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THE ECOSYSTEMS CENTER
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Cover Photography: Upper: Knute Nadelhoffer measures tree growth at the Harvard Forest LTER site in central Massachusetts. Photo by Marty Downs

Middle: Gus Shaver counts Eriophorum flowers on Chandalar Shelf in the Brooks Range of Alaska. Atigun Pass is in the background. Photo by Jim Laundre

Lower left: Karin Limburg of the Institute of Ecosystem Studies, Claire Peterson and Linda Deegan collect fish in a seine at the Plum Island Sound LTER site in northeastern Massachusetts. Photo by Karen Michalec

Lower right: Paul Steudler and Diana Garcia-Montiel establish plots in a pasture for an irrigation experiment in Rondônia, Brazil. Photo by Kevin Carmody

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Above: Kama Thieler sampling soil solutions on tundra in Alaska. Photo by Marty Downs
The Ecosystems Center, founded in 1975, is the largest year-round research program of the Marine Biological Laboratory (MBL). Its mission is to investigate the structure and functioning of ecological systems and their response to changing environmental conditions, to apply the resulting knowledge to the preservation and management of natural resources, and to educate both future scientists and concerned citizens.

The center operates as a collegial association of scientists under the leadership of co-directors John Hobbie and Jerry Melillo. Because the complex nature of modern ecosystems research requires a multidisciplinary and collaborative approach, center scientists work together on projects, bringing expertise from a wide range of disciplines to bear on a variety of questions. We conduct our field studies in many locations, from the North American and European Arctic to Brazil and East Africa, from the temperate forests of New England to the estuaries of the eastern United States.

Center scientists are currently conducting more than 60 research projects all over the world, many in collaboration with colleagues at other institutions. Projects range from large-scale field experiments that trace the flow of nutrients and energy through aquatic and terrestrial ecosystems to the development of mathematical models that simulate ecosystem structure and functioning. We design our experimental manipulations and our modeling analyses to look at the effects of changes, such as a rise in temperature or an increase in nutrients, on components of ecosystems and the processes that link them. An important goal is to be able to predict the long-term responses of ecosystems to environmental changes brought about by human activities, such as land clearing, waste disposal or fuel consumption.

Although experiments take place in many locations and on different scales, we are interested in developing general principles about the way ecosystems work. Our research is unified by similarities in the questions we ask, the methods we use, and the models we construct. Knowledge gained from one ecosystem is applicable to others. By studying a process, such as the decomposition of soil organic matter, in a wide range of temperature and moisture conditions, we can confidently predict its rate in an unstudied system.

The Ecosystems Center staff currently includes 13 principal investigators and 52 research and administrative staff members. The annual operating budget for 1998 was $7 million. Although research programs are funded primarily by grants from federal and state agencies, additional support for research and education comes from private foundations, corporations and individual donors.

In 1998, The Ecosystems Center continued its new educational venture, the Semester in Environmental Science. The program, launched in the fall of 1997, brings undergraduates from a consortium of small liberal arts colleges and universities to the MBL campus for an intensive introduction to environmental sciences from the perspective of ecosystem ecology. In 1998, the number of participating colleges rose to 32. The semester program is supported by the Andrew W. Mellon Foundation and several other private foundations and donors.

What Is An Ecosystem?

Ecosystems vary greatly in size and complexity. Some have readily distinguishable natural boundaries; others are defined more by the questions researchers ask. All encompass animals, plants and microbes as well as their physical environment, linked through a variety of biological, chemical and physical processes. Among the ecosystems we study are tundra, forests, pastures, lakes and streams, coastal estuaries and watersheds. Our study sites are located in the Arctic, the temperate zone and the tropics.

The structure of an ecosystem is measured both by the species present and their abundance and by the distribution of elements such as carbon and nitrogen among the components of the system. Ecosystem components include living organisms, non-living organic matter and inorganic materials. The functioning of an ecosystem is measured by the patterns and rates of processes, such as photosynthesis or predation, that control the variety and abundance of species as well as transferring energy and materials among components of the system. The processes that govern the way ecosystems function are themselves controlled by factors such as temperature, the availability of nutrients and water and the presence or absence of certain species.

Studying the Effects of Change on Ecosystems

Our knowledge of the complex relationships between organisms, processes and controls in ecosystems provides insight into questions about the effects of human activities on the functioning of ecosystems. How does the deposition of acidic compounds derived from power plants, factories and vehicles affect the forests, lakes and streams of the northeastern United States? How do changes in farming practices and residential patterns affect the flow of nutrients and organic matter into New England estuaries and alter the food web in coastal waters? What happens to the production of commercially valuable fish as a result?
Research conducted at The Ecosystems Center addresses such questions in ecosystems around the globe. How will the clearing of tropical forests change the amount of carbon dioxide released into the atmosphere? What will the effect be on global climate? How will change in temperature and atmospheric gas levels affect the productivity of forests? What effects do introduced species or increased use of fertilizers for agriculture have on the ecosystems of tropical lakes and streams?

At the other end of the temperature spectrum, how would warmer temperatures affect arctic ecosystems? Will an increase in the depth of thaw in the permafrost make more nutrients available to plants? Will these nutrients flow into streams and lakes and affect the aquatic food web?

Ecosystems play a critical role in maintaining healthy populations of the organisms that are part of them. The organisms are likewise important to the successful functioning of ecosystems. We are interested in a variety of questions about biodiversity. Which species are most important? If a particular species disappeared from an ecosystem, would the system continue to provide important natural functions, like filtering water, decomposing waste and maintaining plant productivity and soil fertility? Would pests and diseases increase? How many species are necessary to maintain functional ecosystems? If the loss of one species does not result in measurable change, would the loss of 10? Or 100?

**Research at The Ecosystems Center**

It is difficult for one researcher to have all of the skills necessary to study whole ecosystems. We work with each other and with investigators from other institutions, bringing to our joint projects skills in terrestrial and aquatic ecology, microbiology, chemistry, remote sensing, botany, zoology, physiology, hydrology and mathematics. One of the strengths of The Ecosystems Center is the ability of its scientists to interact closely.

Center scientists work at a wide range of field sites. Coastal studies are carried out at the Essex County Greenbelt Association’s station on Plum Island Sound. Studies of temperate forests are conducted at Harvard Forest in central Massachusetts and at the Bear Brooks Watersheds in eastern Maine. Researchers studying tropical systems work with Brazilian colleagues from the Centro de Energia Nuclear na Agricultura of the University of São Paulo at field sites in the western Amazon. The center’s arctic research projects are based at the University of Alaska’s Toolik Field Station and at the Abisko Naturvetenskapliga Station of the Royal Swedish Academy of Sciences. One investigator is participating in a study of environmental changes in Lake Victoria, East Africa.

We believe strongly in the importance of long-term and comparative studies. Ecosystems Center researchers have participated for many years in the Long-Term Ecological Research (LTER) projects at Toolik Lake and Harvard Forest, funded by the National Science Foundation (NSF). Our newest LTER site is the Plum Island Ecosystem (PIE) study. At this site in northeastern Massachusetts, we study estuarine ecology and the effects of changes in organic matter and nutrients from land.

Facilities in Woods Hole include a mass spectrometer for stable isotope analysis, chemical analytical laboratories and experimental chambers. Researchers prepare field samples for chemical analysis and carry out experiments on plant or microbial growth in the aquatic and terrestrial laboratories. In the chemistry laboratory, samples are analyzed for variables such as nutrient content or rates of microbial growth and release of trace gases. The stable isotope facility is used to estimate rates of transfer of nitrogen, carbon or sulfur in aquatic and terrestrial food webs.

**Support for Research and Education**

Support for research at The Ecosystems Center comes from the National Science Foundation, the National Aeronautics and Space Administration, the Environmental Protection Agency, the Department of Energy, the National Oceanic and Atmospheric Administration and the Department of Agriculture. The center has also received funds for research from the Massachusetts Water Resources Authority, the Electric Power Research Institute, the Exxon Corporation and the Andrew W. Mellon Foundation. The Swedish Nature Protection Agency has granted support for research in northern Sweden, and the Sweet Water Trust has provided funds for operating the Plum Island Sound field station. The Proctor & Gamble Company has funded research to test the impact on the environment of commercial chemicals found in household products. The Jessie B. Cox Charitable Trust has provided funding to develop integrated ecological-economic models of the Plum Island Sound watershed for eventual use in watersheds at the global scale.

Support from private foundations is making possible some innovative educational activities. In addition to the ongoing support provided by the Andrew W. Mellon Foundation, the center’s Semester in Environmental Science has received grants from the Davis Educational Foundation, the Burroughs Wellcome Fund, The Starr Foundation, the Charles E. Culpeper Foundation and several private donors. The Texaco Foundation has provided support for Brazilian students to work with center staff members on a study of the effects of converting forested lands into pasture in the Amazon. The center also works with the MBL’s Science Writing Fellowships Program, creating opportunities for journalists to participate in ecological research.

**Applying Ecological Knowledge to Policy and Management**

One of the important reasons for conducting basic research in ecology is the development of a sound foundation for environmental policy and management. Center scientists are actively involved in the application of scientific knowledge to the solution of environmental problems in a variety of ways, including briefing federal and state legislators and administrators, advising resource managers and serving on committees responsible for formulating policy and coordinating research. We also work with non-governmental organizations and government agencies on assessing the impact of development on ecosystems or evaluating the success of various approaches to resource management.
MICROBIAL DIVERSITY AND ECOSYSTEM PROCESSES: OPENING THE BLACK BOX

The microscopic organisms that live in soil and water influence the large-scale cycles of carbon and nutrients, such as nitrogen and phosphorus, in some fundamental ways. The amount of carbon that is stored away in the biosphere each year, for example, represents the small difference between two large numbers, the amount of carbon from the atmosphere that is fixed by plants through net primary production and the amount released by microbes during decomposition. In an article in this report, Jerry Melillo presents estimates of the annual carbon fluxes between the atmosphere and the continent of North America. For this region of the earth, microbes decompose almost 90% of the net primary production. In the process of decomposing organic matter, the microbes produce greenhouse gases such as carbon dioxide and methane. Paul Steudler’s article in this report notes that methane in the atmosphere is increasing by roughly 1% a year.

Microbes in the soil and water also transform organic materials into inorganic forms during decomposition, making them available once again to plants. Billions of metric tons of nitrogen and phosphorus are recycled in this way each year, an amount so large that it is responsible for most of the aquatic and terrestrial primary production on earth. Recycling has two parts. One is microbial decomposition, which produces inorganic nutrients; the other is primary production, in which plants take up and use these nutrients.

In an article in this report, Bruce Peterson describes measuring the cycling of nitrogen in streams with an isotopic tracer, ammonium enriched in $^{15}$N, which is added to the flowing waters. Each molecule of the enriched ammonium moves downstream and is taken up within a certain distance, referred to as the uptake distance. From the perspective of an ecologist interested in microbes, this uptake distance indicates how far a molecule travels from the place where it is produced during decomposition to the place where it is taken up by plants, microscopic algae attached to rocks in the stream. In small streams, the distance is short, recycling is rapid, and the two processes of decomposition and production are closely linked.

Gus Shaver’s article in this report discusses results from a set of long-term experiments in arctic tundra ecosystems. After nearly two decades of fertilization with extra nutrients, changes in primary production are interacting with changes in species composition in experimental plots to bring about some unexpected results. One such result is a shift in above-ground production from the growth of new leaves and twigs to secondary growth, a greater production of woody stems. This change on the production side of the cycle has consequences for the decomposition side. When this wood dies, it decomposes more slowly than leaf litter, leading to slower turnover of organic matter into inorganic nutrients in the soil.

Microbes that live symbiotically with plants and animals also have a strong influence on the cycling of elements. Several types of bacteria that live in close association with plants fix nitrogen in a process that transforms nitrogen gas into organic nitrogen compounds. The amount of nitrogen fixed by microbes is equal, on the global scale, to the amount added to ecosystems via commercial fertilizers. Another type of symbiosis, the close association of mycorrhizal fungi and tree roots, plays a key role in providing nutrients for shrubs and trees, especially in nutrient-poor habitats. Other symbioses are equally important; they allow ruminants such as cattle, sheep and deer to thrive on a diet of grasses by helping to break down the cellulose in these plants.

Microbiologists have made remarkable progress in studying the microbes growing in high-nutrient habitats, including ones that cause human and animal diseases or inhabit the digestive systems of ruminants. But standard methods of culturing and identifying microbes have not worked well for the dispersed populations of low-activity organisms in natural soils and waters. As a consequence, we know relatively little about such fundamental questions as the identity of these soil and water bacteria, the seasonal progression of species and abundance in natural systems or the controls that turn their metabolism on and off.

Ecosystem scientists have dealt with the dearth of information about microbes by concentrating on measuring the substances they produce, the rates at which they do it and the factors that control these rates. They have, in effect, relegated the microorganisms themselves to a "black box" and measured only the inputs and outputs, the rates of microbial processes and the controls on these processes. The contents of the black box - the microbial species, their capacities and their interactions - have not been investigated.

For many ecological questions, the contents of the microbial box do not matter. Among such questions are the fate of the nitrogen in sewage effluent that currently flows into Boston Harbor and the changes that will occur when off-shore disposal of treated effluent begins. Anne Giblin, Jane Tucker and Chuck Hopkinson have been studying the impact of years of sewage effluent and dumping on the sediments of Boston Harbor and observing the effects of the changes that are underway. In their article in this report, they describe their measurements of rates of denitrification, the process by which microbes transform nitrate, a plant nutrient, into inert nitrogen gas.

