The Ecosystems Center

MARINE BIOLOGICAL LABORATORY
WOODS HOLE, MASSACHUSETTS
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Dividing an arctic lake to study the interaction of fertilization and fish.

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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 nine scientists include terrestrial and aquatic ecology, microbiology, chemistry, remote sensing, botany, zoology, physiology and modelling. 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, chemical and mass spectrometer 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 15N, and other spectrometers. The Center's mass spectrometer facility, one of the first in the country to promote the use of stable isotopes in ecological research, is used for analysis of the ratios of isotopes of carbon, nitrogen, and sulfur.

The research projects at the Center are mostly funded by the National Science Foundation; there are also grants from the Department of Energy, EPA, and NASA. Almost all of the projects involve multiple investigators. That is, there are at least two scientists from the Center on every grant or a Center scientist and a scientist from outside the MBL. One grant, the NSF generic ecosystem modelling project, includes four scientists from the Center and two from the University of New Hampshire. The Arctic Long-Term Ecological Research (LTER) project involves 14 investigators, 7 of whom are Ecosystems Center scientists. Finally, the realities of the granting process dictate that each of the Center staff is 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 Ecosystems 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.
The opportunities for research in ecosystem ecology have never been better. The NSF's Long Term Ecological Research Program continues to expand, EPA officials are not only funding studies of whole watersheds but are talking about making ecosystem studies and monitoring the focus of the next decade's research. Finally, the International Geosphere-Biosphere Program, an international coordinated effort of the 1990's, is focusing the attention of scientists and agencies on questions of global change and on the interactions of the physical/chemical environment with the biota. This focus will lead to an increasing demand for ecosystem science, where scientists have developed techniques for large scale, multidisciplinary studies.

It is obvious that there will be many opportunities for exciting research. But ecosystem ecology is, after all, only a few decades old. Has it been successful? Is there the knowledge, the predictive power, and personnel to meet the challenge? From our perspective, there have been many successes and these are documented in recent ecosystem-oriented texts on forests, marine systems, and lakes. Only recently, however, have we learned enough about a number of systems so that meaningful synthesis across systems can begin. The modeling of ecosystems is also coming-of-age; realistic and usable models are now at advanced stages of development. Thus, the current state of the science is good. But there is cause for concern. One estimate is that there are less than 200 scientists who are a part of the reviewing pool at NSF for freshwater and terrestrial ecosystem research and this is clearly not enough active researchers. Synthesis lags data collection. Agencies sometimes receive less than the best advice.

What does ecosystem science need to move forward and how is The Ecosystems Center helping? First, there is a need to unify the field through synthesis of the scientific results. Center scientists recently published a major synthesis of the use of stable isotopes in ecological studies as well as editing a textbook on microbial ecology. One of us is organizing a SCOPE conference on modeling global change.

Second, there is a need for more scientists. Here the Center has had a major impact by steering a large number of our undergraduate interns, research assistants, graduate students, and postdoctoral fellows into a career in ecosystem ecology. Because the MBL is not a degree granting institution, only four graduate students have been trained. The largest impact has been through our research assistants who have gone back to graduate programs after two or three years at the Center. A number of these have now completed PhD programs at institutions such as Duke, Harvard, MIT, Colorado State University, Wisconsin, U.C. Berkeley, University of Massachusetts, and North Carolina State University. In addition, the Center's postdoctoral program has also given additional experience to more than a dozen scientists.

Third, there is a need for advice and help for government agencies. The Center scientists have given their time and energy to helping the government agencies who fund ecosystem research. In recent years they have served on committees advising DOE, EPA, and NSF. One of us has just returned from two years as director of the Ecosystem Studies Program at NSF. Others serve on the science advisory panels at NSF. All review numerous grant applications for agencies.

Finally, there is a need for leadership of professional organizations. Center scientists have served on the Board of Directors and as the president of the Ecological Society of America and the American Society for Limnology and Oceanography. They were instrumental in setting up the newly formed Association of Ecosystem Research Centers, an activist group who will interact with congressional committees on budgets and directions and who will foster institutional cooperation. This organization also plans to develop documents on the successes of ecosystem science.

The field of ecosystem ecology is maturing rapidly and is playing a leading role in planning and beginning the studies of the future of the biosphere in a changed world. Center scientists are in the thick of the fight.
Ecologists measure exchanges of elements among ecosystem components and growth of biota on the scale of as small as a few square meters or of as large as a watershed. While these serve to answer some questions, other questions require the combination of many separate measurements over an entire region or the entire globe. For example, Paul Steudler and Jerry Melillo are measuring the flux of sulfur trace gases from a square meter of the floor of temperate forests under various levels of acid deposition. Measurements have been made a number of times each year in West Virginia, Massachusetts, and Newfoundland as well as in a gradient of amounts of acid deposition from northern Sweden to West Germany. Because these gases form aerosols in the troposphere that might counteract the greenhouse warming of the earth, we need a method to scale up the site specific data to give an estimate of the release of these gases over an entire year and over large regions (e.g., the eastern U.S.).

To do this scaling we will use a Geographical Information System (G.I.S.) linked to an ecological model. The G.I.S. is a large computer program designed to store and retrieve data referenced to a particular geographic location. For a NASA sponsored project, Jerry Melillo, Paul Steudler, Ed Rastetter, and Bruce Peterson are working with Berrien Moore and his colleagues at the University of New Hampshire. We illustrate the G.I.S. and the linkage to an ecological model with examples from an earlier MBL/UNH project on carbon dioxide exchange.

Figure 1.
The amounts of biomass carbon (boxes) and the annual flux of carbon (arrows) for a non-natural grassland in Kurukshetra, India (29°, 51°N, 76°49′E). The data are from various papers of Yadava, Singh and Gupta.
Figure 3.
The interactions of a geographic information system (GIS) and an ecosystem model.

Figure 2.
An example of the various layers of data within a geographic information system unit.

release resulting from land use change in the tropics.

The basic data from the field might be similar to that in Figure 1, which describes the carbon fluxes in a square meter of a managed grassland in India. Most of the carbon resides in the soil organic matter. This pool is supplemented each year by the litter; in this environment the addition equals the net primary productivity (the net of photosynthesis and respiration of the grasses).

The G.I.S. for this project consists of a computer-based data set covering India. Each part of the set describes ecological conditions for a grid cell 0.5° in latitude by 0.5° in longitude. The data within the cell (Figure 2) describe such things as the vegetation, soils, climate, and rainfall. One use of such a data set would be to print a map of all the cells with both alkaline soils and low rainfall.

A description of how a G.I.S. interacts with an ecological model is given in Figure 3. The model is a general one, such as the Generic Ecosystem Model described later, which predicts the carbon in biomass and the productivity in various types of ecosystems and under different conditions of CO₂ and nutrient concentrations. When the model is run for a cell, the G.I.S. provides the parameters for the vegetation type, the driving variables of temperature, moisture, soil type, etc., and the ecological conditions at the beginning of the simulation. The simulation model provides the G.I.S. the predicted flux of carbon, etc., and the ecosystem characteristics at the end of
the simulation. The G.I.S. stores the information.

