Dr. W. John O’Brien, an animal ecologist from the University of Kansas, Lawrence, visited from February until June and worked with Hobbie and Peterson on a synthesis of arctic research. In September, Dr. Richard Waring, a forest ecologist from Oregon State University, Corvallis, began a ten-month stay at the Center as a senior postdoctoral fellow. Dr. Parke Rublee from Whitman College in Walla Walla, Washington, took part in the NSF Arctic project under a research opportunity award.

Because the MBL does not award degrees, graduate students at the Center are enrolled at a variety of universities. Over the past decade, students from Yale, Harvard, Boston University, and North Carolina State University have carried out research at the Center. During 1986, the graduate students were Gary Banta and David White from the Boston University Marine Program. The main barrier to having more graduate students at the Center continues to be the problem of funding their first two years of school when they must attend their home institution full-time.

Post-doctoral fellows work at the Center in association with at least one staff scientist. The shared laboratories and cooperative nature of the research allows the fellows to take full advantage of the diversity of staff and opportunities available at the Center.

David Rudnick joined the Center in October, 1984, after completing his dissertation in oceanography at the University of Rhode Island. He has worked with John Hobbie and Jonathan Cole on the effects of eutrophication on bacterial production in the sea. He has also worked with Bob Howarth and John Hobbie on anaerobic decomposition processes in marine sediments. Dave left the Center in mid-1986 when he was awarded a National Science Foundation Postdoctoral Fellowship in Environmental Biology for a two-year period. He now has a joint appointment with Cornell University’s Section of Ecology and Systematics and Ecosystems Research Center. He is working on a comparison of detrital decomposition in lake and marine sediments with Bob Howarth at Cornell and with John Hobbie, Anne Giblin and Gary Banta at the Ecosystems Center.

Ed Rastetter became a member of The Ecosystems Center’s staff in February, 1986, after completing his Ph.D. in Environmental Sciences at the University of Virginia. He is currently working with John Hobbie, Gus Shaver, Knute Nadelhoffer and Skee Houghton developing a model of the responses of terrestrial ecosystems to changes in atmospheric CO₂ concentration, to changes in climate, and to changes in soil nutrient concentrations. He is also working with Bruce Peterson and Paul Steudler modelling the emissions of trace gases from terrestrial ecosystems and wetlands.

More detailed information on the post-doctoral research contributions may be found elsewhere in this issue.
The Center's Advisory Committee consists of eminent scientists appointed jointly by the Director of the Marine Biological Laboratory and The Ecosystems Center. The Committee meets at least once a year to review programs and personnel of the Center, to assist with planning, and to consider any other matters affecting the Center's capacity to carry on its research. On September 30, 1986, the following Committee members met in Woods Hole with the Center staff and with the Director of the Marine Biological Laboratory.

**Dr. William Reiners**

Professor and Head of the Department of Botany, University of Wyoming. Dr. Reiners' research interest centers on biogeochemical phenomena in terrestrial ecosystems in the context of vegetation dynamics and spatial variability. Dr. Reiners has investigated variation in detritus dynamics over elevational gradients in New England and is currently investigating the patterns of nutrient cycling in the rolling landscape of sagebrush steppe, the effects of sagebrush conversion to grassland on biogeochemical processes, and the acid neutralization capacity of high elevation soils of the Rocky Mountains.

**Dr. Lawrence R. Pomeroy**

Professor at the Institute of Ecology, University of Georgia. Dr. Pomeroy is best noted for his research in marine biology, cycling of nutrients, microbes and particles, and energetics and cycles of elements in marine and aquatic ecosystems. Dr. Pomeroy is a past president of the American Society of Limnology and Oceanography.

