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Upper center: A stream draining cattle pasture in Rondônia, Brazil. Photo by Linda Deegan
Center: Center scientist Ed Rastetter and Bob McKane of the Environmental Protection Agency Research Laboratory in Corvallis, Oregon, collect samples in old growth stand of Douglas fir in the Cascade Mountains. Photo courtesy of Ed Rastetter
Lower center: Diana Garcia-Montiel measures trace gases given off by soils in a pasture in Rondônia, Brazil. Photo by Paul Steudler
Bottom: Jeff Hughes and students examine fish and invertebrates in a salt marsh at the Plum Island Sound LTER research site in northeastern Massachusetts. Photo by Linda Deegan

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Above: Keri Holland. Photo by Tom Kleindinst
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 30 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 scientists and 40 postdoctoral investigators, research technicians and administrative personnel. The annual operating budget for 1997 was $6.7 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.

The Ecosystems Center launched a new educational venture in the fall of 1997, when 16 students from a consortium of small liberal-arts colleges and universities attended the first Semester in Environmental Science at the MBL. This semester-long program in environmental sciences for undergraduates 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 both organisms and their physical environment, linked through a variety of biological, chemical and physical processes. Among the ecosystems we study are tundra, forest stands, 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 Brook 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 National Science Foundation's Long-Term Ecological Research (LTER) projects at Toolik Lake and Harvard Forest. The center has also participated in the NSF's Land Margin Ecosystems Research (LMER) program with a study of the effects of changing land use in the coastal zone on aquatic food webs in Plum Island Sound northeast of Boston.

This year the NSF selected our LMER project, the Plum Island Sound Comparative Ecosystems Study (PISCES), as the newest LTER project. The incorporation of PISCES into the LTER program will make it possible to undertake studies of long-term changes in the watershed and estuary that were not possible before and to attract other projects to the site. It also represents a first step in a new commitment of the LTER program to funding additional sites for coastal research.

Facilities in Woods Hole include a mass spectrometer for stable isotope analysis, chemical analytical laboratories and controlled environment 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 pathways and 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 Department of Energy, the Environmental Protection Agency, the National Oceanic and Atmospheric Administration, the National Aeronautics and Space 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 Harken Foundation is supporting a study of sediments in Lake Victoria.

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.
Our nation needs a new sense of scientific purpose to justify its investment in research and technology. We are hearing this message repeatedly from corporate leaders as well as public figures. Between 1945 and the beginning of this decade, Congressional support for investing in science was motivated, in large measure, by our rivalry with the Soviet Union. Money flowed into science and engineering to assure our competitiveness in a variety of areas important to the security of the nation. With the end of the Cold War, this rationale has diminished in importance while a new one has yet to emerge.

In a recent op-ed piece in *The Boston Globe*, Charles Vest, president of the Massachusetts Institute of Technology (MIT), suggested that the new organizing rationale should grow out of "one of the most ancient and fundamental human values: our love for our children." He noted that today’s parents “are strongly committed to giving their children a viable planet, a viable economy, and a viable future.” Vest identified the coupling of the environment and the economy in a sustainable way as a challenge to science and engineering that would require research in many fields. We at The Ecosystems Center agree.

Over the last decade, Americans have come a long way toward recognizing that environmental and economic interests are inextricably linked. We increasingly understand that the bounty of our nation’s lands and waters and the health of their plant, animal and microbial communities form the natural capital upon which our economy is based. We are also beginning to recognize that a forward-looking economic strategy requires that we protect this natural capital, rather than damaging it and then spending vast sums of money attempting to restore it to health.

To protect our natural capital and to evaluate alternative plans for managing ecosystems, we need an accessible, extensive and continually updated base of environmental knowledge. The state of our environmental knowledge and our ability to use it were evaluated in a recent report to the President of the United States from a special panel of his Committee of Advisors on Science and Technology (PCAST). The authors of the report, titled "Teaming with Life: Investing in Science to Understand and Use America’s Living Capital," judged that we have fallen short on both counts.

How can we improve the situation? The PCAST panel recommended a list of topics for investment in science for a sustainable future. Among them are the search for fundamental ecological principles, the integration of ecological information with the tools of information science, and the education of Americans about the ecological and economic importance of biodiversity and ecosystems. These three topics are central to the business of The Ecosystems Center.