Early in their study they found that most of the nitrogen entering the harbor is carried out to sea by coastal currents rather than sinking into the sediments, where it would be transformed through denitrification. They later found that burrowing animals returned after the dumping ceased, mixing water into the sediments and oxygenating them. This mixing removed the nitrate created by the microbes and prevented extensive denitrification.

Over the last few years, the black box of the microbes has slowly begun to open to the new tools of molecular biology. This revolution will allow the study of microbes as a part of natural systems. Just as we now do with plant and animal species, we will be able to ask questions about how many different species of microbes are present and about their role in ecosystem processes. We will be able to discover the environmental factors that enhance or decrease microbial
activity and look at the importance of diversity of microbes for the functioning of ecosystems.

One fundamental question concerns the distribution of microbes. They easily become airborne and can move throughout the world. But are the bacteria that live in arctic tundra grasslands the same as those that live in steppe grasslands? In other words, are bacteria cosmopolitan? Soil scientists think not. Aquatic scientists are not sure.

In the 1996 annual report of The Ecosystems Center, Michele Bahr and John Hobbie described one of the first studies of bacterial species in fresh water, conducted in Toolik Lake in northern Alaska. This lake is a nutrient-poor environment with extremely low algal primary productivity. In 1998, a team of Dutch and American scientists reported on a comparison of the Toolik Lake species with species found in a nutrient-poor lake in the Adirondack Mountains of New York and in a nutrient-rich, productive lake in The Netherlands. We were surprised to learn that three species were found in all three habitats. While the method used in these studies, the sequencing of a part of the ribosomal RNA gene of the bacteria, has its limitations, it provides evidence for the existence of cosmopolitan bacteria in lakes.

Another ecological approach that makes use of the methods of molecular biology is to link microbial populations with processes that occur in natural systems. An ongoing study by Paul Steudler at The Ecosystems Center and Colleen Cavanaugh at Harvard University, described in this report, offers an example of this approach. The process under study is the consumption of atmospheric methane by microbes in soils. The question is the effect of nitrogen deposition in acid rain on methane consumption in soils. By measuring the properties of the types of microbes responsible for the consumption of methane in the soils, the researchers hope to link the decrease in the rate of the process to a decrease in a specific microbial population.

The consumption of atmospheric methane in the soil is an important counter to the buildup of this gas in the atmosphere. But the consumption is carried out by bacteria with an enzyme that can do two things, consume methane and transform ammonium to nitrate. Which of these two processes dominates depends directly on the amount of methane or ammonium available. If ammonium deposition increases and more ammonium becomes available in a particular soil, the consumption of methane will decrease. This study is making use of the long-term fertilization experiment at Harvard Forest where nitrogen has been added to experimental plots for nearly a decade. These experiments mimic the increasing nitrogen deposition in forests, particularly those near industrialized regions of the world.

Steudler and his colleagues found, as expected, that consumption was greatly reduced in the plots that received extra nitrogen at Harvard Forest. The next question concerned the mechanism for the reduction. The study revealed that the ability of the bacteria to use the low concentration of methane had been greatly reduced. The reason was still unclear; either there was a reduction in the population of microbes consuming the methane, or there was a shift in the species of organisms consuming methane. The researchers plan to answer this question by extracting bacterial DNA from soil samples and by using molecular probes to find out whether ammonium-transforming bacteria or methane-consuming bacteria are present.

During the next decade, we expect to have answers to some fundamental questions about microbes in nature. What species are present? Are microbes cosmopolitan? Does seasonal, annual or decadal succession of microbial communities occur as environments change? Can we compare sites over time and space by constructing profiles of genes controlling microbial functions? Are there always enough species present that ecosystems have functional redundancy built into them? What are the controls on the activity of microbes in natural communities? Does the absence of certain species affect the rates of ecological processes? These are the kinds of questions we hope to answer by looking inside the microbial box.
NUTRIENT CYCLING IN BOSTON HARBOR: OBSERVING THE RECOVERY OF AN ECOSYSTEM

Boston Harbor drew headlines during the 1988 presidential campaign when Republican candidate George Bush condemned it as the dirtiest in the country. The statement was not just campaign hyperbole; Boston Harbor suffered from major water-quality problems. The most serious issue was the city’s antiquated sewage treatment plant, which discharged more than 250 million gallons (66,050 cubic meters) of poorly treated wastewater directly into the harbor each day. Sewage sludge, removed from the wastewater during treatment, was also dumped into the harbor, eliminating any small benefits from the treatment process and introducing high amounts of metals and contaminants. The lack of effective sewage treatment caused high bacteria counts in the water, leading to closures of beaches and shellfishing areas. Winter flounder populations in Boston Harbor had a high incidence of liver tumors and diseases. Concentrations of polynuclear aromatic hydrocarbons in shellfish were high.

Beginning in the early 1990s, the city of Boston took a number of steps to improve wastewater treatment. The discharge of sludge into the harbor ceased in 1991, and the construction of a new sewage treatment plant began. New levels of treatment have been introduced in phases, leading to progressive improvements in water quality in the harbor. By 2000, when the plant is scheduled to be completed, all of the wastewater will receive full "secondary treatment," which removes bacteria, toxins and organic matter. The treated wastewater will be discharged nine miles (14.5 kilometers) offshore, at a depth of approximately 33 meters. Until then, however, wastewater will continue to be discharged into the harbor.

While applauding the idea of improving the treatment of Boston’s wastewater, a number of people raised concerns about the project. Some thought that the improvement in water quality in the harbor from the new plant would not be great enough to justify its $3 billion cost. Others felt that moving the outfall location offshore could damage the Massachusetts Bay ecosystem by increasing the level of nutrients introduced into it and stimulating blooms of harmful algae.

Addressing the latter concern requires a clear understanding of what happens to the nutrients that flow into the harbor in the sewage effluent. Microbes in the harbor sediments are removing some of the excess nutrients coming into the ecosystem in sewage effluent through denitrification, the process by which nitrate is converted into nitrogen gas (N₂). Phytoplankton can take up and use nitrate to build cells, whereas N₂ is an inert gas that escapes into the atmosphere. The argument has been made that moving the discharge nine miles out in the bay would greatly reduce the removal of nitrogen by denitrification as the microbes are less active there than in the rich harbor sediments. Although secondary treatment of sewage removes bacteria, toxins, and organic matter, it does not remove inorganic nutrients such as nitrate and phosphate. If the outfall location were moved, the harbor would become cleaner, but more nutrients could reach Massachusetts Bay and do harm to the ecosystem there.

Ecosystems Center researchers Anne Giblin, Chuck Hopkinson and Jane Tucker are studying the sediments of Boston Harbor and Massachusetts Bay to help determine the effect of the changes underway in wastewater treatment on nitrogen and phosphorus cycling. Our initial studies in the early 1990s indicated that, contrary to expectations, most of the nitrogen entering Boston Harbor was not being removed in the sediments via denitrification. This is not because denitrification rates in the harbor are unusually low; the rates are typical of coastal sediments. Instead we found that the coastal currents carry much of the nitrogen offshore before it reaches the sediments. In 2000, when the wastewater discharge is moved offshore, we will measure the efficiency with which the bottom sediments in Massachusetts Bay remove the added nitrogen.

Although nutrients are still being added to Boston Harbor, the amount of organic matter entering its waters has been greatly reduced as a result of the termination of sludge dumping and the gradual improvement in sewage treatment. This change gives scientists an opportunity to study the recovery of sediments from decades of exposure.
to excess organic matter dumped into the water. The most significant effect of this overload is sediment anoxia, the lack of oxygen associated with increased growth and respiration of microbes that use almost all of the oxygen in the sediments as fast as it diffuses from the water above.

We expected that the decrease in the amount of organic matter dumped into the harbor would decrease microbial respiration and allow oxygen to penetrate deeper into the sediments. Increased oxygen would favor the return of burrowing animals, a higher level of denitrification and a decrease in the amount of phosphate escaping into the water column as the oxygenated sediments adsorb it onto the surfaces of particles.

Boston Harbor sediments did not follow the expected pattern of recovery completely. For several years, rates of respiration and nutrient fluxes from the sediments into the water column increased greatly. Oxygen uptake at Station BH03, the former sludge disposal site in the eastern portion of Boston Harbor, varied considerably from one year to another between 1992 and 1994. Contrary to our initial expectations, we saw no uniform reduction in respiration rates during the first three years after the sludge discharge was terminated (Figure 1a).

Respiration rates measured between 1995 and 1997 by other investigators continued to show a high year-to-year variation. Rates were higher in 1995 than those measured in 1993. Data from 1998, however, indicates that respiration is beginning to decline from levels observed early in the recovery process (Figure 1a).

The cause of the high levels of respiration in the harbor sediments seems to be the appearance of large numbers of benthic animals, primarily small shrimp-like crustaceans called amphipods that burrow in the sediments. These animals, about one centimeter in length, can be present in numbers greater than 1 million per square meter. As they dig their burrows, they mix water into the sediments, increasing oxygen levels and stimulating microbial respiration. In spite of the increased oxygen, the sediments release nitrogen and phosphorus to the water column quite efficiently (Figure 1b and 1c). Although the increased level of oxygen in the sediments leads to increased conversion of ammonium into nitrate by microbes, the rapid removal of nitrate as the water circulates through the sediments prevents extensive denitrification. When these animals are active, nutrient trapping processes in the sediments, such as denitrification and adsorption of phosphorus, apparently do not occur as efficiently as expected.

Higher levels of oxygen in the water and sediments have created conditions favorable to a great increase in the abundance of amphipods throughout Boston Harbor. The result has been a temporary rise in rates of benthic respiration and a release of nutrients from the sediments. The effect is expected to be transitory; we are already seeing evidence that the fluxes are beginning to decrease as the animals "mine" the buried nutrients from the sediments. Phosphate fluxes have been low since 1995, while oxygen uptake and nitrate and ammonium release have been lower for the past two years.

During the next phase of the study, we will continue to follow the response of the harbor sediments after the nutrients in the outfall are diverted offshore. Through long-term studies such as these, we are gaining a better understanding of the complex interactions that govern the recovery of ecosystems from exposure to the deleterious effects of human activities.

Figure 1: The flux of oxygen (O2), dissolved inorganic nitrogen (DIN) and phosphate (PO4) from sediments near the former sludge disposal area in Boston Harbor. Measurements began in September 1991, three months before sludge disposal ceased. a) Flux of O2 from the water into the sediments. b) Flux of DIN, including both ammonium and nitrate, from the sediments into the water column. c) Flux of PO4 from the sediments into the water column.

Jane Tucker, Luc Claessens, Hap Garritt and Amy Nolin
Why is Methane Increasing in the Atmosphere? Nitrogen Deposition and Methane Consumption in Soils

Although methane is less abundant than carbon dioxide in the earth's atmosphere, it is a major contributor to the "greenhouse" effect. The reason is that a molecule of methane in the atmosphere is 25 to 60 times more effective than a molecule of carbon dioxide in trapping heat. The abundance of methane in the atmosphere has been increasing at about 1% per year over the last several decades. This change is taking place either because more methane is being produced from sources such as rice paddies or the digestive systems of ruminants, or because less methane is being taken up by microorganisms on land or in the ocean.

Microbes in the soil that take up atmospheric methane provide an important terrestrial sink that may be decreasing. They include methanotrophs, organisms that consume methane, and ammonium oxidizers, organisms that transform ammonium to nitrate. Certain human activities that introduce excess nitrogen into the biosphere, such as the clearing of forests and grasslands for crops, the use of nitrogen fertilizers and the consumption of fossil fuel, have the potential of decreasing the rate at which these organisms consume methane in soils.

Ecosystems Center researchers Paul Steudler and Yarek Hrywna are working with Harvard University scientists Colleen Cavanaugh and Jay Gulledge on a study of the factors affecting the soil sink for atmospheric methane. This study is one of the first to include both the physiology and biodiversity of soil microbes as factors. Many studies in natural and managed ecosystems have examined the effects of human activities on methane consumption rates, but few have attempted to describe the microbes that are involved in the consumption of methane at atmospheric concentrations. These specialized microbes appear to have unique physiological properties that enable them to utilize the very low concentrations of methane found in the atmosphere. But the identity of the microbes actually carrying out the consumption in the soil is not well known.

We are using a long-term nitrogen addition experiment at the Harvard Forest Long-Term Ecological Research (LTER) site in Petersham, Massachusetts, as a case study for a detailed look at the diversity of the microbes consuming atmospheric methane. Stands of both hardwood and pine forest at this site have been fertilized with extra nitrogen for 10 years. Thus microbes and their activities can be compared in control plots and experimental plots.

The long-term nitrogen addition experiment was designed to examine the effects of nitrogen deposition on temperate forests at rates comparable to those observed in regions where deposition from industrial emissions is high. The additions were begun in 1986 in a mixed hardwood stand that was more than 50 years old and a red pine plantation that was more than 70 years old. Nitrogen is added in the form of ammonium nitrate at annual rates of zero, 50 or 150 kilograms per hectare during the growing season. The forests in this region receive about 8 kilograms of nitrogen per hectare per year in precipitation. We have been measuring various parameters at these sites, including the rates of methane consumption in the soils and the environmental factors controlling these rates over the past decade.