The final product of the G.I.S./model linkage would be a map of the different amounts of CO₂ produced throughout India. This map would be similar to that shown in Figure 4. The G.I.S. could also, for example, add up all of the information from all cells to estimate the annual total of the CO₂ entering the atmosphere from this region. Actually, Figure 4 is derived from two other G.I.S. maps. One was a map of biomass and soil carbon in each cell before man changed the landscape. It was calculated from the types of soils and vegetation. The second map was the same as the first except that it represented present day conditions. The map in Figure 4 shows the difference in carbon in each cell which is the carbon released as a result of changing land use from forestry to agriculture.

Although the use of G.I.S. has just begun in ecosystem studies, it has exciting possibilities. At the Center, G.I.S. has already been applied to study CO₂ release from India and nitrogen loss from the Mississippi River drainage basin. It will soon be applied to estimate annual release of sulfur trace gases from forests and to determine the movement of nutrients across the tundra watershed and into an arctic river.

Figure 4.
The distribution of the change in the organic carbon of soils in India from prehistoric times to the present as calculated with a GIS.
Modelling the Responses of Ecosystems to Long-term Changes in the Global Environment

Knute J. Nadelhoffer

Human activities are changing the global environment at an increasingly rapid rate. Burning of tropical forests and increased use of fossil fuels has increased the concentration of CO₂ and other "greenhouse" gases in the atmosphere which are in turn altering the temperature, rainfall, and cloud patterns throughout the world. Acid precipitation derived largely from the burning of fossil fuels has altered the chemistry of streams, lakes, and soils over broad regions of the globe. How will ecosystems around the world respond to these changes?

During the next few years, John Hobbie, Gus Shaver, Knute Nadelhoffer, Jerry Melillo, and Ed Rastetter will be trying to answer this question for three major ecosystem types (temperate deciduous forests, boreal evergreen forest, and temperate grasslands) using funding from the National Science Foundation. John Aber and Berrien Moore from the University of New Hampshire will work with us. Our strategy is to compile the large volume of data available about these ecosystems and use this information to build and calibrate a general mathematical model that can be applied to all three types of ecosystem.

This model will then be used to project the responses of these ecosystems to various environmental changes. Because the same model will be used on all three ecosystem types, comparisons can be made among ecosystems without the potential complication of differences arising from artifacts associated with different models. That is, any differences found can be attributed to differences in the ecosystems themselves and not to the models used to describe them.

There are a number of aspects of ecosystem function that will have to be explored further using smaller more abstract models before they can be incorporated into the larger model. For example, one potentially confounding factor when predicting the responses of ecosystems to changes in their environment is the ability of organisms to acclimate. Some researchers have predicted that plant productivity will increase if atmospheric CO₂ increases. Such predictions are based upon observations of increased rates of photosynthesis during short term exposures of plants to high CO₂ concentrations. These observations have usually been made in greenhouses or other experimental situations where soil nutrients and water are readily available. Other researchers have argued, therefore, that because there may be several other resources that limit plant productivity in natural systems, high plant productivity with high CO₂ concentrations cannot be maintained in nature. Plants might therefore need to acclimate to the CO₂ concentration by adjusting their photosynthetic rate to match the uptake of other resources in the environment. Unfortunately, not enough is known about how plants acclimate to changes in resource availability when several resources are limiting.

To investigate this phenomenon of acclimation to changes in multiple limiting resources, Ed Rastetter and Gus Shaver have developed a simple mathematical model of the response of a plant to changes in the relative availabilities of two mineral resources (Figure 1). In this model, the plant acclimates to a change in the availability of a resource by shifting the effort it expends on resource uptake away from the resource in greater supply to the one in lesser supply. This shift in effort is triggered by a buildup of one resource relative to the other in the plant tissues. In real plants, this shift in effort will take the form of producing more tissues dedicated to uptake of a particular resource (e.g., leaves or fine roots), an increased production of uptake enzymes in that tissue, and an increase in the expenditure of energy to run the uptake process. Because the materials needed to build and run these tissues and enzymes are in limited supply in the plant, a shift in effort in favor of one resource must be at the expense of other plant functions. This limitation is incorporated into the model by requiring that the total effort for uptake of both resources remain constant. Thus, if the effort expended on the uptake of one resource increases, the effort expended on the other resource must decrease by an equal amount.

The model was run to examine the responses of the plant when one of the resources (resource 1) is available in the environment at a relatively constant concentration (e.g., like CO₂) and the concentration of the other could change based on its rates of replenishment and removal from the environment (e.g., like most soil nutrients). Thus the concentration of resource 1 could change in response to some outside factor such as a man-made disturbance but it could not
Figure 1.

A model for the investigation of multiple resource limitation for an acclimating plant: N1 and N2 are the concentrations of two resources in the environment of the plant; B1 and B2 are the internal concentrations of these resources in the plant biomass; F1 and F2 are the replenishment rates of N1 and N2; P1 and P2 are the uptake rates of N1 and N2 by the plant; and R1 and R2 are the loss rates of B1 and B2 from the plant. The V1 and V2 are parameters that control the uptake rates P1 and P2 and are an index of the effort expended in taking up N1 and N2. Acclimation is simulated by changing the relative magnitudes of V1 and V2 in response to changes in the B1 to B2 ratio in such a way as to restore an optimal balance in the plant (see text).

Figure 2.

Response to changes in the replenishment rate of a depleteable resource and the absolute concentration of a non-depleteable resource. N1, N2, P1, P2, V1 and V2 are as in figure 1.

be depleted or augmented by the plant itself. Resource 2 was continuously replenished in the environment but its concentration in the environment could be drawn down if plant uptake increased or it could build up in the environment if plant uptake decreased. When the concentration of resource 1 was doubled (Figure 2, time = 50) the uptake rate of resource 1 increased and, because uptake effort shifted, the uptake of resource 2 also increased (i.e., productivity increased). However, because of the increased removal of resource 2 from the environment by the plant, its concentration dropped, requiring the plant to exert more and more effort to acquire it. This added effort for taking up resource 2 had to be shifted away from the effort to take up resource 1. Thus the uptake rate of resource 2 dropped because its concentration in the environment dropped and the uptake rate of resource 1 dropped because the plant allocated its effort away from taking it up. Eventually, both uptake rates decreased back to their original levels, that is, back to the level where the uptake rate and replenishment rate of the depleteable resource (i.e., resource 2) were equal.

When the replenishment rate of resource 2 was doubled (Figure 2, time = 50), the concentration of resource 2 increased, its uptake increased, and the uptake effort shifted back in favor of resource 1, thus its uptake also increased. However, because resource 1 could not be depleted, there was no subsequent drop in its uptake and the high productivity could be maintained. Will an increase in CO2 concentration result in increased productivity in ecosystems? Only if some associated factor causes the replenishment rates of the depleteable resources in the environment also to increase.
Although ecosystems are often studied as discrete units of a landscape, in fact they are never completely isolated from each other. Rather, all ecosystems are more or less strongly linked to their neighbors through the transport of water, energy, organic matter, and mineral elements: in other words, one ecosystem’s outputs are its neighbor’s inputs. These transport processes are often extremely important in determining an ecosystem’s productivity, its species composition, and the relative importance of its various element cycling processes. Thus in order to understand how an ecosystem works, it is necessary to understand how it interacts with its neighbors.

Transport processes between ecosystems are also important because they determine how far and how fast the effects of disturbance spread over the landscape. When element cycles are disrupted or changed by disturbance within a single ecosystem, the effects are not always confined to the area directly disturbed. Adjacent areas may be strongly influenced by either an increase or a decrease in the outputs of water, nutrients, or organic matter from the disturbed site.