**Dr. William H. Schlesinger**

Associate Professor of Biology at Duke University, Dr. Schlesinger is an ecosystem ecologist interested in global biogeochemical cycles and the role of soil processes in ecosystem studies. Currently his work centers on desert ecosystems in the southwestern United States where he studies the linkages of soil development to ecosystem processes and to the distribution of desert shrubs. His past research has included studies in swamp, chaparral and forest ecosystems, and important contributions toward understanding the role of soils in the global carbon cycle. Dr. Schlesinger is co-author of *Forest Ecosystems* (with R. H. Waring).

**Dr. David Schindler**

Dr. David Schindler is leader of the Experimental Limnology Program, Department of Fisheries and Oceans, Canada. His research at the Experimental Lakes Area in Ontario pioneered the experimental approach of ecosystem ecology, particularly the manipulation of whole lakes with nutrients and acidification. The information from these studies provides a long-term record of the subtle changes in the entire ecosystem, from the chemistry of the sediment to the response of zooplankton and fish communities. He is also a leader in the public debates in the U. S. and Canada on eutrophication and acidification.
January
14  Michael Rabinowitz, Marine Biological Laboratory, & Department of Neurology, Harvard School of Medicine and Children’s Hospital, Boston. “The Urban Geochemistry of Lead”.
28  John Wilson, NASA, Langley Laboratory. “Atmospheric Methane Sources: Tropical and Subtropical Freshwater Wetlands”.

February
4   John Pastor, Natural Resource Research Institute, University of Minnesota - Duluth. “Moose, Microbes, and Boreal Forests”.
6   Carol Johnston, Natural Resource Research Institute, University of Minnesota - Duluth. “Nutrient Movements Across an Agricultural Landscape: The Role of Wetlands”.
11  Gus Shaver, The Ecosystems Center, Marine Biological Laboratory. “Comparative Element Cycling in Contrasting Alaskan Ecosystems”.
18  Thompson Webb, Department of Geology, Brown University. “A Mapped 18,000-Year History of Eastern North American Vegetation”.
28  Cindy Van Dover, Woods Hole Oceanographic Institution. “Carbonate \(^{13}C/^{12}C \) as Indicators of Habitat for Shrimp and Crabs in the Deep Sea”.

March
4   Mark Altabet, Woods Hole Oceanographic Institution. “Natural \(^{15}N/^{14}N \) Ratios as Indicators for Biogeochemical Processes with Specific Applications for an Open Ocean Site”.
11  Steven Wofsy, Harvard University. “Trace Gas Fluxes to and from Amazon Basin Ecosystems”.
18  Phillip Fearnside, National Institute of Amazon Studies, Manaus, Brazil. “Causes and Trends in Deforestation in Brazilian Amazonia and Some Potential Climatic Effects”.
21  R. A. Houghton and Brian Fry, The Ecosystems Center, Marine Biological Laboratory. “Carbon Isotopes in Tree Rings as Indicators of Anthropogenic CO₂ Accumulation”.
28  Werner Deuser, Woods Hole Oceanographic Institution. “Foraminifera as Hydrographic Recorders”.

April
1   Dan Binkley, School of Forestry and Environmental Sciences, Duke University. “Nutrient Cycles and H+ Budgets of Forest Ecosystems”.
4   Brian Fry, The Ecosystems Center, Marine Biological Laboratory. “Stable Nitrogen Isotopes as Tracers of N₂ Fixation in Forests”.
8   Gary Lovette, Institute of Ecosystem Studies, Millbrook, New York. “Atmospheric Deposition and Interactions with the Forest Canopy”.
11  Brian Fry, The Ecosystems Center, Marine Biological Laboratory. “Nitrogen Isotope Effects During Nitrification”.
15  W. John O’Brien, University of Kansas, Lawrence, Kansas. “A New View of Optimal Foraging in Planktivorous Fish”.
18  Brian Fry, The Ecosystems Center, Marine Biological Laboratory. “Sulfur Isotope Effects in a Model Sulfuretum”.
22  David Rudnick, The Ecosystems Center, Marine Biological Laboratory. “Seasonality and Controls of Carbon Cycling through Coastal Marine Sediments”.