In the field, we measured rates of methane consumption in the whole ecosystem using small chambers placed over the soil surface for short periods. In the laboratory, we used soils from the field experiments to find the depth in the soil profile at which the organisms are consuming methane. As this study continues, we also plan to use both chemicals that inhibit the process of consumption and the metabolic enzymes found in methane consumers to look at the biochemical ability of microbes to use very low concentrations of methane. We also plan to use molecular methods to identify the species of microbes responsible for methane consumption in soils.

Rates of methane consumption in plots that have been treated with high levels of nitrogen have declined over the past decade in comparison with rates in the control plots.
In the first year after the additions were begun, both hardwood and pine high-nitrogen plots showed an immediate reduction in consumption rates relative to the controls of about 25%. This reduction reached 35% to 45% over the next three years (Figure 1). The pine high-nitrogen plot showed a further reduction in consumption of about 65% by 1992. We made a set of growing-season measurements in 1998, a decade after the additions were begun, and were surprised to find that the reductions had reached about 65% in the hardwood plots and 90% in the pine plots.

Measurements of methane consumption in natural hardwood and red pine stands in West Virginia, a location that receives more than double the nitrogen deposition from the atmosphere that Harvard Forest experiences, showed a 67% lower rate of consumption when compared to similar control stands at Harvard Forest. These results are consistent with the long-term patterns of reduced methane uptake in the high-nitrogen plots that we observed in 1998. These results suggest that, over the long term, high levels of nitrogen deposition similar to those measured over the past decade in portions of central Europe and eastern United States may continue to decrease the role that terrestrial soils play in retarding the rate of methane increase in the atmosphere.

Methane consumption did not occur uniformly with depth in the soil profiles at the Harvard Forest plots (Figure 2). The highest rates of consumption were measured in the upper mineral soil (0-5 centimeters) and in the layer of organic matter, where rates were 2 to 14 times greater than those found lower in the soil profile. Nitrogen additions had the greatest effect on oxidation rates in the most active layers; we saw reductions of up to 96% in the high-nitrogen pine plot compared to the controls. We observed the effect of the nitrogen additions throughout the entire soil profile down to 20 centimeters in the pine stand but only through a depth of 10 centimeters in the hardwood plot.

Our laboratory studies are aimed at finding out how the additional nitrogen reduces the consumption of methane in the soils. Certain enzymes, proteins that catalyze the transformation of materials providing the microbes with energy, are able to take up either methane or nitrogen in the form of ammonium. Our studies suggest that when the abundance of ammonium is increased, the enzymes take up proportionately less methane. The increase in ammonium available to the microbes comes either from the fertilizer applied to the experimental plots or from increased rates of nitrogen cycling in these plots.

Enzyme studies with these soils in the laboratory indicate that there are two possible explanations for the changes in consumption that we observed: one possibility is a change in the size of the microbial populations consuming methane, the other is a shift in the type of organisms in the soils that had received treatment with additional nitrogen. One piece of evidence is that we observed a 94% reduction, on average, in the maximum rate at which methane could be consumed in the experimental plots. Another is that we observed a loss in the ability of the microbes in the high-nitrogen plots to use low concentrations of methane.

The next step is to use specific chemicals to inhibit the process of consumption and to try to differentiate the groups of organisms that consume methane. Application of inhibitors to soils in the laboratory should tell us whether the populations of methanotrophs or ammonium oxidizers have changed. More information about the identity of the organisms consuming methane will come from the application of molecular techniques. We plan to extract DNA from samples of soils at different depths and to use molecular probes for the genes that control the formation of the enzyme that oxidizes methane or ammonium. We also plan to use molecular probes to identify the species of microbes containing the gene for this enzyme. We hope that these methods will allow us to link the process of methane consumption with microbial diversity in our efforts to understand the effects of nitrogen additions from human activities on natural systems.

![Graph showing percent reduction in methane consumption over time for pine and hardwood plots compared to controls.](image1)

**Figure 1:** Reduction of soil methane consumption compared with controls is plotted over time for the pine and hardwood plots of the Harvard Forest long-term nitrogen experiment. Pine and hardwood plots treated with high levels of nitrogen are compared to control plots.

![Graph showing methane uptake rates and standard errors measured in laboratory incubations at different soil depths.](image2)

**Figure 2:** Methane consumption rates and standard errors measured in laboratory incubations are shown at different soil depths from the Harvard Forest nitrogen experiment.
Just before the most recent round of international meetings on the United Nations Framework Convention on Climate Change, held in Buenos Aires in November, an interdisciplinary team of U.S. scientists published a paper in *Science* in which they estimated that, during the period from 1988 to 1992, the terrestrial ecosystems of North America took up some 1.7 petagrams of carbon per year from the atmosphere. A commonly accepted estimate of the amount of carbon released into the atmosphere by human activities in this region during this period is roughly 1.5 petagrams per year. Thus the estimate of this team, associated with the Carbon Modeling Consortium (CMC) based at Princeton University, implies that the North American carbon sink more than offsets the release of carbon dioxide \((\text{CO}_2)\) that comes from the burning of fossil fuels, the manufacturing of cement and other anthropogenic sources.

The suggestion that the North American continent functions as a net carbon sink in the global carbon cycle has policy as well as scientific implications. If the CMC analysis were correct, it would have a major effect on the positions of the United States and other North American countries in ongoing negotiations over stabilizing greenhouse gas levels in the atmosphere. Many policymakers would feel less pressure to adhere to the provisions of the Kyoto Protocol, the climate change treaty signed in December 1997 in Japan. This protocol requires developed countries, including the United States, to reduce emissions of \(\text{CO}_2\) and other greenhouse gases from 1990 levels by an average of 5% over the next decade. Many members of the U.S. Congress have expressed concern that such a reduction could seriously damage the nation’s economy.

Several scientists from The Ecosystems Center are reviewing the CMC conclusions about the size of the North American terrestrial carbon sink. Using a biogeochemical process model and measurements made in terrestrial ecosystems, David Kicklighter, Jerry Melillo, Hanqin Tian and Shufen Pan have estimated that, for the period 1988-1992, the land ecosystems of North America took up much less carbon than was estimated by the CMC researchers.

In our analysis, we considered five major factors that influence carbon storage in terrestrial ecosystems: atmospheric levels of \(\text{CO}_2\), climate variability, nitrogen fertilization, forest harvesting and regrowth and fire. We used the MBL Terrestrial Ecosystem Model (TEM) to assess the effect of rising atmospheric \(\text{CO}_2\) and climate variability between 1988 and 1992 on carbon accumulation in vegetated areas of North America other than croplands. Using information on atmospheric \(\text{CO}_2\) concentration, climate, elevation and vegetation, we made monthly estimates of significant carbon and nitrogen fluxes and pools in terrestrial ecosystems. Results from our TEM simulations suggest that the combination of \(\text{CO}_2\) fertilization and climate conditions caused the land ecosystems of North America, particularly forests, to store an average of 0.2 petagrams of carbon per year \((\text{Pg C/yr})\). Amounts of carbon stored ranged from -0.2 to 0.5 Pg C/yr over the five-year period.

Human activities affect the natural cycling of nitrogen as well as carbon. Terrestrial ecosystems, especially those downwind of urban and industrial areas and intensively farmed regions, receive substantial inputs of nitrogen from emissions and fertilizers. We estimated the effects of these inputs on carbon storage in North American ecosystems by combining three types of information: the geographic patterns of vegetation distribution and nitrogen deposition in North America and the likely fate of the nitrogen once it enters an ecosystem.

![Carbon Fluxes in North America, 1980-1989 (Pg C/year)](image)

**Figure 1:** Mean annual carbon fluxes in terrestrial North America, 1980-1989. Gross primary productivity (GPP) equals the net primary production (NPP) or the incorporation of carbon into plant biomass \((C_1)\). Most of the plant biomass is oxidized by the respiration of soil microbes \((\text{RH})\). The remainder of the carbon, the plant biomass minus the \(\text{RH}\), represents net ecosystem production \((\text{NEP})\) and \(C_2\). Disturbance by fire results in an even smaller amount stored as net biome production \((\text{NBP})\) or the amount of carbon stored in terrestrial ecosystems \((C_3)\).
We used our TEM database in combination with landcover data derived from satellite images to develop a map of the vegetation in non-cropland areas of North America. We then used estimates made by our colleague Frank J. Dentener from Utrecht University in The Netherlands to determine the geographic patterns of inputs of inorganic nitrogen, both ammonium and nitrate, across North America. Finally we used results of field studies by Ecosystems Center scientist Knute Nadelhoffer and his colleagues to determine the fate of nitrogen in mid-latitude forest ecosystems.

Using additions of $^{15}$N, an isotope of nitrogen that is relatively scarce in nature, as a tracer, Nadelhoffer and his coworkers determined that 15% of the added nitrogen in forests wound up in non-woody biomass, 5% in woody biomass and 70% in soils. Roughly 10% was lost from forests through leaching from soils and the flux of gases into the atmosphere. We estimated the carbon storage stimulated by nitrogen in each of these pools by multiplying the absolute amount of nitrogen in each pool by the carbon-to-nitrogen ratio of that pool. For North America, this approach suggests that inadvertent nitrogen fertilization of non-cropland areas, especially forests, can result in an annual carbon sink of about 0.2 Pg.

Most of the forests of North America have gone through a cycle of harvesting and regrowth for at least a century. Several recent analyses of forest inventory data show that the remaining carbon, 0.6 Pg, would have accumulated in the terrestrial ecosystems of the region. We thus estimate that fire reduced the amount of carbon accumulated in the region by about 0.1 Pg annually, and that the land ecosystems of North America accumulated carbon at an average annual rate of 0.5 Pg for the period 1988 to 1992.

Forest fires cause rapid transfers of carbon from the land to the atmosphere. To estimate the magnitude of the loss of carbon from the land from 1988 to 1992, we combined estimates of areas by major vegetation types in North America that burned annually with modeling estimates of aboveground carbon stocks for the major vegetation types affected by the fires. We used this information in a simple model that simulated instantaneous carbon loss due to the fires and the subsequent decay of the dead wood left in burned areas. Based on our simulations, we estimate that fires during this five-year period resulted in an average annual carbon loss of about 0.1 Pg from the region.

Our current conception of the annual terrestrial carbon cycle in North America during the years from 1988 to 1992 is shown in Figure 1. Each year during this period the plants on the North America continent took up 12.5 Pg C from the atmosphere through the process of photosynthesis and converted it into organic carbon compounds. Plant respiration returned slightly more than half of this organic carbon, 6.7 Pg C, to the atmosphere as CO$_2$. The remainder, about 5.8 Pg C, was incorporated into plant biomass. Much of this biomass was short-lived; the carbon in plant tissues entered the soil in the form of leaf and root litter, root exudates and so on, where it was oxidized or turned back into inorganic carbon by microbes. We estimate that during this process microbes converted 5.2 Pg of dead plant biomass into CO$_2$ that returned to the atmosphere.

In the absence of major disturbances such as fire, the remaining carbon, 0.6 Pg, would have accumulated in the terrestrial ecosystems of the region. We thus estimate that fire reduced the amount of carbon accumulated in the region by about 0.1 Pg annually, and that the land ecosystems of North America accumulated carbon at an average annual rate of 0.5 Pg for the period 1988 to 1992.

Our estimate of the rate of carbon accumulation in the land ecosystems of North America during the period 1988 to 1992 is about a factor of three smaller than the one estimated by the CMC research team. Work needs to be done to reconcile these two estimates. We need a solid scientific understanding of the workings of the carbon cycle at regional and global scales as we make policies to control the buildup of CO$_2$ in the atmosphere.
LONG-TERM EXPERIMENTS YIELD INSIGHTS INTO CHANGES IN PLANT COMMUNITIES OF TUNDRA ECOSYSTEMS

Human activities have altered both the environmental conditions and the variety and number of plant and animal species present in ecosystems all around the world. To understand how changes in environment and species composition interact with each other and how this interaction affects important ecosystem processes, we need to document changes as they occur and to compare them over time.

Long-term ecosystem-level experiments are an effective means of studying these changes. We can manipulate environmental variables, such as air or soil temperature, light levels and the availability of nutrients like nitrogen or phosphorus, as well as the composition of plant communities in a controlled fashion; the goal is to uncover a clear chain of cause-and-effect relationships.

In collaboration with Terry Chapin of the University of Alaska, Ecosystems Center scientists Gus Shaver, Anne Giblin, Knute Nadelhofer and Ed Rastetter have conducted a series of experimental manipulations of tundra ecosystems at the Long-Term Ecological Research (LTER) site at Toolik Lake in northern Alaska for more than two decades. We have subjected plots with varying assemblages of plant species to similar alterations in air temperature, light levels and nutrient availability, and we are finding both similarities and differences in the responses. After 19 years of fertilizer additions to one set of plots, for example, we are finding that changes in primary productivity interact with changes in species composition to control further changes in productivity and plant biomass.

The Toolik Lake fertilizer experiment, begun in 1981, has one set of plots that receive annual additions of nitrogen and phosphorus fertilizers at the start of each growing season and another set left unfertilized as controls. The original vegetation at the site was moist tussock tundra containing a relatively even mixture of three major plant forms: sedges and grasses (graminoids), deciduous shrubs and evergreen shrubs. The unfertilized control plots have changed relatively little since 1981, with a slight increase in evergreen shrubs and a decrease in graminoids. The fertilized plots, however, have changed dramatically, with large increases in biomass and production and a major change in the composition of the plant communities. When we harvested these plots in 1995, more than 85% of the mass of vegetation in the fertilized plots was a single deciduous shrub species, the dwarf birch *Betula nana*, shown in the accompanying photo of the fertilized plots.