Aquatic ecosystems are particularly dependent upon inputs from the terrestrial ecosystems that they drain (Figure 1), and often much of the variability among different lakes and streams can be explained by variability in inputs from the terrestrial landscape. For the same reasons, aquatic ecosystems are often strongly affected by disturbances that affect only the land surface directly.

Changes in aquatic ecosystems can even be used as sensitive indicators of harder-to-detect changes taking place on land, such as the changes due to acid rain or other chronic but low-level stresses.

Land-water interactions are a major focus of one of the Ecosystems Center’s largest projects, the Long Term Ecological Research (LTER) Program at Toolik Lake, Alaska. Although terrestrial and aquatic ecologists from the Center and elsewhere have been working near Toolik Lake for over a decade, it is only recently that the two groups have begun to work together closely. The arctic LTER program involves seven of the
Arctic grayling being moved by Linda Deegan into an experimental reach of the river.

Figure 2.
Comparison of the size frequency distribution of young-of-the-year (Y0Y) grayling in the control and fertilized reaches of the Kuparuk in 1985 and 1986. Collections were made after 4 weeks of fertilization in 1985 and after 6 weeks of fertilization in 1986. Weights were not adjusted for the one day between collections but such adjustment would increase the weight differential by approximately 10%.

Center's senior staff in collaboration with ecologists from several universities around the USA. The LTER program provides the core funding for data collection and management, and for the setting up and maintenance of several long-term experimental manipulations. Several other independently-funded projects, also based at Toolik Lake, are closely linked to the LTER program and make use of its data base and experiments.

In arctic stream ecosystems, the effects of a change in element inputs can be traced with clarity all the way through the food chain. Over several years of research, we have shown that phosphorus addition to the Kuparuk River causes the entire basis of the food chain to shift from strong heterotrophy (dependence on external energy and carbon inputs) to autotrophy (internal fixation meets most of its carbon and energy requirements). The added nutrients dramatically stimulate the growth and photosynthesis of algae. The algae, in turn, are eaten by insect grazers which thus provide an abundant food supply to the arctic grayling. A recent experimental addition of nitrogen plus phosphorus to the stream resulted in a dramatic increase in fish growth (Figure 2).

What controls the amounts of nitrogen and phosphorus that normally get into arctic lakes and streams? How does disturbance to the terrestrial landscape affect these element inputs, and how far away from a lake or stream must a disturbance be for it to have no effect on aquatic element cycles? One of our long-term research interests is in providing
answers to these questions; to do so we are studying the transport of mineral nutrients over the terrestrial parts of the arctic landscape.

We already know that arctic terrestrial ecosystems vary widely in the relative importance of the major processes of element cycling. Some parts of the terrestrial landscape are strongly nitrogen-limited, and some parts are phosphorus-limited. The predominant form of available nitrogen is usually ammonium, but nitrate is frequently important. As a result of these differences, arctic terrestrial ecosystems also differ in their outputs of nitrate, ammonium, and phosphate in soil water. To understand the relative contribution of each ecosystem type to the chemistry of lakes and streams, we need to consider not only the relative areas of each terrestrial ecosystem type, but also their specific arrangement in the landscape.

Our current terrestrial research is focused on six contrasting ecosystem types in the Sagavanirktok River valley near Toolik Lake (Figure 1). The site was chosen because it includes all of the major terrestrial ecosystem types found over the rest of northern Alaska in one, easily-studied place. Along this sequence of ecosystems there is a wide range in both the absolute and relative concentrations of nitrogen and phosphorus in soil solution (Figure 3), reflecting the variation we also have found in soil nutrient mineralization, plant uptake, and other element cycling processes.

We believe that the element cycles of the six ecosystems along our sequence are linked to each other, and to the river, through the flow of nutrients in soil solution over the top of the permafrost that underlies the whole transect. Using a conceptual model of element cycling along the transect to help focus our thinking (Figure 4), we are gradually developing comparative nitrogen and phosphorus budgets for each ecosystem type along the transect. We are using these budgets to determine the relative importance of internal element recycling versus transport between ecosystem types along the transect. Our current thinking is that the uphill ecosystems, the tussock tundra and hilltop heath, are quite important sources of nitrogen to the hillslope and footslope areas. The wet sedge tundra may actually be losing large amounts of gaseous nitrogen by denitrification of nitrogen inputs from above. The footslope and wet sedge tundra are also major sinks
for phosphorus. As a result, little nitrogen or phosphorus is transported into the riverside willow zone and thus into the river from uphill ecosystems. The high productivity of the willow zone is driven mainly by other nutrient sources, including in situ nitrogen fixation, greater access to freshly-deposited mineral soils, and perhaps the river water itself.

These results are important because they suggest that the type of ecosystem that borders a stream is an important regulator of aquatic element inputs. Streams that drain wet sedge tundra should be lower in element inputs than streams that drain more "leaky" upland tundras. Because element mobility is higher in the upland systems, there is greater potential for rapid spread of the biogeochemical effects of disturbance in the uplands. The next step is further model development to translate our conceptual model into a more detailed simulation model of element transport over the arctic landscape and of the longer-term effects of disturbance on element transport.
Sulfur Storage in Lakes—A Tale of Two Basins

Anne E. Giblin

Sulfate concentrations in lake waters of the northeastern United States have increased in the last 100 years because of acid deposition from anthropogenic sources. The goal of a project of Anne Giblin, Bruce Peterson and Brian Fry is to understand how this deposition has changed the lake sulfur cycles. We have evidence that in response to this increase in lake water sulfate, bacterial sulfate reduction in the anaerobic zones of lake sediments has also increased. This process could counteract acidification because a portion of the acid entering lakes can be neutralized by microbial sulfate reduction; this occurs only if the sulfides produced by this process are stored in the sediments. However, if sulfides diffuse into oxygenated portions of the sediment or overlying water and become reoxidized to sulfate, acidity is produced. Therefore in order to accurately model how lakes respond to changes in sulfate loading it is necessary to understand controls on sulfide storage in lake sediments.

Oxygen concentrations in bottom water, iron concentrations in the sediments, lake productivity, and sulfate concentrations in the water column are all factors that could potentially affect sulfur storage in lakes. Unfortunately, when comparing the sulfur cycle in different lakes several of these factors vary at once, making the importance of a single variable difficult to determine in field studies.

A natural experiment at Trout Lake, Wisconsin, allows the variables to be sorted out. This lake is unusual in hav-

Figure 1. Map of Trout Lake, Wisconsin, showing the main basin and a small anoxic basin where water movement is greatly restricted. Dotted lines indicate sills where water depth is less than 20 feet.
Figure 2.
Oxygen and sulfate in the water column of the main basin (●) and the anoxic basin (▲) on August 29, 1987. Cross hatch lines indicate the depth of the sediment.

Figure 3.
The concentration of total sulfur and chromium reducible sulfur (CRS) in sediments from the main basin and the anoxic basin of Trout Lake. Both cores were taken where the water depth was 18 m.