Richard H. Waring
May

2   Brian Fry, The Ecosystems Center, Marine Biological Laboratory. “Carbon Isotope Fractionation in Freshwater Sediments, Plants and Food Webs”.
9   Brian Fry, The Ecosystems Center, Marine Biological Laboratory. “The Problem with Methane: Two Puzzles for Isotope Sleuths”.
16  Brian Fry, The Ecosystems Center, Marine Biological Laboratory. “Stable Isotope Modelling: A Few Simple Ins and Outs”.
29  Fred Lipschultz, Engineering Sciences Laboratory, Harvard University. “Nitrogen Cycling in the Low Oxygen Waters Off the Coast of Peru”.

September

9   Don Charles, Indiana University, Bloomington. “Indicators in Recent Lake Sediments of Acid Deposition in the United States”.
23  R. H. Waring, Oregon State University, Corvallis. “Using Airborne Spectroradiometers to Estimate Ecosystem Processes of Photosynthesis, Primary Production and Decomposition”.

October

1   Jeff White, Indiana University, Bloomington. “Trace Metal Transport and Deposition in Freshwater Sediments: The Role of Dissolved Organic Carbon and Iron Oxides”.

November

4   Sarah Horrigan, State University of New York at Stony Brook. “Seasonal Patterns of Ammonium Oxidation in Estuaries: Long Island Sound and the Chesapeake Bay”.
25  Charles Driscoll, Syracuse University. “Effects of Acidification on the Biogeochemistry of Aluminum”.

December

2   Dr. Fred Short, Jackson Marine Laboratory, University of New Hampshire. “An Epidemic Disease in Elmggrass, Zostera marina”.
16  Gus Shaver, The Ecosystems Center, Marine Biological Laboratory. “Production/Biomass Relationships and Element Cycling in the Arctic Landscape”.

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Facilities

The program in stable isotopes was initiated with an award from the A. W. Mellon Foundation and is continuing quite successfully. The Mellon funds were used as a partial match for an NSF grant to purchase the isotope ratio mass spectrometer and to hire Assistant Scientist Brian Fry.

The purpose of this program is to stimulate the use of the stable isotopes, especially those of carbon, nitrogen, and sulfur in ecological research, both terrestrial and aquatic. Not only will this facility be available for cooperative research at the Center and within the Woods Hole community, but it is also available to ecologists across the country for training. It is expected that a number of scientists each year will come to MBL for several weeks at a time to learn how to plan ecological research with stable isotopes, prepare samples for analysis, and operate the mass spectrometer. While mass spectrometers are available at major universities, this instrument is dedicated to ecological use and a visiting scientist can consult with experts in stable isotopes such as Fry and Bruce Peterson.

Appointments

Dr. Jerry Melillo, Associate Scientist at The Ecosystems Center, has taken a leave of absence from the MBL to serve a two-year term as Project Director of the Ecosystems Studies Program at the National Science Foundation in Washington. Among his responsibilities will be overseeing budgets and programs of ecosystems research funded by NSF.

For the past two years Jerry has been a panel member of the NSF Ecosystems Study Review. All proposals submitted to the NSF are first reviewed by outside reviewers and then by the review panel, which make their own recommendations of whether or not to fund a proposal totally, partially or not at all. As a result of his direct involvement at the national level, Jerry hopes to gain more insight into how science is perceived and how programs are developed. Jerry’s research projects here at the MBL will continue with other Ecosystems Center scientists and his research assistants.