The interaction of this change in species composition with the direct effects of the fertilizer on production and biomass is shown in a comparison of results from a harvest of the experiment in 1983 with the harvest in 1995 (Figure 1). In 1983, we found that the vegetation in the fertilized plots had increased in biomass by 32% and in aboveground production by 67%, relative to the unfertilized plots. By 1995, the changes were even greater: biomass had increased by 250% in the fertilized plots, and aboveground production had increased by 220%.

In the 12 years between these harvests, the composition of the plant communities had also changed dramatically, reflecting the increased abundance of the dwarf birch. One of the consequences of this change in species composition was that about half of the aboveground production in the fertilized plots was accounted for by secondary growth, the production of new wood as branches increase in diameter, as opposed to the apical growth of new leaves and twigs. Furthermore, the total amount of new leaf and twig production actually declined in fertilized plots between 1983 and 1995, even as total production increased. By 1995, the production of new leaves and twigs in the fertilized plots was the same as the production in the control plots.

How can total production in fertilized plots continue to increase when leaf production decreases? Because photosynthesis occurs in the leaves of plants, we generally expect leaf mass and total production to be positively correlated. In the Toolik Lake fertilizer experiment, however, total leaf mass (including evergreen leaves more than one year old) was actually lower in fertilized plots than in control plots by 1995 (Figure 2).
The resolution of this paradox lies in the characteristics of dwarf birch leaves, which dominated the canopy of the fertilized plots in 1995 but were much less significant in the fertilized plots in 1983 or in the control plots in either year. The principal difference is that dwarf birch leaves are thin, and the leaves of other species are thick. Birch leaves have a much higher specific leaf area, or leaf area per unit of leaf mass, than those of other species in the community.

The fertilizer treatment also caused specific leaf area to increase in all species, further increasing the leaf area of the whole community in fertilized plots. As a result of these differences, we observed more than 160 square centimeters of leaf area per gram of leaf mass in the fertilized plots in 1995 and only 65 square centimeters of leaf area per gram of leaf mass in the control plots. Thus the total leaf area in the fertilized plots was about twice that of the control plots in 1995 (Figure 2), roughly the same difference that we observed in aboveground production (Figure 1). Leaf area in the fertilized plots was also double that of control plots in 1983, but the difference in production was only 67%, suggesting that the production per unit of leaf area also increased between 1983 and 1995.

The increase in specific leaf area in the fertilized plots dominated by dwarf birch has had further consequences. As a result of the lower relative requirement of resources for leaf production, a higher proportion of total production in each plant can be allocated to the growth and branching of woody stems. Greater branching allows the birch shrubs to grow more rapidly, and greater production of slowly replaced woody stems means that overall biomass turnover time is reduced. When this wood dies, it decomposes more slowly than leaf litter, leading to slower organic matter turnover in the soil.

In sum, these results show how changes in environmental conditions interact with changes in species composition to control changes in production and biomass. The changes in species composition that resulted from fertilization appear to have allowed an increase in production that is significantly beyond what would have occurred if we had fertilized this nutrient-limited ecosystem but maintained the composition of the plant community in its original state.

Figure 1: Comparison of aboveground biomass and aboveground production in fertilized and control plots at the Toolik Lake Long-Term Ecological Research site in Alaska in 1983 and 1995. Segments of each bar show the contribution to biomass or production by evergreen, deciduous, or grass and sedge (graminoid) species. The production of new wood through secondary growth is shown separately from apical leaf and twig production for the evergreen and deciduous species.

Figure 2: Comparison of total leaf mass and leaf area for plant communities in fertilized and control plots at the Toolik Lake site in Alaska in 1983 and 1995.
LINX BETWEEN LAND AND WATER: AN INTERSITE STUDY OF NITROGEN CYCLING IN SMALL STREAMS

Human activities, such as the use of fertilizer, the cultivation of legume crops, the disposal of sewage and the burning of fossil fuels, are accelerating the flow of nitrogen through the biosphere. These activities add nitrogen to natural systems in forms that plants can take up and use. This increase in biologically available nitrogen is affecting ecosystems everywhere as anthropogenic nitrogen is distributed around the world through atmospheric circulation and water transport.

As agricultural fields and forests become saturated with nitrogen, the excess moves with the groundwaters into wetlands, streams, lakes, rivers and eventually the coastal ocean. These aquatic ecosystems receive nitrogen that has been taken up and recycled through biological processes of growth and decay as it passes through the upland systems. Recycling within ecosystems controls when and in what form nitrogen will be exported downstream. Consequently information on nitrogen cycling in ecosystems is needed to understand and predict how downstream ecosystems will be affected by the addition of anthropogenic nitrogen in watersheds.

Small headwater streams are the first aquatic ecosystems to receive nitrogen exported from the land. These streams funnel water to larger streams. Considering their small dimensions, they play a disproportionately large role in nitrogen transformations in the landscape. Nitrogen cycling and export has been studied intensively in small streams and watersheds, partly because their size permits relatively easy experimental manipulation and sampling.

Several years ago a group comprising some 40 stream ecologists came together at the Coweeta Hydrological Station in North Carolina to plan a study comparing nitrogen cycles in small streams throughout North America. Researchers who have worked in 10 intensively studied small watersheds agreed to use identical experimental protocols and models to assess and improve our understanding of nitrogen retention, storage and regeneration in the streams under study.

We named our study the Lotic (flowing water) Intersite Nitrogen Experiment or LINX. One prerequisite for inclusion was the ability of each participating group to supply data to construct a nitrogen budget and to calibrate a model of nitrogen cycling for each stream prior to preparation of a formal proposal to the National Science Foundation (NSF). The study sites represent various types of terrestrial ecosystems throughout the United States (Figure 1). Lead investigators include Pat Mulholland of the Oak Ridge National Laboratory, Jack Webster from Virginia Polytechnic Institute, Judy Meyer from the University of Georgia and Bruce Peterson of The Ecosystems Center.

The experiments at each site involved adding an inorganic nitrogen tracer in the form of ammonium to each stream over a period of six weeks. The ammonium was enriched in $^{15}$N, a stable isotope of nitrogen that is rare in nature. Our sampling was designed to measure the movement of the nitrogen tracer through the water, detritus and food webs of each stream. All components of the ecosystem that contain nitrogen were repeatedly sampled for measurements of nitrogen concentration and tracer content for several months.

The study is now entering its synthesis phase, during which each site team will present its findings at a workshop. In addition, experts on particular aspects of nitrogen cycling are preparing manuscripts for publication that compare and contrast results among the sites. One goal is to discover whether the observed patterns of nitrogen cycling are common to all streams. Another is to develop a general model structure that will allow us to simulate nitrogen cycling in streams in widely different settings.

Although the results of the study are not yet fully analyzed, they have generated a great deal of enthusiasm. The tracer experiments have yielded new information on nitrogen cycling. We have obtained in-situ estimates of the rates of a number of biogeochemical and physical processes, such as ammonium uptake, nitrification, nitrate uptake, the settling of fine particulate nitrogen, nitrogen uptake by primary producers, and the transfer of nitrogen among species in the food web. At the ecosystem scale, we can now determine the efficiency of nitrogen uptake, the amount of time nitrogen remains in the stream ecosystem, and the
rates of transformation of nitrogen into the forms that are exported downstream.

We are also able to trace the migration of insects that become "labeled" with the $^{15}$N tracer during the experiment as they leave the study area of the stream by swimming or flying away. Streamside predators, such as spiders that feed on insects emerging from the stream, are easily identified by their elevated $^{15}$N levels. So much of this information is new that it is difficult to judge as yet what the most significant findings will turn out to be.

Wilfred Wollheim of The Ecosystems Center is analyzing the dynamics of inorganic nitrogen in all of the study streams. His comparisons of the rates of ammonium uptake among sites show that ammonium uptake distance, the distance traveled by an ammonium molecule before it is removed from the stream water, increases as stream size increases (Figure 2). This correlation has been predicted from theoretical analyses of stream channel morphology and hydraulics but never before measured directly with tracers. It shows that, even across extremely diverse stream types, ammonium uptake distance can be predicted in good part from stream size alone.

Not all of the variation in nitrogen uptake distance is caused by the physical characteristics of streams. When discharge rates are equal, streams with highly productive benthic communities are up to 10 times more active in ammonium uptake than are unproductive streams. For example, some of the sites shown in Figure 2 with low uptake distances but higher discharge rates are highly productive and fertilized streams. Because discharge in the streams studied varies over several orders of magnitude, however, even a ten-fold difference in biological activity is not great enough to alter the fact that uptake distance is primarily controlled by physical factors.

As the algae, bacteria and fungi on the bottom of the streams we study assimilate the labeled ammonium, the microbial community and detritus on the stream bottom become highly enriched in $^{15}$N. This material erodes off stream bottom rocks and sediments over time and is carried downstream in the form of fine particulate organic material. Filter-feeding insects, such as blackfly larvae, feed on this suspended material. As a result, the tracer accumulating in their tissues reflects the downstream distribution of enriched particles.

Using the longitudinal distribution of $^{15}$N in both filter-feeding insects and suspended particles, we can calculate the rates of sloughing and sedimentation of these fine particles. As with the ammonium uptake distances, we find that particle transport distance is positively correlated with stream discharge (Figure 3). Fine particles containing $^{15}$N are carried downstream more than 100 times farther in the largest streams than in the smallest streams.

The finding that the transport and uptake of nutrients and fine particles can be scaled predictably from very small to large streams is a hopeful sign for the development of biogeochemical models of stream ecosystems. Other investigators are comparing other aspects of the nitrogen cycle among the LIXN streams. As data are assembled and interpreted, we will test our LIXN nitrogen-cycle model to determine whether its structure properly reflects the data on nitrogen cycles from the tracer experiments. Because we now have tracer measurements from a diverse set of streams of different sizes, we will be able to develop nitrogen-cycle simulations of the stream networks of entire watersheds. Our long-term goal is to able to link, via physically-based and biologically realistic models of stream networks, the nitrogen cycle in forests with the nitrogen cycles of downstream lakes and estuaries.
THE SEMESTER IN ENVIRONMENTAL SCIENCE: HIGHLIGHTS OF THE SECOND YEAR

Students participating in the second Semester in Environmental Science (SES), held on the MBL campus in the fall of 1998, got a chance to meet the pioneers from the year before at the first-ever SES reunion in mid-September. Ecosystems Center research assistant Sam Kelsey, a member of the 1997 class, organized the event, which brought 14 of the 16 original SES students back to Woods Hole for a weekend to meet the new students and renew old friendships. Four of the alumni had continued their involvement with The Ecosystems Center as interns or employees. Many of the others had also continued to pursue their interest in ecology, accepting internships at other ecological institutions.

The second-year contingent comprised 12 students from 11 colleges who spent 15 weeks at the MBL hearing lectures and talks and participating in laboratories and field projects. The SES program is designed to give undergraduates from small liberal-arts colleges and universities a comprehensive introduction to the environmental sciences from the perspective of ecosystems ecology. The educational institutions that have joined the MBL in the Environmental Science Consortium grant a semester's worth of credits to students that complete the program successfully.

The members of the consortium now number 32. Nine colleges, many from the West and Midwest, joined during 1998. In keeping with the consortium's goal of more participants and greater diversity, program administrator Kenneth Foreman is continuing to work on attracting new institutions and their students.

The first 10 weeks of the semester are taken up with lectures, laboratories and field studies that are intended to prepare students to undertake independent research projects during the latter part of the semester. Two courses, one focused on aquatic ecosystems, the other on terrestrial, form the core of the program. In them are covered basic topics such as primary and secondary production, decomposition, nutrient cycling and the flux of materials and energy among components of ecosystems. The courses also address issues of broad concern, such as changes in global element cycles, the effects of changing land use on estuarine and freshwater ecosystems, fuel emissions and acid deposition, and the effect of changes in biodiversity on the functioning of ecosystems. Core course leaders for 1998 were Knute Nadelhoffer for terrestrial ecology and Chuck Hopkinson for aquatic ecology.

"As we move into the next century we recognize a whole variety of environmental changes taking place across the globe. And we're very interested in developing an educated public and a group of scientists who can think about these changes clearly and perhaps be involved in solutions to problems that these changes may cause."

Jerry Melillo
Co-Director of The Ecosystems Center

Phoebe Congalton, SES student from Sarah Lawrence College, gathers leaves as part of her project on soil and leaf litter quality and decomposition across an urban-rural gradient.

SES student Alexis Schoppe of Dickinson College, draws water samples from Waquoit Bay with the help of SES Associate Director Ken Foreman.
Field and laboratory exercises in the core courses make use of two local sites: a mixed oak and pine forest in Falmouth, portions of which receive wastewater from the town’s sewage treatment plant, and a coastal pond and estuary in Waquoit Bay. Students spend more than 20 hours each week in the field and the laboratory, building an understanding of how these ecosystems function by collecting, analyzing and discussing their own data.

Students also take an elective course intended to deepen their understanding in a specific area of ecosystems science. The choices for the 1998 semester were a course in microbial methods, taught by John Hobbie and Joe Vallino, and a course in mathematical modeling, taught by Ed Rastetter.

SES students also participate in a seminar on science writing. The students in the 1998 seminar, led by science writer George Liles, surveyed different forms of science writing and explored the ways in which media cover current environmental stories. Seminar speakers included journalists and scientists who discussed their own work and the larger issues of writing about science for a popular audience. Students sketched news articles, profiles of scientists, press releases and newspaper-length science essays and completed one piece of polished writing. Several of their articles were published in the SES newsletter.