The goal that underlies our field and laboratory research is to develop general principles about the way ecosystems work. We focus on ecological processes, such as the decomposition of organic matter, photosynthesis and evapotranspiration. Photosynthesis is the process by which plants convert atmospheric carbon dioxide into more complex organic molecules, and evapotranspiration refers to the flux of water from plants and soil into the atmosphere. We ask similar questions and apply similar methods to studying the factors that control the pattern and rate of decomposition, for example, in a variety of contexts, from the terrestrial and freshwater ecosystems of the Arctic, the temperate zone of the Northern Hemisphere and the tropics of South America and Africa to estuarine and coastal marine ecosystems around the country. We are trying to build a general understanding of the decomposition process so that we can predict its pattern and rate in places not yet studied. We use the same approach to understanding and generalizing about other ecosystem processes.

Two of the essays in this annual report offer examples of detailed process studies. With the help of British and Swedish colleagues, postdoctoral research associate Anne Hartley and Ecosystems Center scientists Jerry Melillo and Christopher Neill are studying the effects of warming and elevated carbon dioxide concentration on nitrogen cycling, plant productivity, and the species of plants found in the tundra of northern Sweden. The results of this study will help us understand how ecosystems might respond to climate change.
In the western Amazon, postdoctoral research associate Diana Garcia-Montiel and center scientists Linda Deegan, Jerry Melillo, Christopher Neill and Paul Steudler are working with Brazilian colleagues to discover how the conversion of tropical forests to pastures affects the availability of phosphorus to plants. Since phosphorus is the nutrient that is thought to limit plant growth in tropical pastures, this research has implications for the sustained use of tropical ecosystems for agriculture.

Another major focus of research at The Ecosystems Center involves linking key ecological processes in integrated models that represent the behavior of ecosystems. In an article in this report, Linda Deegan, Robert Garrity, Anne Giblin, John Hobbie, Charles Hopkinson, Bruce Peterson and Joe Vallino describe their use of an ecosystem model to see how the interplay between freshwater discharge from the land and salt-water intrusion from the ocean affects phytoplankton and fish populations in the Plum Island Sound estuary on the northeast coast of Massachusetts.

To gain confidence in our ecosystem models we test them against new field data. The center’s arctic research group provides a good example of this approach in an article in this report. Postdoctoral research associate Marc Stieglitz and center scientists Anne Giblin and John Hobbie, along with colleague George Kling of the University of Michigan, describe a successful comparison of results from modeling hydrological and thermal processes in a watershed to detailed field records from northern Alaska.

We also use our state-of-the-art ecosystem models as a basis for extrapolating from our understanding about processes on the local level to large regions and the whole globe. Extrapolating from the small scale to larger scales often requires that we simplify complex ecosystem models to improve their computational efficiency. As part of the scaling activity we use geographic information systems and other technological innovations to organize model inputs and outputs. Inputs refer to the information that models require to run, such as data on temperature, precipitation and the amount of sunlight. Outputs are the predictions of the model, such as the rate at which organic matter is stored in a forest as it regrows after harvest or the amount of nitrogen stored in the sediment of an estuary.

Scaling is a major theme of the article in this report by postdoctoral research associate Hanjin Tian and center scientists John Helfrich, David Kicklighter and Jerry Melillo. They describe their use of an ecosystem model combined with a geographic information system to study the effects of the El Niño-Southern Oscillation cycle on carbon storage in the undisturbed ecosystems of the Amazon Basin.

The Ecosystems Center is actively involved in education as well as basic research. Our educational activities include a semester in environmental science for undergraduates from small colleges and universities, summer internships for undergraduates at our Woods Hole laboratory and our field sites throughout the world, and a week-long, hands-on field and laboratory course for professional journalists. A goal common to all of these activities is the education of citizens as well as future scientists about the importance of preserving biodiversity and the integrity of ecosystems for the well-being of human society.

In addition to the studies described above, former postdoctoral research associate Xiangming Xiao and center scientists Jerry Melillo and David Kicklighter are collaborating with economists on ecological analyses. The center’s Terrestrial Ecosystem Model has been used for the terrestrial ecologic component of a global-scale integrated assessment project at MIT that addresses the consequences of human activities and approaches to resource management. This same group of scientists is also working with economists in the Stanford Energy Modeling Forum.

Through research and teaching, the staff of The Ecosystems Center is working to help build our environmental knowledge base and to show others ways of using it. We will continue our collaborations with economists to explore ways of linking environmental and economic concerns. The scientific work that we do in support of this essential linkage is science for a sustainable future.
Deforestation and the combustion of fossil fuels have increased carbon dioxide (CO₂) levels in the atmosphere by 26% over the last two centuries. The atmospheric concentration of CO₂, an important contributor to the heat-trapping capacity of the atmosphere, is expected to double by the year 2050. Global climate models predict that an increase of this magnitude would raise the average annual temperature of the globe by 1.5° to 4.5° Celsius. Scientists from The Ecosystems Center have investigated the potential impact of elevated temperatures and atmospheric CO₂ levels on ecosystem processes at a variety of sites around the world.