Awards

The Ecosystems Center Director John Hobbie was awarded a one-year visiting professorship by the Swedish Natural Science Research Council (NFR) in September, 1986. The $100,000 Tage Erlander professorship allows Hobbie to spend the academic year 1988-89 working on a research plan of his own design at a Swedish University of his choice. The Erlander professorship, created in 1981 in honor of Sweden’s prime minister from 1946-69, is awarded to one scientist per year, selected from an international pool of experts in natural sciences and mathematics. In announcing the award, Ingvar Lindqvist, Secretary General of the Swedish Natural Science Research Council, described Hobbie as “a leading expert in the field of biochemical cycles with special interest in studies of microbial control of decomposition in the ocean, of carbon and nitrogen cycling in freshwaters and of the role of forests in the carbon dioxide increase in the atmosphere”. According to Lindqvist, “these are also areas of great interest to Swedish biological research. There are several scientists and research groups in Sweden working within these fields. We are convinced that their activity would benefit from your knowledge and experience”. Hence, the invitation extended to Hobbie.

Hobbie plans to spend most of the year, beginning sometime in September 1988, at the University of Stockholm, working with the Askö Laboratories. Hobbie is familiar with Sweden having spent two and a half years in Uppsala doing his post-doctoral work from 1962 to 1965 where he became interested in microbial cycling of organic compounds in lakes.

Former Ecosystems Center education staff member Colleen Cavanaugh was awarded the 1986 International Recognition of Professional Excellence (IRPE) prize by the Marine Ecology Jury of the Ecology Institute. The jury cited Cavanaugh for her research on chemosynthesis in hot-vent fauna and other sulfide rich habitats.
on Ecosystems and Community Implications of Population Models at Syracuse University, August 10-16. He spoke on “Spatially explicit models linking geology, hydrology and plant dynamics on barrier beaches and sand dunes”. In September, he participated in a workshop on Use of Supercomputers for Modelling Ecosystems and Landscape Processes in Fort Collins, Colorado. There he talked about “Array and parallel processing in landscape dynamics”.

Anne Giblin spoke on “Pyrite formation in salt marsh sediments” at the Northeastern Estuarine Research Society in Duxbury in April 1986. Together with Bob Howarth and Dave White, she presented “The role of sulfate reduction in mitigating the effects of acid deposition in lakes” at the annual meeting of the American Society of Limnology and Oceanography (ASLO) at the University of Rhode Island in June.

Skee Houghton participated in a consultation and seminar at Oak Ridge National Laboratory, Oak Ridge, Tennessee in May. He also gave a series of three lectures and reviewed the ecological program of the Earth Resources Laboratory, NSTL/NASA, NSTL Station, Mississippi in July. In October, he co-authored a paper with G. M. Woodwell, “Biotic impoverishment. Changes in the structure and function of natural communities under chronic disturbance”, presented at a conference in Woods Hole. Also in October, Skee prepared tabular data for use in “World Resources Report 1987”, a publication of the World Resources Institute of Washington, D.C. In November, Ske titled another article on global deforestation.

In January, Gus Shaver attended a symposium on “The role of landscape heterogeneity in the spread of disturbance” at the University of Georgia. In February, Gus spoke on the “Comparative element cycles of contrasting Alas- kan vegetation types” at the Marine Biological Laboratory. He also participated in the U.S. DOE Arctic Research Program Planning Meeting in San Diego and a seminar at the NASA-Ames Research Center on “Production/biomass relationships and element cycling in contrasting Alaskan ecosystems.” In August, he attended the annual meeting of the Ecological Society of America and co-authored 2 papers presented during the meeting at the University of Syracuse. Gus attended a workshop on “The use of supercomputers in landscape ecology” in September at Colorado State University and conducted 2 seminars at Syracuse University in October. He also gave a seminar on “Production/biomass relationships and element cycling in contrasting Alaskan ecosystems” in December at the Institute of Ecosystem Studies in New York.

Belowground processes in forest ecosystems were the focus of three papers presented at the joint annual meeting of the American Society of Agronomy, the Crop Science Society of America, and the Soil Science Society of America, November 30 - December 5 in New Orleans. The papers and posters, given by the team of Knute Nadelhoffer, Jane Tucker and Andrea Turner, featured nitrogen and carbon cycles and decaying plant and organic soil matter.