Speakers for the Science Writing Seminar were Colleen Cavanaugh, professor at Harvard University; James Shreeve, author of popular science books and articles; John Leaning, Cape Cod Times reporter; Scott Allen, Boston Globe reporter; Chet Raymo, Boston Globe science columnist and book author, and Kevin Chu, National Marine Fisheries Service scientist and former U.S. representative to the International Whaling Commission.

The students also attended seminars presented each week by visiting distinguished scientists and talked with them before and afterwards. The 1998 speakers were Nancy Rabalais of the Louisiana University Marine Consortium, Colleen Cavanaugh of Harvard University, Cindy Lee of the University of New York at Stony Brook, James Kitchell of the University of Wisconsin, Richard Wright of the Norwegian Institute for Water Research, and Peter Vitousek of Stanford University.

During the final five weeks of the program, students carried out their independent research projects. Topics ranged from the effects of spray irrigation with sewage effluent on trophic dynamics in oak forests to a study of heavy metals in the sediments of Cape Cod harbors. Each student presented his or her results at a day-long symposium for the entire laboratory.

“Everybody’s got a little something different to add. I think I’m the only chem major, but we have a computer science major, a sociology major, a couple of environmental science, a biology, a microbiology, so everybody comes with a different perspective on things.”

Kerry Radloff
Mount Holyoke College
SES ’98
Education at The Ecosystems Center

Although the Marine Biological Laboratory (MBL) does not grant degrees, The Ecosystems Center is actively involved in education in a variety of ways. In addition to serving as adjunct professors, guest lecturers and members of doctoral committees at a number of colleges and universities, investigators conduct workshops and teach in courses given at MBL. Senior staff members supervise the work of postdoctoral research associates at the center. Visiting scientists and students come to work on projects, some for a week or two and some for a year.

Science Writers
In June, as part of the MBL’s Science Writing Fellowship program, eight science writers joined researchers at Long-Term Ecological Research (LTER) sites at Harvard Forest and Plum Island Sound for a hands-on course in environmental science. Writers who participated were Monica Allen of the Bangor Daily News, Randall Edwards of the Columbia Dispatch, Ralph Haurwitz of the Austin American-Statesman, Diedtra Henderson of the Seattle Times, Frank Roylance of the Baltimore Sun, Angela Swafford of Mas Vida/CBS Telenovelas, Diane Toomey of WUNC Radio, and Jody Warrick of the Washington Post. Their five-day course included a day at each of the field sites and three days of lecture and laboratory work at the center. Knute Nadelhoffer, Chuck Hopkinson, Ed Rastetter, Jane Tucker, Marty Downs and Kama Thieler were guides and teachers. During the summer, Diedtra and Angela traveled to the Arctic LTER site in Toolik, Alaska, for two weeks of field and lab work, while Kevin Carmody from the Chicago Daily Southtown went to Brazil for two weeks to write about the history of deforestation in Rondônia.

Semester in Environmental Science
The Semester in Environmental Science (SES) completed another successful semester. Many Ecosystems Center principal investigators and scientific staff members participated. Chuck Hopkinson and Knute Nadelhoffer led the aquatic and terrestrial core components of the course, Ed Rastetter taught a class in ecosystem modeling as an elective, and John Hobbie and Joe Vallino taught the elective in microbial methods in ecology. Linda Deegan, Anne Giblin, John Hobbie, Chuck Hopkinson, Jerry Melillo, Knute Nadelhoffer, Chris Neill, Bruce Peterson, Ed Rastetter, Paul Steudler, Joe Vallino, Jeff Hughes and Mat Williams gave lectures for the core courses, and Michele Bahr, Bonnie Kwiatkowski, Pat Micks, Sam Kelsey and Jason Wyda were teaching assistants. Ken Foreman, the SES associate director, and Marsha Chandler, the program’s administrative assistant, kept the program running. Much of the rest of the center’s staff became involved in an unofficial status, helping students with field work or lab assignments.

Science Education on the Local Scene
Michele Bahr, Pat Micks, Knute Nadelhoffer and Jane Tucker served as judges at the Falmouth Community Schools Science Fair in March. Mat Williams and Knute judged projects at Falmouth Academy.

Wil Wollheim, Michele Bahr, Kathy Newkirk and Pat Micks advised junior high school students on developing science fair project ideas and designs for their experiments.

Karie Slavik talked to seventh and eighth grade girls about entering careers in science.

Chris Neill continued his column on birds and natural history for the Falmouth Enterprise, and also wrote an article, "Rondonia Redux," for the Sanctuary magazine of the Massachusetts Audubon Society.

Student Research Opportunities
A number of students participated in the National Science Foundation’s Research Experience for Undergraduates (REU) program. Linda Deegan and Jeff Hughes advised students Suzanne Graham of San Diego State University and Jessica Davis of Roger Williams University. They published the results of their work at Waquoit Bay in the Biological Bulletin on the effects of eelgrass density on the feeding

SES faculty, staff and students

Darrell Herbert
efficiency of mummichog. Jennifer Sweeney of Hiram College also worked with Linda on the Plum Island Sound LTER project.

Pat Micks and Knute Nadelhoffer supervised Kristin May of Oregon State University at the Harvard Forest LTER site. Karie Slavik and Bruce Peterson advised Stephanie Parker from Middlebury College. Her project involved studying micro-algal communities of rock and moss substrates in the fertilized reach of the Kuparuk River.

Laura Gough and Gus Shaver supervised Megan Hedlund of Lycoming (PA) College, and also organized a session at the Toolkit site for REU students to present their posters. John Hobbie presented the Director’s Award to Megan for her poster entitled "Tundra vole herbivory in Eriophorum vaginatum."

Postdoctoral Research Assistants

Laura Gough joined The Ecosystems Center in 1996 after completing her doctorate at Louisiana State University in the Department of Plant Biology. In 1998, she continued her sampling of soil characteristics and plant species composition in several Alaskan arctic tundra types. Laura also investigated the changes in species composition that have occurred in the long-term nutrient, light, and temperature manipulations as part of the LTER research. This year she had an additional opportunity to examine effects of small mammal herbivory in the tundra as the vole populations were very high. In August, Laura traveled to Abisko in northern Sweden with REU student Megan Hedlund and Gus Shaver to look at relationships among soil pH, plant species composition, and aboveground biomass in several plant communities. She also continued her participation in an LTER cross-site comparison on the relationship between diversity and productivity at different spatial scales and in different habitats.

Darrell Herbert joined The Ecosystems Center in 1996 after completing his doctorate at the University of Hawaii, where he studied with James Fownes in the Department of Agronomy and Soil Science. He conducted his thesis research on the effects of nutrient limitation on primary production and the tradeoffs between light use and nutrient use in forests across a soil chronosequence in the Hawaiian Islands. Darrell is working with Ed Rastetter at the center, where he is using the Multiple-Element Limitation (MEL) model to look at plant species competition and the effect on element cycles in ecosystems. The object of his work is to understand the role of species characteristics in the functioning of ecosystems.

Anne Hartley finished her doctorate in 1997 at Duke University, where she worked with William Schlesinger in the Department of Botany. Her dissertation research focused on nitrogen dynamics in the northern Chihuahuan Desert. Anne continues to investigate the impact of environmental change on the nitrogen cycle in her postdoctoral research at The Ecosystems Center. She is working with Chris Neill and Frank Bowles of Research Designs on two global climate simulation experiments in the subarctic tundra of northern Sweden. Anne completed a soil warming experiment in 1997 and is investigating the potential interactive effects of elevated carbon dioxide (CO₂) and air warming on soil nutrient cycling and plant growth in subarctic tundra.

Brian Bovard is working with Jerry Melillo and members of the terrestrial ecosystem modeling group. Brian received his doctorate in 1998 from the Department of Botany at Duke University, where he studied with Boyd Strain. For his thesis, he studied the physiological responses of jack pine and quaking aspen to drought and elevated CO₂. His research at The Ecosystem Center focuses on developing a version of the Terrestrial Ecosystem Model that incorporates the effects of tropospheric ozone on ecosystem
processes. Brian is also working with Anne Hartley, Chris Neill, and Jerry Melillo to study the photosynthetic responses of the subarctic tundra of northern Sweden to climate change.

Karen Buzby joined The Ecosystems Center in 1998 to work with Linda Deegan, investigating the factors that control arctic grayling populations in streams on the North Slope, Alaska. She completed her doctorate in 1998 at the College of Environmental Science and Forestry at the State University of New York at Syracuse, where she studied with Charles Hall. In her dissertation research, she examined the role of hurricane disturbance on the ecological efficiency of streams in the Luquillo Mountains of Puerto Rico. Since she came to The Ecosystems Center, Karen has been analyzing long-term trends in arctic grayling abundance and survival with respect to environmental factors.

Jeffrey Hughes came to The Ecosystems Center in 1996 to work with Linda Deegan and Bruce Peterson on a tracer study of nitrogen flow through the food web of a northern Massachusetts estuary. Jeff received his doctorate in 1993 at the University of Rhode Island with Candace Oviatt, where he focused on small-scale interactions of benthic organisms and sedimentary organic matter. Subsequently, he held a post-doctoral appointment at Rutgers University under Sam Wainright, studying bacterial response to sediment resuspension. Currently, Jeff is working with Linda Deegan to extend a model of nitrogen loading in coastal embayments to predict effects on juvenile fish and the quality of fish habitat. They have found that recent, rapid declines of eelgrass habitat in several southeastern Massachusetts estuaries have resulted in dramatic changes in fish abundances and community composition.

Diana Garcia-Montiel joined The Ecosystems Center in 1997 to work with Paul Steudler and Chris Neill on a project on trace gas fluxes associated with changes in land cover and land use in the Brazilian Amazon. She completed her doctorate in 1996 at Colorado State University, where she studied with Daniel Binkley in the Department of Forest Sciences. She conducted her thesis research on changes in nutrient cycling during natural and managed tropical reforestation in Puerto Rico and Hawaii. At The Ecosystems Center, she is focusing on the quantification of phosphorous availability to plants and on the measurement of trace gas fluxes in forests and pastures in Brazil.
ECOSYSTEMS CENTER EVENTS AND ACTIVITIES

HIGHLIGHTS OF 1998

New Appointments and Elections

Jerry Melillo was elected president of the Scientific Committee on Problems of the Environment (SCOPE) at its 10th General Assembly, held in Piscataway, New Jersey, in June. SCOPE was created 30 years ago by the International Council of Scientific Unions to assess information on anthropogenic environmental changes and disseminate it worldwide.

John Hobbie became chairman in May of the scientific advisory panel for the Interagency Florida Bay Science Program, a study of the entire bay ecosystem supported by both federal and state governments. The panel reviews agency plans and provides independent, impartial advice to the program management committee.

Anne Giblin is president-elect of the Estuarine Research Federation. Linda Deegan was elected president of the New England Estuarine Research Society at the 1998 fall meeting.

Gus Shaver returned to the Ecosystems Center in August after completing a two-year term as a program officer in the Ecosystem Studies Program of the National Science Foundation (NSF) Division of Environmental Biology.

Research associates Robert (Max) Holmes and Hanqin Tian were promoted during the year to the newly created position of staff scientist I at The Ecosystems Center. Max came to the center in 1995 as a postdoctoral research associate after completing his doctorate at Arizona State University. Hanqin joined the center as a postdoctoral research associate in 1996, the year that he received his doctorate from the State University of New York at Syracuse.

Events at the MBL and Other Local Venues

The Marine Biological Laboratory (MBL) was host to an institute in October for authors, illustrators and biologists interested in children’s books about science. Co-sponsors for the three-day workshop were the Center for Children’s Literature and the MBL Science Writing Fellowships Program. Support was provided by the Geraldine R. Dodge Foundation, the National Fish and Wildlife Foundation and Harcourt Brace & Company.

Ecosystems Center participants included Jerry Melillo, who gave a keynote talk on children’s books and environmental science on the second evening of the workshop. A session on ecosystems ecology and research featured talks by several center scientists. Chris Neill discussed deforestation in Brazil; Bruce Peterson talked about the circulation of arctic waters, and Anne Giblin discussed recent research on changing environmental conditions and fish populations in Lake Victoria in East Africa.

Ecosystems Center staff members Knute Nadelhoffer and Kama Thieler were hosts to an international workshop on the use of carbon-14 as a tracer in tundra ecosystem research for two days at the end of October. The workshop was sponsored by the Feedbacks from Arctic Terrestrial Ecosystems (FA TE) project of the International Arctic Science Committee (IASC) and Global Change and Terrestrial Ecosystems (GCTE), a component of the International Geosphere-Biosphere Programme (IGBP).
The workshop attracted researchers from Sweden and Russia as well as from several U.S. institutions. Knute and Kama presented a poster on belowground carbon sources and sinks in tundra ecosystems. Other center participants were Darrell Herbert, Marty Downs, Laura Gough, Jim Launpre, Ed Rastetter and Gus Shaver.

The U.S. National Assessment Synthesis Team met at the J. Erik Jonsson Woods Hole Center of the National Academy of Sciences (NAS) in August to review recent progress and to draft a report on the potential consequences of climate variability and change. Jerry Melillo is a co-chairman of the team, along with Anthony Janetos of the World Resources Institute and Thomas Karl of the National Oceanic and Atmospheric Administration (NOAA) Weather Service. The report is to be submitted to the President and the Congress in January 2000.