Sediments from the small anoxic basin contain two to three times more sulfur than sediments taken from the same depth in the main basin (Figure 3), whereas carbon concentrations in the sediments are nearly identical. The difference between the sulfur concentrations in the two basins is due to a much greater accumulation of inorganic reduced sulfur (measured as chromium reducible sulfur) in sediments from the anoxic basin. Since inorganic reduced sulfur (pyrite, FeS and elemental S) is formed via dissimilatory sulfate reduction, the differences in sulfur content between the two basins probably reflect differences in rates of sulfate reduction and of inorganic sulfur reoxidation rather than differences in the sedimentation of organic sulfur.
The sulfur stable isotope ratios of sediments from the two basins also showed interesting differences and these may allow identification of the source of sulfur added to the sediments (Figure 4). In the small anoxic basin, the ratio of heavy ($^{34}$S) to light ($^{32}$S) sulfur shifts to higher values, probably reflecting addition of anthropogenic S with a higher $^{34}$S content than natural background. In contrast, the core from the main basin shows a large shift to negative values in the recently deposited sediment near the top of the core. The lowest values occur near the peak of total sulfur concentrations and may reflect biological fractionation of sulfur isotopes during sulfate reduction. Using stable isotopes to trace anthropogenic sulfur additions may be simpler where this fractionation is small, for example in areas with anoxic bottom waters.

We are now in the process of transplanting sediment from one basin into the other to see how quickly the sulfur profiles will change in response to changes in the overlying water. By combining controlled laboratory experiments with natural experiments such as we found at Trout Lake, we hope to determine the importance of bottom water oxygen on sulfur storage in lakes.

We thank the staff at the University of Wisconsin’s Trout Lake Station for their assistance in this research.

Figure 4.
The $^{34}$S values of sediments taken from the main basin ($\square$) and from the small basin ($\bullet$).
The Fate of Organic Matter in Coastal Ecosystems

The growth of heterotrophs in coastal waters depends upon the organic matter produced in forests, marshes, seagrass meadows and in the plankton. Determining the origins, pathways of use and fate of this material is a long-term goal of ecosystem science. In coastal ecosystems the task is complicated by the complex patterns of tidal currents and riverine flows. Two projects at The Ecosystems Center are currently addressing this issue.

The first project, that of John Hobbie and Anne Giblin, examines the fate of carbon in sediments. Since coastal waters are shallow, much of the particulate carbon produced by algal photosynthesis sinks to the bottom where it is either decomposed by microbes, consumed by animals, or buried. All of these sediment processes are important to the ecology of coastal waters and must be understood so that the results of changes in future circulation and nutrient loading can be predicted. For example, the decomposition rate often controls whether or not the overlying water becomes anaerobic, an increasingly common occurrence which destroys benthic animals. The freshly sedimented organic matter is extremely important to animals and often accounts for most of their annual growth. Even burial is important because if the burial rate increases in the future, as expected by some, then more carbon will be removed from circulation in the biosphere and atmosphere with a possible slowing of the global buildup of carbon dioxide.

A portion of the organic matter reaching the sediment surface is consumed by oxic respiration. However, in these organically rich systems only the top centimeter or less is aerobic and the combination of subsequent sedimentation and the burrowing of marine worms moves a great deal of organic matter into the anaerobic layers of the sediment. Here, some is decomposed by fermenting and sulfate reducing bacteria and some is permanently buried. Our earlier work examined the controls of the fermentation-sulfate reduction process in the laboratory and concluded that contrary to our expectations, there was no evidence for a reduction in rate of anaerobic decomposition from the high concentrations of the measured metabolic products such as sulfide and ammonium. This laboratory study, however, needed to be confirmed with field data.

The coastal waters of Massachusetts and Rhode Island provide a variety of waters differing in primary production and, presumably, in the amount of sedimented organic matter. One end of our productivity transect was the oligotrophic-mesotrophic Buzzards Bay. An embayment near Orleans, Massachusetts, Town Cove, had approximately double the primary production. The range of productivities was further extended by the experimental manipulations being carried out at the University of Rhode Island Marine Ecosystem Research Laboratory (MERL) where 12 m³ tanks contain sediment and water from Narragansett Bay. The tanks were fertilized with various levels of inorganic nutrients so that algal productivity had a five-fold range.

With this range of coastal systems, we asked the question does the rate of sulfate reduction (a measure of anaerobic decomposition) in sediments increase as the primary production increases in overlying waters? If there were to be a proportionate increase in the sulfate reduction rate as the production increased, then we could say that our laboratory results were confirmed - or at least were not negated. We argue that if the same process of sulfate reduction appears to be functioning throughout the entire range of productivities, then no inhibition of this process appears to be operating under the most eutrophic conditions. It is at this extreme that we would expect inhibition caused by the build up of reduced byproducts. If the sulfate reduction rate increases in proportion to the primary productivity, then it is likely controlled solely by the amount of available organic matter.

The results of the measurements of sulfate reduction in seven coastal habitats agree with the idea that the amount of the available organic matter, not inhibition, controls this process over this range (Figure 1). For example, in the MERL tanks experimental manipulations the sulfate reduction increased from 300 to over 2000 nmol cm⁻² day⁻¹. The rate in the eutrophic Orleans sample was 9-fold higher than in the oligotrophic-mesotrophic Buzzards Bay.

A second project focuses on the fate of dissolved organic matter in the water column. Budgets for carbon in coastal ecosystems invariably show that dissolved organic matter (DOM) comprises the bulk of the organic matter circulat-
ing in riverine and estuarine waters. Mass balance studies have shown that much of this is refractory, passing through coastal ecosystems with no change. Yet the intensive bacterial activity measured in estuarine waters indicates that organic matter is being used and that bacteria are responsible for most of this use. Indeed bacterial respiration is the largest component of total ecosystem respiration in estuaries. This means that in order to understand the overall controls of estuarine metabolism or to understand how estuaries process and transform organic matter we need to know more about the origins, utilization and fate of DOM taken up by bacteria.

Center scientists are currently working with Dick Wright and Rick Coffin (Gordon College, Wenham, Massachusetts) to develop methods for identifying the labile organic matter sources contributing to bacterial production in the Parker River Estuary of Northern Massachusetts. Our goal is to develop methods for measuring DOM and its stable isotope composition and to obtain uncontaminated samples of bacterial biomass from estuarine waters for isotope ratio analyses.

The rationale for using stable isotopes to identify the plant origin of bacterial substrates is illustrated in Figure 2. Upland plants, phytoplankton and Spartina have widely different ratios of \( ^{13}C/^{12}C \). Our recent pilot study experiments have shown that DOM leached from oak tree leaves and from Spartina is isotopically similar to the bulk plant. When leachate or glucose is added to sterile (0.2 \( \mu \)) filtered estuarine water which is then inoculated with natural bacteria, the isotopic composition of the resulting bacteria is also the same as that of the substrate isotope ratio. These experiments suggest that the \( ^{13}C \) values of bacteria can be used to determine the original plant source of their growth substrates. In water samples from the Parker River we have found that bacteria growing in unamended water have \( ^{13}C \) values ranging from -11 to -26%. Most often the ratios are similar to Spartina (\( ^{13}C = -12\% \)) but at the most upstream station we found ratios similar to those expected when upland C-3 plants contribute most of the labile substrates.

Our interest in the fate of organic matter in coastal ecosystems does not stop at the level of bacteria. We are working as well on the interactions between animals and decomposition processes in sediments and on linking the microbial food web to macroconsumers with isotope tracers. The long-range goal is to predict how changes in nutrient and organic matter inputs will affect the biota of coastal ecosystems. Man is currently causing such changes but our understanding of the consequences lags badly.
The Ecosystems Center has recently established a Stable Isotope Laboratory to promote use of stable isotopes in ecological and environmental research. Stable isotopes are safe, nonradioactive markers present in all natural materials. Stable isotope measurements are currently used in a wide variety of research and educational projects. Applications include tracing the fate of sulfur and nitrogen in acid rain, following the effects of added sewage and nutrients in lakes and streams, and understanding the controls of the processes of photosynthesis and decomposition of organic molecules.