Paul Steudler along with Jerry Melillo attended the Fall AGU Meeting in San Francisco and presented “The effect of acid rain on the emissions of carbonyl sulfide and carbon disulfide from European forest soils”. Paul, Jerry and Liz Ferry also presented two papers entitled: “Carbonyl sulfide and carbon disulfide emissions from temperate forest soils” and “Factors controlling the emission of carbonyl sulfide and carbon disulfide from temperate forest soils” at the 2nd International Symposium on Biosphere-Atmosphere Exchange, in Mainz, West Germany, in March.

Tom Stone participated in the SIR-B workshop on Science Results at the Jet Propulsion Laboratory in Pasadena, California in the Spring and talked about “Forest clearings in Amazonia analyzed with SIR-A and Landsat data”. In September, he traveled to San Juan, Puerto Rico to discuss the “Management of the forests of tropical America: technology and perspectives”.

At the joint meeting of the American Society of Limnology and Oceanography and the Phycological Society of America, held in June at the University of Rhode Island, Bruce Peterson and John Hobbie presented a paper on “Tests of the continuous-flow epilithon bioassay: Comparisons with whole-plant enrichments.” At this meeting, Hobbie ended his two-year presidency of ASLO and presided over the annual banquet held at Rosecliff, Newport. Bruce also acted as Program Chairman at the December ASLO/AGU meeting in San Francisco, attended by many of the Ecosystems Center scientific staff.

At the Ocean Sciences Meeting of the American Geophysical Union and the American Society of Limnology and Oceanography, held in New Orleans in January, Dave Rudnick, John Hobbie and Bob Howarth presented a paper on “Control of detrital decomposition in suboxic sediments: The importance of pore water irrigation.” Dave also gave talks on carbon cycling in marine sediments at the Ecosystems Research Center at Cornell University, the Institute for Ecosystem Studies at the Mary Flagler Cary Arboretum in Millbrook, NY and here at the Ecosystems Center of the Marine Biological Laboratory.

In August, Hobbie gave a paper on arctic microbial food webs at the 3rd International Workshop on the Measurement of Microbial Activities in the Carbon Cycle of Aquatic Ecosystems at Utrecht, The Netherlands. Also, he took part in an overview at Athens, Georgia, of the EPA programs in ecological risk assessment.
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Nancy Plummer, Laboratory Technician

Sandra Povia, Laboratory Technician


Fry, B., H. Gest and J. M. Hayes. Sulfur isotope effects associated with protonation of HS⁻ and volatilization of H₂S. *Chemical Geology* 58:253-258.


Houghton, R. A. Biotic changes consistent with the increased seasonal amplitude of atmospheric CO₂ concentrations. *Journal of Geophysical Research*.


**PUBLICATIONS IN PRESS**


National Science Foundation

NSF-BSR-8507493
"Nutrient cycling in an arctic landscape: Interactions between ecosystems along a riverside toposequence.”
September 1985 - September 1988
Investigators: Shaver, Giblin, Nadelhoffer
$810,000

NSF OCE-8415687
"Controls of anoxic decomposition processes in marine sediments.”
February 1985 - July 1987
Investigator: Hobbie
$209,706

NSF DPP-8320544
"Response of arctic freshwater ecosystems to environmental stress.”
June 1984 - November 1987
Investigators: Hobbie, Peterson
$1,429,808

NSF BSR-8509732
"The biota and the global carbon cycle: Effects of changes in climate and in global element cycles.”
November 1985 - October 1987
Investigators: Hobbie, Peterson, Houghton, Shaver
$269,218

NSF BSR-8509733
"Acquisition of a mass spectrometer.”
November 1985 - October 1986
Investigators: Hobbie, Giblin, Houghton, Shaver, Melillo, Peterson
$150,000

DOE-19X-43393C
"Mathematical models for use in defining the role of the terrestrial biota in the global CO₂ cycle.”
October 1983 - September 1986
Investigators: Houghton, Melillo
$623,645