Jane Tucker attended a meeting with the Cape Cod Commission in October to discuss the usefulness of stable isotopes in tracing effects from the Boston sewage treatment plant outfall in Cape Cod Bay. The commission is charged with reviewing and regulating projects of significant regional impact on Cape Cod.

Jane, Anne Giblin, Chuck Hopkinson and former center staff member Dave Giehtbrock were featured in a documentary that appeared on public television stations in November. The topic was the relationship among people, science and public policy in the cleanup of Boston harbor.

**LTER Workshops and Meetings**

John Hobbie and Kathy Regan organized the annual planning meeting for the Arctic LTER project at Toolik Lake, Alaska, held at the MBL in February. Participants from The Ecosystems Center were Michele Bahr, Neil Betz, Karen Buzzy, Anne Giblin, Laura Gough, Anne Hartley, Bethanie Hooker, Bonnie Kwiatkowski, Jim Launpre, Knute Nadellhoffer, Bruce Peterson, Ed Rastetter, Gus Shaver, Karie Slavik and Mat Williams. Michele gave a talk on the Life in Extreme Environments (LEXEN) project.

At the Harvard Forest Long-Term Ecological Research (LTER) annual symposium, held in Petersham, Massachusetts, on March 11, Pat Micks made a presentation on forest soil carbon and nitrogen dynamics in relation to above- and below-ground plant inputs. Knute Nadellhoffer spoke on changes in carbon and nitrogen dynamics in soils in response to soil warming at the annual meeting of the New England Regional Center for the National Initiative for Global Environmental Change, which followed the next day.

Hap Garratt participated in two LTER workshops in 1998, one in Baltimore in the end of July for information managers, and the other in Oracle, Arizona, in October for the education committee.

John Hobbie, Chuck Hopkinson and Gus Shaver attended an LTER Coordinating Committee meeting in Madison, Wisconsin, in October. Gus also attended the spring meeting in Fort Collins, Colorado, in April.

In December, Joe Vallino participated in a workshop on modeling ecosystem processes at regional scales, jointly sponsored by the NSF LTER office and by the National Partnership of Advanced Computational Infrastructure Earth System Science. Focus of the workshop was on the uses of supercomputers for ecosystem modeling.

John Hobbie made a presentation on the concept of microbial observatories for intensively studied sites at a meeting of the LTER National Advisory Board, held during December at the Sevilleta National Wildlife Refuge in New Mexico.

**Arctic System Science Workshops**

In January, John Hobbie and Ed Rastetter attended a planning meeting for the Arctic System Science (ARCSS) Land-Atmosphere-Ice Interactions (LAI) program in Washington, D.C.

Bruce Peterson attended an ARCSS committee meeting in October, following the annual American Association for the Advancement of Science (AAAS) Arctic Science Conference in Fairbanks, Alaska. At the conference, Bruce presented a poster on contemporary water and constituent balances in the pan-arctic drainage system.

**Calendar of Other Conferences and Workshops**

Bruce Peterson and Ed Rastetter attended the national
meeting of the joint NSF and Environmental Protection Agency (EPA) Water and Watersheds Program, held in Corvallis, Oregon, at the end of January. Ed presented a poster on the Ipswich River water and watersheds project.

Dave Kicklighter participated in Worldwide Net Primary Productivity Working Group workshops at the National Center for Ecological Analysis and Synthesis (NCEAS) in Santa Barbara, California, in February and October. The latter workshop was followed by another on intercomparisons of ecological models and data.

Bruce Peterson attended the 10th Symposium Ibérico de Estudios de Bentos Marinho in Faro, Portugal, in February, where he gave a plenary talk on isotope tracers in benthic food webs.

Hanjin Tian traveled to Spain in March to attend a conference of the GCTE and Land Use and Coverage Change (LUCC) programs of the IGBP. He gave a paper on the roles of climate variability, atmospheric carbon dioxide and land-use change in the net carbon exchange between the biosphere and the atmosphere.

Karen Buzby and John Hobbie attended a workshop on the restoration of fisheries by enrichment of aquatic ecosystems at the Institute of Limnology, Uppsala University, Sweden, at the end of March. They presented a paper describing the results of 25 years of lake fertilization in arctic Alaska.

Dave Kicklighter participated in a Carbon Cycle Model Linkage Project (CCMLP) workshop in Potsdam, Germany, in April, as well as a CCMLP workshop at the NAS center in Woods Hole in September. Hanjin Tian also attended the Woods Hole workshop.

Jeff Hughes and Linda Deegan made a presentation on the effects of nitrogen loading on juvenile fish in estuaries at the fifth annual eelgrass workshop, sponsored by the EPA and held in Boston in April. They also attended a conference earlier that month in Vineland, New Jersey, where they gave a talk on saltmarsh support of marine transient species.

In April, Linda Deegan, Chris Neill, Paul Steudler and Matt Williams attended an all-scientists meeting for the international Large-Scale Biosphere-Atmosphere Experiment in Amazonia, which is supported by the U.S. National Aeronautics and Space Administration (NASA) and led by Brazil. The purpose of the meeting, held in Baltimore, was to coordinate efforts among more than 30 research teams working on the biogeochemistry of the Amazon Basin.

John Hobbie attended a workshop for economists and ecologists on valuing the world’s ecosystems at NCEAS in Santa Barbara, California, in June.

Dave Kicklighter participated in an Energy Modeling Forum workshop on climate change impacts and integrated assessment, held in Snowmass, Colorado, in August.

John Hobbie attended the International Symposium on Microbial Ecology, held during August in Halifax, Nova Scotia, and gave a paper on microbial food webs in oligotrophic arctic lakes.

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John Helfrich 1945-1998

John Helfrich, who had been at The Ecosystems Center since 1975, died suddenly of a heart attack in October. John had worked for John Hobbie on microbial ecology in Alaska and salt marshes, was research administrator for the center for many years, and most recently worked for Jerry Melillo as a research assistant on the Terrestrial Ecosystem Model project. He was co-author on a number of articles including several on climate change that were published in *Nature* and other journals. John’s skill with computers was legendary, and he shared it willingly with grateful staff members.

John left two teenaged daughters, Mariah and Sarah.

The Woods Hole Community Hall was full the afternoon of John’s service, the crowd spilling out into the entranceway and on to the front steps. Colleagues, fellow Morris dancers, theatre friends, and members of the Woods Hole and Falmouth community were there, and many spoke about John. One poignant reminder of John’s impact on everyone at The Ecosystems Center came from staff member Marty Downs:

“I wasn’t going to speak this afternoon...there are lots of people here who knew John better than I did, but I feel like I got one last gift from him this morning, and I’d like to share it with you. I was out walking, by Squeteague Harbor, where I’ve walked a hundred times before, and suddenly I was seeing the day as John might have, if he had known he had just one gorgeous sunny October Saturday left. I appreciated every sharp, clean breath of air. Saw every golden-green blade of Spartina. Just watched the sun flash and shimmer on the waves. And I picked up a little trash as I went, and thought about the simple, direct ways that John made the world better. I thought about how complicated I often make things, when they could be so simple — and a few lessons that John might want us to remember.

- Appreciate the sun when it shines.
- Feel the breeze on your skin.
- Wear comfortable clothes (if you must wear clothes).
- Pick up trash.
- Listen well to your friends.
- Share your love.”
Gus Shaver traveled to Tromsø, Norway, in August to give a paper at an International Arctic Science Committee workshop on the role of the polar regions in global change. John Hobbie also attended the workshop and presented a poster on the impact of global change on the biogeochemistry and ecosystems of freshwater bodies in arctic Alaska. John preceded his trip to Tromsø with a visit to the Kristineberg Marine Station on the west coast of Sweden as a member of a team reviewing the programs of the station.

In September, Gus presented a paper at a workshop on plant ecology at high latitudes and altitudes, held in Abisko, Sweden. The following month, he attended a workshop in Estes Park, Colorado, on the application of long-term ecological research to management needs. The focus was on integrating results from research sites to develop regional perspectives.

John Hobbie attended "50 Years of Oceanography," an anniversary symposium held at the National Academy of Sciences in Washington, D.C. in October. His contributions to oceanography and those of Bruce Peterson were described in a talk on major breakthroughs in biological oceanography, given by Richard Barber of Duke University.

Marty Downs participated in a workshop at the MBL during October on the use of carbon-14 labeling in trace gas exchange research in northern terrestrial ecosystems.

Ed Rastetter attended a workshop at NCEAS on unifying models of nitrogen fixation in December. Later that month, Knute Nadelhoffer visited NCEAS for a workshop on the estimation of denitrification and other nitrogen sinks at the landscape scale, sponsored by SCOPE. Knute is a participant in a SCOPE project titled "Nitrogen Transport and Transformations: A Regional and Global Analysis."

Meetings
Anne Giblin, Dave Kicklighter and Jerry Melillo attended the annual AAAS meeting in Philadelphia in February. Jerry gave a talk on issues related to policy in the environmental sciences. Jerry also attended the annual meeting of the National Alliance for Research Centers of Excellence at the University of Puerto Rico in Mayaguez.

Chuck Hopkinson gave a talk on microbial degradation of dissolved organic matter at the American Geophysical
Union (AGU)/American Society for Limnology and Oceanography (ASLO) Ocean Sciences meeting, held in San Diego in February.

John Hobbie and Bruce Peterson attended meetings of the Arctic Research Consortium of the U.S. (ARCUS) in Washington, D.C. in March and September. Bruce presented a talk on the pan-arctic water balance at the September session. In December, John Hobbie participated in an ARCUS workshop, held in Marshall, California, on the logistical and infrastructure needs of a potential environmental observatory in Barrow, Alaska.

At the spring AGU meeting in Boston in May, Hanqing Tian presented a comparison of modeling results and isotope measurements with regard to the exchange of carbon dioxide between the terrestrial biosphere and the atmosphere during the 1990s.

Several Ecosystems Center staff members involved in tracer studies of the transformations of nitrogen in streams discussed their research at the annual North American Benthological Society meeting, held on Prince Edward Island, Canada, in early June. Max Holmes presented a paper on interpreting nitrogen-15 data in whole-ecosystem tracer studies. Bruce Peterson spoke on the transformation and export of ammonium during tracer additions to streams. Wil Wollheim gave a talk on estimating ammonium uptake length with tracer additions. Karie Slavik compared primary production in spring, mountain and tundra streams on the North Slope of Alaska. Beth Hooker presented a poster on a coupled field and modeling analysis of nitrogen cycling in an outlet creek.

Later in June, Laura Gough attended the annual meeting of the Society of Wetland Scientists in Anchorage, Alaska, where she gave a talk on the diversity of northern Alaskan plant communities. Joe Vallino attended the annual ASLO meeting in St. Louis, Missouri, and gave a paper on terrestrial organic matter inputs and aquatic food webs.

The Ecosystems Center was well represented at the annual meeting of the Ecological Society of America (ESA), held in Baltimore in August. Laura Gough spoke on the effects of fertilization on herbaceous plant communities. Darrell Herbert presented a poster titled "Hypothetical species diversity-productivity relationships driven by nutrient and light competition interactions." Knute Nadelhoffer gave a talk on the influence of nitrogen deposition on carbon sequestration in temperate forests, one of three presentations featured in the news story on the ESA meeting in Science later in August. Other center staff members attending were Chris Catricala, Ed Rastetter and Gus Shaver.

Linda Deegan organized the fall meeting of the New England Estuarine Research Society (NEERS), held in Falmouth in October. Jeff Hughes presented a paper on recent declines of eelgrass in southeastern Massachusetts estuaries and the effects on fish abundance and diversity. Anne Giblin also attended. In April, Jeff spoke on nitrogen loading effects on the quality of juvenile fish habitat at the annual NEERS meeting in New London, Connecticut.

At the annual meeting of the Soil Science Society of America, held in Baltimore in October, Ed Rastetter gave a talk on validating models of ecosystem response to climate change.

Max Holmes made a presentation on riverine nutrient fluxes from Eurasia into the Arctic Ocean at the winter AGU meeting in San Francisco in December.

Lectures and Seminars

Jerry Melillo gave talks on the potential effects of climate change for natural ecosystems to two groups of business leaders. The first of these presentations was for the International Petroleum Industry's Environmental Conservation Association, which met during February at the headquarters of Mobil Corporation in northern Virginia. The second was for the Environmental Section of the Business Roundtable, an organization of U.S. corporations, which met in October in Annapolis, Maryland.

Jerry also gave talks on the role of land ecosystems in the global carbon budget at the University of Puerto Rico in February, Massachusetts Institute of Technology in March, the University of Colorado in April and Cornell University in November.

Anne Giblin lectured on Lake Victoria sediments and fish populations at a Boston University biology department seminar in February. Later that month, Ed Rastetter gave a seminar on validating models of ecosystem response to climate change at the University of New Hampshire's department of natural resources.
Gus Shaver gave seminars at the State University of New York at Stony Brook and at George Mason University in Fairfax, Virginia, in March. He also spoke at Kansas State University in April.

Chris Nell visited the Konza Prairie LTER site in early April and gave a seminar at Kansas State University on links between soil nutrient cycling and surface water chemistry in the Brazilion Amazon Basin. Later that month, Joe Vallino gave a lecture on developing estuarine ecosystem models at the University of New Hampshire.

Max Holmes presented a seminar in April on nitrogen tracer addition experiments in aquatic environments at the University of Rennes in France, where he was a visiting scientist. He also gave a graduate seminar for the Boston University Marine Program on the use of stable isotopes in ecological research.