Christopher Neill, Anne Hartley and Jerry Melillo are looking at how warming and elevated CO₂ concentrations change carbon and nitrogen cycling in plants and soils and, ultimately, the species of plants that are found in the tundra of subarctic Sweden. We are particularly interested in studying subarctic ecosystems because climate models predict that atmospheric warming will be greatest at high latitudes. These ecosystems also contain large stores of carbon and nitrogen in soil organic matter. Soil microbes transform this organic nitrogen into inorganic nitrogen, usable by plants, during mineralization. Warming is likely to accelerate soil nitrogen mineralization rates, increasing the supply of plant nutrients, which in turn could enhance plant growth and alter the composition of plant communities.

We used two types of experiments, developed in consultation with Francis Bowles of Research Designs, Woods Hole, to simulate an increase in atmospheric temperature and CO₂ concentration during the short subarctic growing season at Abisko Research Station in northern Sweden. In the first, we used buried heating cables to warm the tundra soil by 5°C. In the second, we added CO₂ to air and warmed it by 5°C; this air was blown into open-top chambers and onto the tundra surface. We collaborated with Rose Crabtree of the University of Sheffield, United Kingdom, on the soil-warming experiment and Bengt Carlsson of the University of Lund in Sweden on the CO₂ enrichment and air warming experiment. These studies were designed to investigate the effects of elevated CO₂ and warming on soil nitrogen availability and plant growth.

Although warming the air did not alter soil nitrogen cycling by the end of the second growing season, it increased the growth of all three dominant shrubs, velvet-leaf blueberry (Vaccinium myrtillus), lingonberry (Vaccinium vitis-idaea) and crowberry (Empetrum hermaphroditum) (Figure 1). These results are consistent with previous greenhouse warming experiments and suggest that higher air temperatures promote plant growth directly rather than indirectly through changes in the soil nitrogen cycle.

When we warmed tundra soils by 5°C with buried heating cables, we found that the net amount of nitrogen mineralized in soils doubled during the second growing season (Figure 2). The increase in nitrogen availability most likely contributed to an observed increase in blueberry growth in this experiment. This is the first evidence that warming of subarctic tundra may stimulate plant growth indirectly by increasing soil nitrogen availability. In the fifth year of the study, we found that soil warming had no further effect on plant growth and soil nitrogen availability; however, the summer of 1997 was unusually dry and hot. We will continue this study to determine whether subarctic tundra ecosystems are well buffered against warming over the long term.

Previous studies in subantarctic tundra ecosystems that have altered nutrient availability through fertilization have

![Figure 1: Response of dwarf shrubs in the Swedish subarctic to 5°C rise in air temperature and elevated CO₂ by the end of the second year of treatment.](https://example.com/figure1.png)
shown shifts in plant species composition. Despite the increase in soil nitrogen mineralization in the second year, we found that soil warming had no effect on plant community composition after five years of treatment. Our results suggest that in the most extreme climate warming scenario (5°C increase in temperature), soils will mineralize an order of magnitude less nitrogen than was applied in previous fertilization experiments. High-dose fertilization studies provide insight into controls on plant communities, but they do not accurately simulate the increases in nitrogen availability predicted for a warmer climate.

We were surprised to find that the shrubs did not grow more in the CO₂-enriched air. Modeling studies at The Ecosystems Center and elsewhere suggest that the capacity of arctic vegetation and soils to take up and store atmospheric carbon depends on nitrogen availability. The absence of a plant growth response to elevated CO₂ may be due to soil nutrient limitations. Although CO₂ enrichment had no effect on plant growth, this treatment increased the ratio of carbon to nitrogen in the leaves of the deciduous shrub blueberry and, to a lesser extent, the crowberry (Figure 3). When these leaves fall, plant material with a high ratio of carbon to nitrogen is added to the soil. This organic matter is less nutritious and consumed less readily by microbes, reducing the amount of nitrogen that is mineralized in the soil. Thus a change in leaf tissue chemistry could slow soil nitrogen cycling in the long-term and potentially dampen the response of subarctic ecosystems to warming.

Will the Swedish tundra be altered by changes in atmospheric temperature and gas concentrations? Our research shows that the subarctic tundra responds to warming over the short term, but we need longer-term studies to answer this question conclusively.

Experimental plots at Abisko, Sweden.

Figure 2: Net mineralization of nitrogen over growing seasons in experimental plots with elevated soil temperature (grey bars) versus disturbance control plots (black bars) in kilograms of nitrogen per hectare per season. The difference in results between the experimental and the control plots was significant only for the 1994 season.