DOE-19X-43393C
"A LANDSAT-based estimate of deforestation in critical areas of the globe.”
December 1983 - December 1987
Investigators: Houghton, Hobbie
$512,554

III. NASA

National Aeronautics and Space Administration
"Global changes in biogeochemical cycles in response to human activity.”
Subcontract to University of New Hampshire.
June 1986 - May 1989
Investigators: Melillo, Peterson
$495,581

JPL-957003/OS-6-7203
"An analysis of deforestation/ reforestation in the Amazon River basin using SIR-B Imagery.”
September 1984 - September 1987
Investigator: Stone
$75,000

Jet Propulsion Laboratory
"An analysis of deforestation and reforestation in the Amazon River basin using radar imagery.”
October 1986 - October 1987
Investigator: Stone
$30,000
IV. Miscellaneous

Institute of Ecosystem Studies, New York Botanical Garden
“The role of sulfate reduction and sulfur storage in generating alkalinity in lakes.”
September 1984 - January 1987
Investigator: Giblin
$29,975

Water Resources Research Center, U.S.G.S.
“Role of sulfate reduction in mitigating the effects of acid deposition in lakes”
July 1986 - July 1987
Investigators: Giblin, Peterson
$9,225

U.S. EPA, Watershed Manipulation Project
“Nitrate mobility and nitrogen cycling.”
September 1986 - August 1989
Investigator: Nadelhoffer
$289,067

Exxon Corporation
“Trace gas emissions from temperate and boreal forests.”
January 1986 - December 1987
Investigators: Melillo, Steudler
$50,000
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 funding from the following foundations:

Atlantic Richfield Foundation
Robert Sterling Clark Foundation
Clowes Fund
Charles E. Culpeper Foundation, Inc.
Arthur Vining Davis Foundations
Henry L. and Grace Doherty Charitable Foundations
Exxon Corporation
Max C. Fleischmann Foundation
Ford Foundation
General Electric Foundation
Grace Foundation, Inc.
Grass Foundation
Charles Hayden Foundation
International Business Machines Corporation
Charles A. Lindbergh Fund
Andrew W. Mellon Foundation
NL Industries Foundation, Inc.
Jessie Smith Noyes Foundation, Inc.
Rockefeller Brothers Fund
Rockefeller Foundation
Rowland Foundation
Sherman Foundation, Inc.
Surdna Foundation, Inc.
Woods Hole Oceanographic Institution
World Wildlife Fund
National Resources Defense Council
FINANCIAL RESOURCES FOR ECOSYSTEMS RESEARCH AND EDUCATION

The operating budget of the Ecosystems Center remained level in 1986 at $1,980,000. There are two sources of funds for the Center’s programs, grants from government agencies for specific research projects and gifts and income from gifts from private foundations.

Contract Research

Most of the Center’s income is in the form of research grants from government agencies to individual scientists or groups of scientists. Awards for basic research from the National Science Foundation and the Department of Energy make up most of the total.

Other Gifts and Income

The Center was founded with gifts from private foundations; current gifts and income from past general use donations provide the flexibility for the development of new research projects, the carrying out of public policy activities, and the Center’s educational programs. During 1986, the Center continued to spend the $340,000 awarded in 1984 by the A. W. Mellon Foundation for the purpose of salary support for staff and postdoctorals and for developing new projects dealing with the use of stable isotopes in ecological research and with the subtle responses of ecosystems to man’s wastes. Additional support was received from the EXXON Corporation for research on trace gas releases from forests. Income from the Ecosystems Reserve Fund, which is approximately the same size as the annual operating budget, helps to defray costs of operations, the consultations of staff with government policy groups, and a seminar program which brings an outside speaker to the Center each Tuesday. In addition, the Reserve Fund supports two postdoctoral fellows, a valuable aid for keeping scientists challenged.