The stable isotope methodology has been little used in ecology, in part because of high costs of purchasing and maintaining large, sophisticated mass spectrometers required for isotopic measurements. The Ecosystems Center took a lead in promoting this new technology by establishing the Stable Isotope Laboratory in 1985, with funds from NSF and from the A. W. Mellon Foundation. Brian Fry and Bruce Peterson head the laboratory which houses a state-of-the-art Finnigan 251 isotope ratio mass spectrometer and associated sample preparation devices. Expansion of the laboratory is planned for the future. In the fall of 1987, Brian Fry and Bruce Peterson received a National Science Foundation grant to acquire a second, fully automated mass spectrometer, several growth chambers, and a backup emergency power system. The new equipment should greatly expand our ability to rapidly perform and analyze experiments involving stable isotopes.

The Laboratory is operated with an educational outreach philosophy. Through conversation and consultation, staff members at The Ecosystems Center encourage other scientists and students to begin to use stable isotopes in their own research. Samples may be submitted to the Stable Isotope Laboratory, and are analyzed on a cost-recovery, not-for-profit basis. For example, students in MBL summer courses and from other institutions have had samples measured, and three student papers based on stable isotope results were in press or in review at the end of 1987. Educational outreach also extends to Ph.D. level scientists. One highlight of this type of interaction was a week-long national workshop on Stable Isotopes conducted by Brian Fry in Woods Hole. The May workshop is discussed in more detail in the Events section of this report.

The long-term goal of the Stable Isotope Laboratory is to introduce appropriate uses of this new technology in ecosystems science, through writing, teaching, and research. The isotopic measurements offer a new way to view traditional patterns of carbon, nitrogen and sulfur cycling in nature, and provide a way to independently check current ideas about sources and fates of organic matter in ecosystems. We hope to make these measurements an integral and informative part of ecosystems science conducted in the decades ahead.
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 several post-doctoral fellows, and encourages the visits of other scientists. In 1987, Dr. Richard Waring, a forest ecologist from Oregon State University, Corvallis, completed a ten-month visit to The Ecosystems Center as a senior postdoctoral fellow, collaborating on research and writing with members of the scientific staff.

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 working with Bruce Peterson and Paul Steudler modelling the emission of trace gases from terrestrial ecosystems and wetlands and also, as part of the LTER research team, he is modeling the flux of nutrients in the Arctic tundra. In mid-1987, Ed was appointed an Assistant Scientist at the Center.

Carole McIvor joined the Center staff in 1987 as a post-doctoral fellow after completing her Ph.D. in Environmental Sciences at the University of Virginia where she worked with Bill Odum on the role of stream geomorphology in influencing habitat selection by marsh fishes. Carole will be the coordinator for the Arctic LTER, a job which has two components: coordination of research efforts between terrestrial and aquatic portions of the project, and assisting Bruce Peterson on assembling and synthesizing data on the Kuparuk River work.

George Kling was also hired in 1987 as a post-doctoral fellow after finishing his Ph.D. in Zoology at Duke University. The title of his thesis was “Comparative Limnology of Lakes in Cameroon, West Africa”. He is currently working with Brian Fry and Bruce Peterson on tracing carbon and nitrogen flow through Arctic lake food webs using stable isotope distributions in the biota. He is also working with Anne Giblin, Bruce Peterson and Brian Fry on the response of sulfur, iron and nutrient cycling in lakes to increases in sulfur loading from atmospheric deposition.

In July 1987, Jim Raich was appointed a post-doctoral fellow after completing his Ph.D. in Forest Ecology at Duke University. The subject of his thesis was “Influence of treefall gaps on seed germination and tree regeneration in Malaysian Dipterocarp forest”. Jim is currently working with Bruce Peterson, Ed Rastetter and Paul Steudler on the development of a global model of plant production which will be utilized to predict the effects of changing land-use patterns on global runoff and trace gas emissions.

Rich Bowden also joined the staff at The Center in July 1987 as a post-doctoral fellow after completion of his doctorate at Yale University on “The nitrogen budget of a moss (Polytrichum) ecosystem developing upon glacial outwash sands”. His thesis research investigated the importance of mineral soil nitrogen in explaining the observation that forest nitrogen accumulation rates are frequently in excess of measured nitrogen inputs. Rich is conducting research with Ecosystems Center scientists Jerry Melillo and Paul Steudler on a National Science Foundation grant to examine “chronic nitrogen additions to forest ecosystems: the effects on nitrogen cycling, canopy chemistry and nitrous oxide emissions”. In manipulations, nitrogen is added to hardwood and forest stands at the Harvard Forest to simulate long-term additions of atmospheric nitrogen.
The Center's Advisory Committee consists of eminent scientists appointed jointly by the directors of the Marine Biological Laboratory and The Ecosystems Center. The Committee meets every two years 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. Current members of the Committee are:

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 and the acid neutralization capacity of high elevation soils of the Rocky Mountains.

Dr. Lawrence R. Pomeroy
Alumni Foundation Professor, Department of Zoology, 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 and the 1987 recipient of the G. Evelyn Hutchinson Award awarded for continued scientific creativity and contributions.

Dr. William H. Schlesinger
Professor of Botany 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 which aspects of soil development are linked to rates of nutrient cycling and to the distribution of desert shrubs in the southwestern United States. 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 a scientist on staff at the Experimental Limnology Program, Department of Fisheries and Oceans, Canada and was project leader from 1968 to 1987. 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.
February

3 Margaret Schoeninger, Harvard University. “Uses of Stable Isotopes in Archaeology as Tracers of the Human Diet.”
17 Stuart Findley, Institute of Ecosystem Studies, Mary Flagler Cary Arboretum, Millbrook, New York. “Microbial Growth on Particulate Detritus: Fuel for Aquatic Ecosystems.”
24 Jean Hartmann, Harvard Graduate School of Design. “A Latitudinal Study of Spartina alterniflora.”

March

3 Brian Rothschild, Woods Hole Oceanographic Institution. “Unified Theories in Biological Oceanography.”
10 Mike Bender, University of Rhode Island. “The Global Oxygen Cycle - Constraints from Oxygen Isotopes.”

April

7 George Hornberger, University of Virginia, Department of Environmental Sciences. “Predicting Regional Effects of Acidic Deposition on Surface Waters: An Example from Southern Norway.”
28 Mark McDonald, Institute for Ecosystems Studies, Mary Flagler Cary Arboretum, Millbrook, New York. “Dispersal Patterns of Woody Plants: The Role of Vegetation Structure and Landscape Configuration.”

May

5 Robert Aller, Marine Science Research Center, State University of New York, Stony Brook. “Complete Oxidation of Solid Phase Sulfides by Metals and Bacteria in Anoxic Marine Sediments.”
Weekly seminars stimulate the ongoing scientific arguments.

12 David Caron, Woods Hole Oceanographic Institution. "Feeding by Heterotrophic Microorganisms - The Balance Between Carbon, Nitrogen and Phosphorus Assimilation."