Jeff Hughes spoke on the health of coastal ecosystems in the Aquavets course at MBL in May.

In October, John Hobbie gave a talk on the microbes of Toolik Lake, Alaska, at a seminar for the Estuarine, Coastal and Ocean Sciences program at the University of Massachusetts in Boston.

In December, Linda Deegan lectured in a seminar series at Connecticut College on upland land use changes in estuarine ecosystems. Anne Giblin also presented a talk on acid rain and the sulfur cycle of lakes.

Mat Williams gave a lecture in December at the NASA facility in Ames, California, on spatial and temporal patterns in the gross primary productivity of terrestrial ecosystems.

Laura Gough gave lectures during the year at the University of Michigan and at Brown University. Both talks were on plant species diversity in stressful habitats, relating patterns to mechanisms.

Committee Memberships

John Hobbie serves on the board of directors and executive committee of ARCUS. He attended a board retreat in June and participated in a meeting with state and federal agency representatives designed to foster better communications between agency and academic scientists. He continues to serve on the Arctic Research Commission of the U.S. and on the board of advisors of the Smithsonian Environmental Research Center in Edgewater, Maryland.

John also completed his service as chairman of a National Research Council committee charged with reviewing the effectiveness of the Community Development Quota (CDQ) program of the National Marine Fisheries Service. This program uses a percentage of the Bering Sea fishery quota for economic and social development in 56 native Alaskan coastal communities. The committee’s report on the CDQ review was released in December.

Jerry Melillo continues to serve on the design committee for the Report on the State of the Nation’s Ecosystems, Supported by both private and public funds, this project is being managed by the H. John Heinz Center for Science, Economics and the Environment. The first full report is expected in 2001.

Jerry is co-chairman of the synthesis team of the U.S. National Assessment: the Potential Consequences of Climate Variability and Change. He is also a member of the scientific steering committee for the System for Analysis, Research and Training (START), an international system of regional research networks.

Anne Giblin is the ASLO representative to AAAS and a member of the biological section of the AAAS Council of Delegates. She is on the advisory committee for Cornell University’s program in biogeochemistry and environmental change. She also serves on the science board of the Cape Cod National Seashore.

Knute Nadelhoffer served as an external member of the Appointments Board at the Swedish Agricultural University in Uppsala until March 1998. He is also on the editorial board of Oecologia.
Chuck Hopkinson serves as an advisory panelist for the Florida Department of Environmental Protection. The panel's charge is to review and evaluate Everglades nutrient threshold research. Chuck is also a member of the Committee on the Causes and Management of Coastal Eutrophication of the National Research Council and editor in chief of *Mangroves and Salt Marshes*. Jeff Hughes has been appointed associate editor for *Estuaries*.

Bruce Peterson is a member of the ARCSS committee. He also acts as a consultant to Procter & Gamble Company on the effects of solutes in stream ecosystems.

Gus Shaver serves on the interdisciplinary advisory board of the Arctic and Alpine Research Committee of the University of Colorado and on the advisory committee for the Fritz Went Laboratory at the Desert Research Institute of the University of Nevada at Reno. He is also a member of the steering committee for Focus 1 (ecosystem physiology) of the GCTE program.

Kathy Newkirk is past chairman of the executive committee of the Association of Women Soil Scientists. She was recently appointed to the Council of Soil Science Examiners.

**MBL Boards and Committees**

Bruce Peterson completed a term in 1998 as member of the MBL Science Council, a committee of scientists that advises the director and trustees of the laboratory on the scientific aspects of personnel and policy issues. Chuck Hopkinson was elected to the council in August. Chuck is also chairman of the radiation safety committee and a member of the program committee for the MBL annual scientific meeting.

Anne Giblin is chairman of the MBL's diving control board, of which Jane Tucker is a member. Anne and Linda also serve on the laboratory's Fellowship Committee. Jane serves on the Hay Committee, which reviews employee job classifications at the MBL.

Ed Rastetter is chairman of the computer advisory committee, and Joe Vallino and Jim Laundre are members. Ken Foreman, Jerry Melillo and Paul Steudler serve on the research services and space committee.

John Hobbie is chairman of the laboratory's safety committee, and Paul Steudler is a member. John also serves on the joint library advisory committee.

*John Hobbie and Megan Hedlund at REU poster session, Toolik Lake, Alaska*

*Chuck Hopkinson, Joe Vallino and summer interns Katherine Pease and Nina Kilham getting ready for a nutrient addition experiment in the Ipswich River*

*Sarah Jablonski*

*Tracy Jillson*
Seminars at the Ecosystems Center during 1998

January

27 Kathleen Newkirk and Christine Catricala, Marine Biological Laboratory, "The Harvard Forest soil warming experiment: Interannual variation in soil respiration and partitioning root vs. microbial respiration."

February

3 Bruce Peterson, Marine Biological Laboratory, "Water balance for the Pan-Arctic drainage system."
10 John Edmond, Center for Global Change Science, Massachusetts Institute of Technology, "Weathering yields and nutrient chemistry of lakes."
17 Karen Buzby, Marine Biological Laboratory, "Trophic dynamics of a small tropical montane stream."

March

3 Brian Bovard, Botany Department, Duke University, "The responses of two boreal forest tree species to drought."
17 Peter Stone, Center for Global Change Science, Massachusetts Institute of Technology, "A flexible climate model for use in integrated assessments, and some results on ecosystems impacts."
24 Eric Davidson, Woods Hole Research Center, "Nitrogen trace gas emissions from soils: some examples of scaling from plot studies to global budgets."
31 Jonathan Cole, Institute of Ecosystem Studies, "Net heterotrophy in aquatic ecosystems."

April

7 Aaron Ellison, Mount Holyoke College, "Scale-dependencies in ecology and conservation of mangrove ecosystems."
21 Kel Wieder, Villanova University, "Carbon in boreal peatlands—past, present, and future interactions with climate."
28 Kernell Ries, United States Geological Service, "Hydrological model for the Ipswich River basin."

May

5 Diana Garcia-Montiel, Marine Biological Laboratory, "Changes in nutrient cycling during tropical reforestation."
12 William Romme, Fort Lewis College, "Ecology and management of aspen in the Rocky Mountains."
19 Knute Nadelhoffer, Marine Biological Laboratory, "How does N deposition influence carbon sequestration in temperate forests?"

October

7 John Aber, University of New Hampshire, Department of Natural Resources, "Nine years of N additions at the Harvard Forest: Are we saturated yet?"
20 Harold Hemond, Massachusetts Institute of Technology, Department of Civil and Environmental Engineering, "The ecology of arsenic in lakes of the Aberjona Watershed."

November

3 Gus Shaver, Marine Biological Laboratory, "Two years as an NSF Program Officer: How the system really works."
17 Richard Signell, United States Geological Survey, "Modeling red tide in the Gulf of Maine."
24 David Bryant, University of New Hampshire, Department of Natural Resources, "Forest community dynamics and nutrient availability on a chronosequence of landslide deposits in northern New Hampshire."

December

1 David Caron, Biology Department, Woods Hole Oceanographic Institution, "Microbial growth and grazing in oceanic ecosystems."
8 Linda Deegan, Marine Biological Laboratory, "The link between upland land use and fish production in estuaries."
15 Hanqin Tian, Marine Biological Laboratory, "Spatiotemporal variations in terrestrial carbon sink induced by interannual climate variability."
STAFF AT THE ECOSYSTEMS CENTER DURING 1998

Administrative Staff
John E. Hobbie, Co-Director
Ph.D., Indiana University
Jerry M. Melillo, Co-Director
Ph.D., Yale University
Kenneth H. Foreman
Associate Director of Environmental Studies Program
Ph.D., Boston University
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Boston University
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Ph.D., Cornell University
Gaius R. Shaver, Senior Scientist
Ph.D., Duke University
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Anne E. Giblin, Associate Scientist
Ph.D., Boston University Marine Program
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Ph.D., University of Wisconsin
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Ph.D., University of Virginia
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Joseph J. Vallino, Assistant Scientist
Ph.D., Massachusetts Institute of Technology
Mathew Williams, Assistant Scientist
Ph.D., University of East Anglia
Paul A. Steudler, Senior Research Specialist
M.S., University of Oklahoma
Robert M. Holmes, Staff Scientist I
Ph.D., Arizona State University
Hangqin Tian, Staff Scientist I
Ph.D., State University of New York, Syracuse

Educational Staff Appointments
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Karen Buzby, Postdoctoral Research Associate
Ph.D., State University of New York at Syracuse
Diana C. Garcia-Montiel, Postdoctoral Research Associate
Ph.D., Colorado State University, Fort Collins
Laura Gough, Postdoctoral Research Associate
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Anne E. Hartley, Postdoctoral Research Associate
Ph.D., Duke University
Darrell A. Herbert, Postdoctoral Research Associate
Ph.D., University of Hawaii
Jeffrey E. Hughes, Postdoctoral Research Associate
Ph.D., University of Rhode Island

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James P. Byun, Research Assistant
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Elizabeth Carpino, Research Assistant
M.E.M., Duke University
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Jane Tucker, Senior Research Assistant  
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M.S., University of Wyoming
Amos Wright, Research Assistant  
B.A., Hampshire College
Jason C. Wyda, Research Assistant  
M.S., Florida Institute of Technology

Consultants
Francis P. Bowles, Research Systems Consultant  
Principal, Research Designs
Ph.D., Harvard University
Margaret C. Bowles, Administrative Consultant  
B.A., Bryn Mawr College
Heidi E. Golden, Research Consultant  
M.S., University of Massachusetts
Robert Golder, Graphics Consultant  
Rhode Island School of Design
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Visiting Scientists and Scholars
Wei Jun Cai, Visiting Scientist  
University of Georgia
Alex Filgueira, Visiting Student  
University of Elche, Spain
Jennifer King, Visiting Graduate Student  
University of California, Irvine
Tianxing Lao, Visiting Scientist  
Chinese Academy of Sciences
Wendy Loya, Visiting Graduate Student  
Kansas State University
George Kling, Visiting Scientist  
University of Michigan
George Luther, Visiting Scientist  
University of Delaware
Allen Striegler, Visiting Graduate Student  
University of Michigan
Cristina Zago, Visiting Scientist  
Instituto per lo Studio della Dinamica delle Grandi Masse, Venice, Italy


In Press


# Grants for Research and Education in Effect During 1998

## I. National Science Foundation

**NSF-ATM-9529836**
"Inter-American Institute (IAI) Workshop: Biogeochemical Consequence of Land Use Change in the Amazon Basin"
Investigators: Melillo, Steudler, Neill
$50,000

**NSF-BIR-9602540**
"Field Station and Marine Laboratory (FSML) Program: Ecosystems Research Equipment for the Marine Biological Laboratory"
September 1996 – August 1999
Investigators: Burris, Deegan, Peterson
$85,504

**NSF-DEB-9211775**
"The Arctic LTER Project: Terrestrial and Freshwater Research on Ecological Controls"
September 1992 – December 1999
Investigators: Hobbie, Peterson, Shaver
$4,230,405

**NSF-DEB 9318085**
"Lake Victoria: Structure and Function of a Tropical Ecosystem"
(subcontract from University of Michigan)
February 1994 – January 1999
Investigator: Giblin
$35,561

**NSF-DEB-9408794**
"Predicting Forest N Dynamics Using Ecosystem-Scale $^{15}$N Tracers"
Investigator: Nadelhoffer
$410,000

**NSF-DEB-9407829**
"An Isotopic Tracer Experiment at the Ecosystem Scale"
October 1994 – September 1998
Investigator: Peterson
$610,000

**NSF-DEB-9416807**
"Investigating Controls on the Benthic Flux of Nitrogen and Phosphorus from Lake Sediments: A Comparative Ecosystems Approach"
Investigator: Giblin
$200,000

**NSF-DEB-9411975**
"Harvard Forest: Long-Term Ecological Research"
(subcontract from Harvard University)
Investigators: Melillo, Nadelhoffer, Steudler
$746,130

**NSF-DEB-9509613**
"Multiple Resource Interactions and Ecosystem Function"
October 1995 – September 1999
Investigators: Rastetter, Shaver
$400,000

**NSF-DEB-9528017**
"Collaborative Research: Carbon and Electron Acceptor Cycling in Lake and Estuarine Sediments during Early Diagenesis"
September 1996 – August 1999
Investigator: Giblin
$149,965

**NSF-DEB-9628860**
"Nitrogen Uptake, Retention, and Cycling in Stream Ecosystems: An Intersite $^{15}$N Tracer Experiment" (subcontract from Virginia Polytechnic Institute and State University)
September 1996 – August 1999
Investigator: Peterson
$327,347

**NSF-DEB-9708092**
"Physiological and Molecular Diversity of Atmospheric CH$_4$ Oxidizers in Soil"
August 1997 – July 2000
Investigator: Steudler
$600,000

**NSF-DEB-9711626**
"Terrestrial Biospheric Responses to Atmospheric Deposition and Application to Integrated Assessment"
Investigator: Rastetter
$400,000

**NSF-DEB-9726862**
"Integrated, Ecological-Economic Modeling of Watersheds and Estuaries at Multiple Scales"
October 1997 – September 2000
Investigators: Hopkinson, Vallino, Rastetter
$810,000

**NSF-DEB-9810222**
"The Arctic LTER Project: The Future Characteristics of Arctic Communities, Ecosystems, and Landscapes"
October 1998 – September 2004
Investigators: Hobbie, Shaver, Peterson
$4,199,882