September

22 Berrien Moore, Complex Systems Research Center, University of New Hampshire. "On Inverse Methods for Combining Chemical and Physical Oceanographic Data: A Steady State Analysis of the Atlantic Ocean."

29 Dan Nepstad, School of Forestry and Environmental Studies, Yale University. "Deep Roots and Drought: Barriers to Forest Regrowth in Abandoned Amazon Pastures."

October

5 Steve Goodwin, Department of Microbiology, University of Massachusetts-Amherst. "Microbial Hydrogen Metabolism in Natural Anaerobic Ecosystems."

13 Stephen Nodvin, Environmental Sciences, University of Maine. "Soil Processes and Sulfate Loss at Hubbard Brook Experimental Station."


27 John Aber, Complex Systems Research Center, University of New Hampshire. "Detection and Implications of Nitrogen Saturation in Forest Ecosystems."

November


10 Mitchell Lloyd Sogin, Department of Microbiology, University of Colorado Health Sciences Center. "A New Perspective on Eukaryotic Evolution."

17 Jack Cosby, Environmental Sciences, University of Virginia. "Identification of Light-Photosynthesis Models and Photosynthetic Parameter Variation for a Macrophyte Dominated Stream Using the Extended Kalman Filter."

December

1 Ivan Valiela, Boston University Marine Program, Marine Biological Laboratory. "Preliminary Studies of Nutrient Transport from Coastal Watersheds to Coastal Embayments."

8 Barry Rock, Complex Systems Research Center, University of New Hampshire. "Spectral Characterization of Forest Decline Damage."

15 Chris Neill, Environmental Institute, University of Massachusetts-Amherst and Delta Waterfowl and Wetlands Research Station, Manitoba, Canada. "Nitrogen Limitation Along a Water Depth Gradient in a Manitoba Prairie Marsh."
THE ASSOCIATION OF ECOSYSTEM RESEARCH CENTERS

Ecosystem scientists from around the United States have recently formed a new national organization, the Association of Ecosystem Research Centers. The organization, comprising more than 30 research and teaching centers and representing as many as 500 scientists, has elected John E. Hobbie, the Director of The Ecosystems Center, as their first president. According to Hobbie, the AERC has been formed to represent ecosystem ecology in the public sector, for example, before congressional committees and government agencies, and to help advance this science through fostering cooperation among the centers of research.

At the first annual meeting of the Association, held in October at the National Academy of Science in Washington, DC, the focus of discussion was how to organize and be effective. The AERC representatives heard talks by representatives of federal agencies and by representatives of public affairs sections of groups such as the National Association of Land Grant Universities and Colleges. The first year of AERC will be spent in exploring ways to have representation in Washington, to deal with congressional staff, and to communicate among members.

Hobbie says the Association will provide information derived from ecosystem research to federal agencies, legislators and policy makers concerned with environmental problems. In addition, it will furnish its member institutions with a forum for sharing manpower, techniques and information. This collaboration and cooperation is essential, he says, if scientists are going to be able to answer important environmental questions.

ARCTIC LTER SITE

With a National Science Foundation grant of $2.25 million, a field station at Toolik Lake in Alaska became one of the newest Long-Term Ecological Research (LTER) sites. This grant will provide five years of support for 14 investigators, seven of whom are staff at The Ecosystems Center: John Hobbie, Brian Fry, Anne Giblin, Knute Nadelhoffer, Bruce Peterson, Ed Rastetter and Gus Shaver; Carole McIvor of the Center is serving as coordinator. The research site is in the northern foothills of Alaska’s Brooks Range, 130 miles south of Prudhoe Bay, near Toolik Lake and the Kuparuk River. The LTER program at Toolik Lake is designed to build on the aquatic and terrestrial research begun in 1975, to provide core funding for ongoing, long-term experiments, and to link terrestrial, lake and stream studies more precisely. The heart of the program is a series of parallel, whole-ecosystem experiments in lakes, streams, and the major terrestrial ecosystem types. The experiments are of two kinds: “top-down” manipulations of herbivores or predators, and “bottom-up” manipulations of nutrient availability. The overall goal is to understand and to separate the role of animal consumers versus plant/nutrient responses as controls over terrestrial and aquatic ecosystems.

As principal investigator of the LTER project, John Hobbie plans to develop the Toolik Lake field station’s research facilities and to generate a broad ecological data-base pertaining to the arctic ecosystem. An important reason for continuing these experiments in the long-term is that not all species respond at the same rate, and that there is much to be learned by observing the sequence of changes and interpreting their causes. A second major goal of the arctic LTER project is to advance understanding of how mineral nutrients move over the arctic landscape, from terrestrial to aquatic ecosystems.

BIOLOGICAL FACILITIES CENTER

The Ecosystems Center’s Stable Isotope Laboratory became one of twenty Biological Facilities Centers in the United States with a $747,000 grant from the National Science Foundation. The awards are the first given under the NSF’s new Biological Centers Program, and are designed to encourage interdisciplinary scientific collaborations through shared use of state-of-the-art laboratory equipment, and to provide sophisticated instrumentation to biological research centers investigating some of the most challenging problems in biotechnology and environmental biology. The grant will supply the lab with three new pieces of equipment: a second isotope ratio mass spectrometer, a set of four walk-in growth chambers and a backup power system. The mass spectrometer measures with extreme accuracy the ratios of heavy to light isotopes.
contained in organic material; these ratios function as natural tracers for the origin and fate of carbon, nitrogen and sulfur in diverse contexts. The growth chambers, which can be maintained at any desired temperature and sunlight intensity, will allow scientists to grow small trees, or algae and bacteria from the ocean. Then the material can be analyzed for isotope content as a function of growth conditions.

The equipment will be employed in eight Ecosystems Center research projects involving marine and aquatic food webs, terrestrial biogeochemistry and sulfur cycling in air and water. The lab will also serve as an "outreach" tool to attract other scientists to visit the Center and take advantage of the facilities.

WORKSHOPS

During 1987, The Ecosystems Center hosted two workshops in Woods Hole, both with the support of grants from the National Science Foundation. The understanding and knowledge exchanged during both workshops may prove to be invaluable to the scientific community as a whole.

ASLO/NSF Land-Sea Interface

In May, The American Society of Limnology and Oceanography organized a workshop of coastal scientists to identify a number of concepts and theories which will unify the diverse field of aquatic studies by biologists, chemists, physical scientists, and geologists and to develop frameworks of creative research to test and refine these concepts and theories. The workshop, funded jointly by the Division of Ocean Sciences and the Division of Biotic Systems and Resources at the National Science Foundation, will also serve to advise the NSF of opportunities for advances in knowledge and predictive power about interactions between land and ocean taking place in the region called the land-sea interface. This region of the globe includes areas where there is major interaction between the natural and anthropogenic inputs from the terrestrial oceans and environment.

The steering committee was chaired by John Hobbie (MBL) and included Larry Pomeroys (Univ. Georgia), Jay Zieman (Univ. Virginia), Don Boesch (Louisiana Universities Marine Consortium), Fred Nichols (USGS, Menlo Park) and Glenn Cannon (NOAA, Seattle). Together with the other participants, they attended two days of intensive discussions, key-note addresses and smaller sessions which addressed special issues. A group of rapporteurs (E.Turner, M.Kemp, J. Hobbie, W. Odum, J. Zieman and J. Wells) spent part of a third day writing up a report on the workshop. This report will cover the state-of-the-art, present directions of research on this topic, problems, future direction and costs, and needs for technology. While the emphasis will be on the big picture, gaps will also be identified as will be the short-term, logical, next steps. This report will then be widely distributed to the aquatic research community and agencies.

NSF/MBL Stable Isotope Tracers

Twenty-nine students and Ph.D. level investigators came to Woods Hole to attend seminars, discussion groups, demonstrations and laboratory experiments in May as part of the NSF/MBL Stable Isotope Tracer Workshop. Brian Fry (Ecosystems Center, MBL) and Marilyn Fogel (Geophysical Laboratory, Carnegie Institution of Washington) coordinated the workshop and scheduled two or three different lecturers to speak each day to provide variety and a minimum quorum for lively discussion. Bob Michener, Brian's research assistant, analyzed samples and helped supervise the laboratory portion of the workshop in which participants learned hands-on sample preparation techniques designed to reduce sample analysis costs. The hands-on teaching and interaction of a sophisticated ecological audience with stable isotope experts has stimulated new applications of stable isotopes in ecosystem research.

Variations in hydrogen, carbon, nitrogen, oxygen and sulfur stable isotopic compositions provide convenient tools for tracing the origins and processing of organic matter in ecosystems. A combination of high analytical costs and a basic unfamiliarity with how stable isotopic abundances are altered and preserved in natural systems has prevented a wider use of these tools in ecology. To overcome these difficulties, Brian Fry organized the one-week workshop "Stable Isotopes as Natural Tracers of Ecosystem Processes" funded with grants from NSF and the Finnigan Corporation. The workshop provided a less expensive means to expose a larger audience to this theory and practice of stable isotope research during 5 days of lecture and laboratory sessions. Lecturers had diverse backgrounds in chemis-
try, geochemistry, plant physiology, zoology, and paleoceanography and addressed five major topics related to stable isotopes: theory of isotopic fractionation, nutrient cycling, historical reconstruction, ecosystem-level experiments, and landscape ecology.

**APPOINTMENTS**

Ed Rastetter, who became a member of The Ecosystems Center staff in February, 1986 as a postdoctoral fellow, was appointed Assistant Scientist in 1987. Ed came to the Center 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 modeling the emission of trace gases from terrestrial ecosystems and wetlands, and, as part of the LTER research team, he is modeling the flux of nutrients in the Arctic tundra.

**MEETINGS**

Members of The Ecosystems Center staff participated in many workshops and meetings, both nationally and internationally, during the past year.

In January and again in March, John Hobbie attended the Workshop on Arctic Interactions held in Boulder, Colorado and hosted by the University Corporation for Atmospheric Research. September 1 and 2, John participated in a workshop to improve the process of assessing the risks of toxic impacts on terrestrial ecosystems by identifying and characterizing critical terrestrial systems in Corvallis, hosted by Oregon State University in cooperation with the Environmental Protection Agency (EPA). September 8-10, John took part in a workshop held at the State University of New York at Stony Brook, in an effort to contribute to the scientific portions of a Technical Development Plan to guide a proposed estuarine research program for the National Oceanic and Atmospheric Administration. Hobbie was also an invited participant in a workshop held in Villach, Austria, sponsored by the Royal Swedish Academy of Sciences’ International Institute for Energy, Resources and the Human Environment to discuss “Developing policies for responding to future climatic change”. Hobbie was also very active on the National Science Foundation Advisory Committee for the Division of Polar Programs, and he served as a member of the Hudson River Foundation Panel.

Dr. Jerry Melillo, Senior Scientist at The Ecosystems Center, continues his leave of absence from the MBL serving as Project Director of the Ecosystems Studies Program at the National Science Foundation in Washington. Among his responsibilities at the NSF is overseeing budgets and programs of ecosystems research funded by NSF. Jerry will return to the Ecosystems Center in 1988 to serve as Acting Director while John Hobbie spends a one-year visiting professorship in Sweden sponsored by the Swedish Natural Science Research Council.

In October, Carole McIvor attended a meeting of the Estuarine Research Federation in New Orleans where she presented a talk on “Microhabitat selection in a marsh fish assemblage”. At the Southern New England Chapter meeting of the American Fisheries Society in Narragansett, Rhode Island in December, Carole gave a paper on “Habitat selection in marsh fishes”.

Jim Raich spoke about the “Influence of treefall gaps on seedling community structure in Malayan coastal hill de Collective forest” at the 38th Annual AIBS (American Institute of Biological Sciences) meeting held in August at Ohio State University.

Brian Fry presented a talk on “The structure of offshore food webs: Preliminary stable isotope results from Georges Bank” at the University of Rhode Island in February and again in July he presented information on the Georges Bank food web structure to the National Marine Fisheries Service in Narragansett. In May, at the Stable Isotope Workshop held here in Woods Hole, Brian held seminars on “^{18}N/N^{14}N in terrestrial systems”, “Overview of food web tracer studies”, “Microbial sulfur cycling” and “Stable isotopes in ecosystem studies”. Brian visited the Oak Ridge National Laboratory, Tennessee in June to deliver a talk about sulfur deposition and storage in lake sediments and in September, he attended the American Chemical Society meeting in New Orleans and spoke about “Sulfur stable isotopes as indicators of acid deposition histories in lakes”. In November, Brian spoke about “Bacterial imprints recorded by sulfur stable isotopes” at the Carnegie Institution of Washington Geophysical Laboratory.

At the Second Annual Landscape Ecology Symposium held in March in Charlottesville, Virginia, Anne Giblin, Gus Shaver, Knute Nadelhoffer and Jim Laundre discussed “How changing land use patterns may alter nutrient dynamics in arctic river floodplains”. In April, Anne attended a workshop on local by-laws and planning issues in the Buzards Bay Basin and spoke about the role of scientific information in the regulatory process. At the ASLO (American Society of Limnology and Oceanography) meeting in Madison, Wisconsin in June Anne presented a poster on “Controls on the burial of reduced sulfur in lake sediments”. During the past year, Anne was invited to speak about varying aspects of sulfur cycling at the University of Rhode Island, the Univer-
sity of Delaware, the Institute of Ecosystem Studies, the University of Massachusetts and Harvard University. Last year the Waquoit Bay National Estuarine Research Reserve appointed Anne Chairman of the Research Advisory Committee.

At the winter ASLO meeting, held in New Orleans, papers by Ecosystems Center staff were presented - "The influence of pore water chemistry on detrital decomposition" by J. Hobbie, D. Rudnick, G. Banta and A. Giblin and "Hydrogen and acetate cycling in two anoxic sediments" by P. Novelli, A. Michelson, M. Scrauton, G. Banta, J. Hobbie and R. Howarth.

Rich Bowden attended the annual meeting of the Ecological Society of America and with two colleagues presented "Foliar uptake of 15N-labelled cloud/fogwater by red spruce (Picea rubens) seedlings".

During the past year, Gus Shaver has served on a number of panels and committees, including the EPA's Advisory Panel on Research Needs in Climate Change, the National Science Foundation's Advisory Panel on Long-Term Technological Needs of the LTER Program and the Swedish Natural Sciences Research Council for Review and Evaluation of Candidates for Research Fellowship in Ecophysiology. In July, 1987, Gus attended the International Symposium on Vegetation Structure in Utrecht, The Netherlands where he presented a paper. In October, he gave a talk at the University of Colorado on the Toolik Lake LTER program and a talk at Colorado State University on Biogeochemical diversity in an arctic landscape. He also participated in the DOE CO2 workshop held in Woods Hole. In November, he served on the NSF Committee on Long-term technological needs of the LTER program.