**NSF-EAR-9630278**
"Links Between Soil Nutrient and Surface Water Biogeochemistry following Deforestation for Pasture Agriculture in Amazonia"
September 1996 – September 1998
Investigators: Deegan, Neill
$290,000

**NSF-EAR-9807632**
"Predictions of Bioavailability of Riverine-Dissolved Organic Matter from Bulk Measures of Geochemical Composition"
October 1998 – September 2000
Investigators: Hopkinson, Vallino
$259,483
NSF-OCE-9214461
"LMER: Plum Island Sound Comparative Ecosystems Study (PISCES): Effects of Land Use and Organic Matter-Nutrient Interactions on Estuarine Trophic Dynamics"
Investigators: Hopkinson, Hobbie, Giblin, Deegan
$1,780,000

NSF-OCE-9416294
"Coordination for Land-Margin Ecosystem Research (LMER)"
September 1994 – February 2000
Investigator: Hobbie
$543,936

NSF-OCE-9726921
"LTER: Plum Island Sound Comparative Ecosystem Study (PISCES): Effects of Changing Land Cover, Climate and Sea Level on Estuarine Trophic Dynamics"
January 1998 – December 2004
Investigators: Hopkinson, Deegan, Giblin, Hobbie, Peterson, Vallino
$3,359,981

NSF-OCE-9419078
"SCOPE Workshop on Estuarine Synthesis"
September 1994 – February 1999
Investigator: Hobbie
$55,000

NSF-OPP-9318529
"Attaining Ecological Understanding at Regional Level: The Kuparuk River as a Model Arctic System"
June 1994 – May 1999
Investigator: Hobbie
$569,642

NSF-OPP-9407022
"Controls of Structure and Function of Aquatic Ecosystems in the Arctic"
June 1994 – May 1999
Investigators: Hobbie, Deegan, Peterson, Rastetter
$2,731,000

NSF-OPP-9415411
"Primary Production in Arctic Ecosystems: Interacting Mechanisms of Adjustments to Climate Change"
April 1995 – March 2000
Investigator: Shaver
$938,750

NSF-OPP-9522061
"Ecological Responses to Increase in Carbon Dioxide Concentration and Temperature: A Global Change Study at Abisko, Sweden"
September 1995 – August 1999
Investigator: Melillo
209,967

NSF-OPP-9524740
"Contemporary Water and Constituent Balances for the Pan-Arctic Drainage System: Continent to Coastal Ocean Fluxes"
October 1995 – August 1999
Investigator: Peterson
$959,987

NSF-OPP-9615949
"Key Connections in Arctic Aquatic Landscapes"
May 1997 – June 2000
Investigators: Hobbie, Deegan, Giblin, Peterson
$2,989,784

NSF-OPP-9615942
"Belowground Carbon Sources and Sinks in Arctic Tundra Ecosystems"
April 1997 – March 1999
Investigator: Nadelhoffer
$478,000

NSF-OPP-9732281
"The Response of Carbon Cycling in Arctic Ecosystems to Global Change: Regional and Pan-Arctic Assessments"
April 1998 – March 2003
Investigators: Hobbie, Rastetter, Williams
$1,000,000

NSF-OPP-9615563
"Global Change and the Carbon Balance of Arctic Ecosystems: The Importance of Carbon-Nutrient Interactions in Soils"
April 1997 – March 2000
Investigators: Nadelhoffer, Giblin, Shaver
$742,776

NSF-OPP-9614038
"Modeling Canopy Carbon and Energy Balances in the Pan-Arctic: Scaling from Leaf to Region"
September 1996 – August 1999
Investigators: Rastetter, Shaver, Williams
$285,707

NSF-OPP-9614253
"The Role of High Latitude Ecosystems in the Global Carbon Cycle"
(subcontract from the University of Alaska)
September 1996 – August 1999
Investigator: Melillo
$115,000

NSF-OPP-9622157
"Development of a Linked Hydro-Biogeochemical Model for an Arctic Watershed"
March 1996 – March 1999
Investigator: Giblin
$115,024
II. U.S. Department of Energy

DOE-901214
Northeast Regional Center of the National Institute for Global Environmental Change (NIGEC) "Atmosphere-Biosphere Feedback Mechanisms in Forest Ecosystems" (subcontract from Harvard University) September 1990 – June 1998
Investigators: Melillo, Nadelhoffer, Steudler
$920,525

DOE DE-FC03-90ER61010
Northeast Regional Center of the National Institute for Global Environmental Change (NIGEC) "Human Influences on Forest Nitrogen Budgets and their Implications for Forest Carbon Storage" July 1998 – June 2001
Investigators: Melillo, Nadelhoffer, Steudler
$592,800

DOE DE-FG02-92ER61438
Investigators: Hopkinson
$1,316,891

DOE DE-FG02-95ER62108
"A Proposal to Support Two Joint TCP-VEMAP Workshops" September 1995 – August 1999
Investigator: Melillo
$50,000

W/IGEC-98-013
Western Regional Center of the National Institute for Global Environmental Change (WESTGEC) "Stand Age, Productivity and Hydraulic Conductance of Douglas Fir in the Wind River Basin" (subcontract from Oregon State University) May 1998 – April 2001
Investigator: Williams
$39,925

III. National Aeronautics and Space Administration

NASA-92-08/NAGW-2669
"Changes in Biogeochemical Cycles" (subcontract from the University of New Hampshire) January 1991 – December 2000
Investigators: Melillo, Peterson, Steudler
$3,399,743

NASA-98-247
"A Satellite-Based System for Monitoring Biogeochemical Fluxes Between the Continental Land Mass and Coastal Oceans: A Focus on River Plumes" (subcontract from the University of New Hampshire) September 1998 – August 2001
Investigator: Peterson
$45,000

NASA NCC5-338
Investigator: Melillo
$278,895

NASA-NAG5-3859
Investigators: Melillo, Neill, Steudler
$800,000

NASA-NCC5-279
Investigators: Deegan, Neill
$477,191

NASA-NAGW-4436
Investigator: Williams
$19,834

NASA-NCC5-293
Investigators: Williams, Rastetter
$328,673

NASA NAG5-6275
"The Role of Land-Cover Change in the High Latitude Ecosystems: Implications for the Global Carbon Cycle" (subcontract from the University of Alaska Fairbanks) March 1998 – August 2001
Investigator: Peterson
$74,997

IV. National Oceanic and Atmospheric Administration

NOAA-NA76FD106
Investigator: Deegan
$30,666

NOAA NA 46RG0470
Investigator: Giblin, Hopkinson
$77,036

NOAA/NMFS-40AANF803410
"Biodiversity in Coastal Marine Ecosystems: Evaluation of Biodiversity in Submerged Aquatic Vegetation Habitats" September 1998 – April 1999
Investigator: Deegan
$24,498
V. U.S. Environmental Protection Agency

EPA-CR 823713-01-0
"Interaction of Factors that Control Greenhouse Gas Fluxes: A Transect Study"
June 1995 – June 1999
Investigators: Melillo, Steudler $1,043,936

EPA-CR 825757-01-0
"Social and Ecological Transferability of Integrated Ecological Assessment Models"
October 1997 – September 2000
Investigator: Deegan $850,575

EPA-CR 824767-01-0
"Tracing the Fate of Nitrogen Inputs from Watersheds to Estuaries"
Investigators: Deegan, Peterson $232,323

VI. U.S. Department of Agriculture

96-111
"Predicting the Effects of a Changing Physical and Chemical Climate on Primary Production, Nutrient Cycling and Water Yield for Forests of the Northeastern U.S.: A Comparison of Models and Scales."
(subcontract from the University of New Hampshire)
Investigator: Melillo $60,000

95-37101-1879
"Influences of Above- and Belowground Litter on Forest Soil Organic Matter Dynamics"
August 1995 – August 1999
Investigator: Nadelhoffer $316,000

SRS 33-CA-97-073
"PnET-IIS/TEM Model Comparison and Expansion, Phase II"
April 1997 – April 1999
Investigator: Peterson $83,468

97-35101-4318
"Is Forest Productivity of Old Forests Limited by Tree Hydraulics"
(subcontract from Oregon State University)
October 1997 – September 2000
Investigators: Rastetter, Williams $56,102

VII. Electric Power Research Institute

94-033
"Carbon Cycle Model Linkage Project"
(subcontract from the University of New Hampshire)
August 1993 – June 1998
Investigator: Melillo $118,725

RP3316-04
"Vegetation/Ecosystem Modeling and Analysis Project"
September 1993 – December 1999
Investigator: Melillo $906,703

VIII. Other Research Grants

Massachusetts Water Resources Authority G2360-178D/S138
"Harbor and Outfall Monitoring Phase III"
(subcontract from Battelle Memorial Institute)
November 1997 – June 2001
Investigators: Giblin, Hopkinson $417,196

Jessie B. Cox Charitable Trust
"Integrated Ecological-Economic Modeling of Watersheds and Estuaries at Multiple Scales"
March 1998 – February 2001
Investigator: Hopkinson $150,000

University Corporation for Atmospheric Research-A9912166
"Support for the National Assessment Synthesis Team"
December 1998 – May 2000
Investigator: Melillo $59,975

Sweden Nature Protection Agency-802-116-94-Ff
"Ecological Responses to Increases in Carbon Dioxide Concentration and Temperature: A Global Change Study at Abisko, Sweden"
Investigator: Melillo $155,904

Texaco Foundation
"Environmental Fellowship Program"
September 1990 – December 1999
Investigator: Steudler, Melillo $485,000

Exxon Corporation
"Global Change Research"
April 1994 – December 1999
Investigator: Melillo $200,000

Sue Donovan
Exxon Corporation
(subcontract from the Bermuda Biological Station for Research)
"Investigate the Cycling of Natural and Man-made Nitrogen Compounds Between the Atmosphere, the Land Environment and the Ocean"
Investigator: Melillo $55,000

The Procter & Gamble Company
"Parameterization of the Stable Isotope Tracer Model (SISTM) for the Procter & Gamble Experimental Stream Facility (ESF)"
May 1998 – February 1999
Investigator: Peterson $30,170

Andrew W. Mellon Foundation
"Scaling of Land-Atmosphere and Land-Water Linkages: A Whole Ecosystem Approach"
June 1996 – May 1999
Investigator: Staff $600,000

Massachusetts Institute of Technology 5700000403
"MBL-MIT Cooperative Research Activity"
July 1997-June 1998
Investigator: Melillo $94,722

CR Environmental
"New York City Department of Environmental Protection Catskill Reservoir Study"
May 1997 – December 1998
Investigator: Giblin $20,687

Department of Environmental Protection, Florida
"Everglades Nutrient Threshold Research Peer-Review Panel"
February 1997-February 1998
Investigator: Hopkinson $14,625

Grants for Support of Semester in Environmental Science and Facilities

Andrew W. Mellon Foundation
"Semester in Environmental Science at the Marine Biological Laboratory"
June 1996 – June 2001 $4,821,249

Davis Educational Foundation
"Semester in Environmental Science"
July 1996 - July 2001 $200,000

The Burroughs Wellcome Fund
"Semester in Environmental Science"
March 1996 - March 2000 $100,000

The Starr Foundation
"Semester in Environmental Science"
December 1997 - December 2001 $500,000

Charles E. Culpeper Foundation
"Semester in Environmental Science"
April 1997 - April 2000 $150,000

Rowley River at Plum Island Sound LTER site
The annual operating budget of The Ecosystems Center for 1998 was $7,003,538, 3.5% higher than the previous year. Roughly 80% of the income of the center comes from grants for basic research from government agencies. The other 20% comes from gifts and grants from private foundations, including support for the Semester in Environmental Science, as well as from institutional support for administration and income from the center’s reserve and endowment funds.

These non-governmental funds provide flexibility for the development of new research projects, public policy activities and educational programs. More information about sources of support appears in the Introduction to The Ecosystems Center and in Research Grants in Effect in 1998.

The combined total value of the center’s reserve fund and endowment at the end of 1998 was $6,306,351, a decrease of 3.25% from the 1997 year-end value of $6,518,534. Income from the reserve fund and endowment helps defray the costs of operations, writing proposals, consulting for government agencies and the center’s seminar program.

Over the years since it was founded in 1975, the center has received support from these foundations, corporations and industry consortia:

Atlantic Richfield Foundation
The Burroughs Wellcome Fund
Robert Sterling Clark Foundation, Inc.
The Clowes Fund, Inc.
Conservation, Food & Health Foundation, Inc.
The Jessie B. Cox Charitable Trust
Charles E. Culpeper Foundation, Inc.
Arthur Vining Davis Foundations
Davis Educational Foundation
Henry L. and Grace Doherty Charitable Foundation, Inc.
Electric Power Research Institute
Environmental Resources Management Group
Exxon Corporation
Max C. Fleischmann Foundation
The Ford Foundation
General Electric Foundation
Grace Foundation, Inc.
The Grass Foundation
The Harken Foundation
Charles Hayden Foundation
International Business Machines Foundation
Charles A. Lindbergh Fund
The Andrew W. Mellon Foundation
NL Industries Foundation, Inc.
Jessie Smith Noyes Foundation, Inc.
Rockefeller Brothers Fund
The Rockefeller Foundation
Rowland Foundation, Inc.
Scherman Foundation, Inc.
Phoebe Speck Sunshine Fund
The Starr Foundation
Surdna Foundation, Inc.
Sweet Water Trust
Texaco Foundation
Wingwalker Initiatives
THE ECOSYSTEMS CENTER
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