In May, Knute Nadelhoffer spoke to a group of visiting Connecticut teachers on "Estimating below ground productivity in forest ecosystems" and made a presentation during the stable isotope workshop short course on "Shifts in 15N composition during decomposition of forest soil organic matter". In June, Knute was a participant in a peer review workshop of the Environmental Protection Agency's Forest Response Program in Orono, Maine. In October, he attended the Harvard Forest Program in Forest Microbiology meeting held in Petersham, Massachusetts where he discussed "Nitrogen retranslocation from senescing fine roots in temperate forests". At the Soil Science Society of America meetings, held November 30-December 3 in Atlanta, Knute presented three posters: "Effects of temperature on C, N, and P mineralization in soils from a tundra toposequence", "Changes in 15N and 15C compositions during decomposition of forest soils" and received special recognition as an outstanding presentation at the symposium from the Forest and Range Soils Division of the Soil Society of America for his poster "Recovery of organic matter stocks and fertility following experimental impoverishment of temperate forest soils".

Bruce Peterson also attended several meetings and workshops and served on panels during the year. In April, he attended the NSF Streams Workshop at the Flathead Lake Biological Station in Montana. At Brian Fry's stable isotope workshop in May Bruce spoke about "sulfur, nitrogen and carbon isotopes as tracers of organic matter flow in estuaries" and about "carbon and nitrogen isotopes as food web tracers in the Kuparuk River". At the June ASLO meeting in Madison, Wisconsin Bruce gave a talk on "Phosphorus fertilization of a tundra river: a synthesis". July and August Bruce spent his time on the North Slope of Alaska working on the NSF Division of Polar Programs project and on a study of graying migration supported by the National Geographic Society. At the Oak Ridge National Laboratory in Tennessee, in October, he discussed "Stable isotope tracers of organic matter flow in a tundra river". Also in October, Bruce served on the National Science Foundation's Ecosystem Studies Panel.

Paul Steudler attended a symposium on Biogenic Sulfur in the Environment, sponsored by the American Chemical Society, Division of Environmental Chemistry, held in New Orleans in September, where he presented a paper on "Carbonyl sulfide and carbon disulfide emissions from temperate and boreal forest soils", co-authored by Jerry Melillo, Liz Ferry, Jane Tucker and Andrea Turner.
STAFF OF THE ECOSYSTEMS CENTER 1987—88

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Margaret O'Brien, Research Assistant
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Jill Oppenheimer, Research Assistant
B.A. Oberlin College
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Jane Tucker, Research Assistant
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Andrea R. Turner, Research Assistant
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David White, Research Assistant
M.S. University of Michigan
Tim Yandow, Research Assistant
B.S. University of Vermont


Houghton, R. A. Biotic changes consistent with the increased seasonal amplitude of atmospheric CO2 concentrations. Journal of Geophysical Research 92:4223-4230.


In Press


McIvor, C. C. Food, predation risk and microhabitat selection in a marsh fish assemblage. Submitted to *Ecology.*


ment of Energy, Office of Technical Information, Washington, DC.


Smith, T. J., C. C. McIvor and M. B. Robblee. The ecology of seed predation in tropical, tidal forests in North America, Central America and Australia. Submitted to *Ecology.*


### I. National Science Foundation

**NSF-BSR-8704734**
- "Workshop on stable isotopes as natural tracers of ecosystems processes."
- January 1987 - December 1987
- Investigator: Fry
- $28,490

**NSF-BSR-8702328**
- "An LTER program for the Alaskan arctic."
- September 1987 - August 1992
- Investigators: Hobbie, Fry, Giblin, Nadelhoffer, Peterson, Rastetter, Shaver
- $2,250,000

**NSF-BSR-8615191**
- "The changing sulfur cycle of lakes: Its ecological significance in element cycle interactions and productivity."
- February 1987 - January 1990
- Investigators: Giblin, Fry, Peterson
- $816,178

**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-BSR-8509732**
- "The biota and the global carbon cycle: Effects of changes in climate and in global element cycles."
- November 1985 - April 1988
- Investigators: Hobbie, Houghton, Peterson
- $269,218

**NSF-BSR-8417169**
- "Controls of forest litter decomposition: relationships of phenolic and lignin degradation products to substrate disappearance, extracellular enzyme activity and nitrogen immobilization/ mineralization patterns."
- (Subcontract from Clarkson University)
- April 1985 - March 1988
- Investigator: Melillo
- $288,189

**NSF-ATM-8505480**
- "Carbonyl sulfide and carbon disulfide emissions from temperate and boreal forests along an acid rain gradient."
- Investigators: Steudler, Melillo
- August 1985 - July 1987
- $234,700
- December 1987 - November 1990
- $482,966

**NSF-BBS-8714281**
- "A biological facility center for application of stable isotope technology in environmental science."
- September 1987 - August 1989
- Investigators: Fry, Peterson
- $474,000

**National Science Foundation**
- "Sulfur isotopic fractionation at the O₂/H₂S interface of the Black Sea."
- (Subcontract from Woods Hole Oceanographic Institution "Marine microbial sulfur transformations.")
- July 1987 - June 1989
- Investigator: Fry
- $27,237

**National Science Foundation**
- "Chronic nitrogen additions to forest ecosystems: Effects on nitrogen cycling, canopy chemistry and nitrous oxide emissions."
- (Subcontract from University of New Hampshire)
- June 1987 - May 1991
- Investigators: Steudler, Melillo
- $777,778

**NSF-OCE-8615055**
- "Phytoplankton decomposition in the sediments of oceans and lakes: An experimental approach."
- December 1986 - November 1988
- Investigators: Hobbie, Giblin
- $234,629

**NSF-OCE-8615406**
- "For workshops organized by ASLO on current topics in aquatic ecology."
- January 1987 - June 1988
- Investigator: Hobbie
- $36,558
II. Department of Energy

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

III. NASA

National Aeronautics and Space Administration
“Global changes in biogeochemical cycles in response to human activity.” (Subcontract from University of New Hampshire)
September 1986 - August 1989
Investigators: Melillo, Peterson, Rastetter, Steudler
$495,581

JPL-837003/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

Water Resources Research Center,
U.S.G.S.
“Role of sulfate reduction in mitigating the effects of acid deposition in lakes.”
July 1986 - July 1988
Investigators: Giblin, Peterson
$14,875

Exxon Corporation
“Trace gas emission from temperate and boreal forests.”
January 1986 - May 1988;
Investigators: Melillo, Steudler
$70,000

U.S. EPA, Watershed Manipulation Project
“Nitrate mobility and nitrogen cycling.”
September 1986 - August 1989
Investigators: Melillo, Nadelhoffer
$289,067
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
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Charitable Foundations
Exxon Corporation
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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
Scherman 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 the past year at $2,150,050. 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 to individual scientists or groups of scientists from government agencies. 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 1987, the Center received a grant of $350,000 from the A. W. Mellon Foundation for salary support for scientists and postdoctoral fellows, the stable isotope project, groundwater management research, and the development of global data bases. 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 the postdoctoral fellows, a valuable aid for keeping scientists challenged.