Figure 3: Carbon to nitrogen ratios in crowberry and blueberry leaves after exposure to elevated air temperature (5°C) and CO₂ enrichment after one growing season.
The availability of phosphorus, an important nutrient for plants, exerts a critical control over the growth of tropical rain forests. The warm, moist conditions that have existed for thousands of years in most of the regions where these forests grow have created deep and highly weathered soils. The soluble minerals have been carried away by rainwater, leaving only the most resistant materials, such as clays and iron and aluminum oxides. In these soils, most of the rocks that release phosphorus readily have long since weathered away.

Understanding the availability of phosphorus is the key to evaluating the fertility of soils in tropical forests. Most of the phosphorus in these soils has been recycled from primary minerals into insoluble iron and aluminum compounds and into forms of organic matter that do not decay easily. An important portion of the total phosphorus in these ecosystems is stored in the tissues of forest plants, primarily trees.

In the Amazon Basin, large areas of forest are cleared each year for human use, predominantly for cattle pastures. When forests are cleared, typically by cutting and burning, the phosphorus stored in the forest plants is released into the soil. It can then be taken up by the grasses that grow in the newly created pastures. But phosphorus in the soil can move quickly between different forms or fractions that vary greatly in their solubility and availability to plants. The productivity of these pastures will be closely related to the changes that occur in the availability of phosphorus in the soils.

Ecosystem Center investigators Diana Garcia-Montiel, Christopher Neill, Paul Steudler, Jerry Melillo and Linda Deegan are trying to understand how the conversion of forest lands into pasture affects the distribution of soil phosphorus among accessible and resistant fractions. We study soils in forested sites and in pastures that were created between three and more than 40 years ago. We are thus able to observe the changes that take place in soil phosphorus over a long time period. All of these sites are located on Fazenda Nova Vida, a 50,000-acre cattle ranch in the Brazilian state of Rondônia. Cattle ranches dominate the cleared forest lands in this rapidly changing region.

To determine the amounts of the different fractions of phosphorus in forest and pasture soils, we used a sequential extraction procedure adapted for tropical soils. Passing the soil solution through specially-designed resins that adsorb soluble phosphate, we first extracted the inorganic phosphorus that is dissolved in soil water and thus easy for plants to take up. We then used a bicarbonate solution to extract the phosphorus in microbial cells and the moderately available inorganic phosphorus that is adsorbed on the surfaces of soil minerals. Finally, we used sodium hydroxide to extract the resistant forms of phosphorus from inorganic and organic material. This fraction, which is harder for plants to take up, is the phosphorus associated with iron and aluminum in the soil.

Figure 1. Amount of phosphorus in various soil fractions along a sequence of sites from forest to pastures of different ages: a) inorganic phosphorus readily available for plant uptake; b) relatively available inorganic and microbial phosphorus; c) inorganic phosphorus associated with iron and aluminum in the soil, and d) resistant organic forms of phosphorus. The fractions are arranged from most available (top) to least available (bottom).
We found that the phosphorus dissolved in soil water (resin P) increases in the first few years after forest is cleared and pasture is established (Figure 1a). The adsorbed and microbial phosphorus (bicarbonate P) also increase (Figure 1b). These results suggest that phosphorus is readily available to plants and cycling actively in the soils of young pastures. In five-year-old pastures, the amount of phosphorus in these pools begins to fall. By the time a pasture is nine years old, the phosphorus in these available fractions decreases to less than the amounts in the original forest.

During the same time, the amount of the less usable phosphorus associated with iron and aluminum (sodium hydroxide P) increases in both inorganic and organic forms (Figure 1c and d). All of the pastures we examined had more phosphorus in these fractions than the original forest. During the first decade after a pasture is created, phosphorus moves from the biomass of the original forest plants into available forms in the soil and then into more stable and less available forms.

The changes in soil phosphorus that occur over the years following forest clearing are similar to changes that occur during the geological course of soil development in the absence of any disturbance by human activity. In young soils, phosphorus exists as a component of primary rock minerals, mainly calcium apatite. As weathering takes place, this mineral-bound phosphorus dissolves and is adsorbed onto clay mineral surfaces. Finally it is coated with iron and aluminum oxides. It is very hard for plants to take up phosphorus in this form. Some phosphorus is also reworked through soil microbes into resistant forms of soil organic matter.

The clearing of forest in Rondônia appears to reset the clock on the natural course of soil development by making phosphorus available to plants in easily usable mineral form. But the sequence of transformations that occur over thousands of years in normal soil formation takes place in a few short years after clearing. Instead of primary minerals, the source of the new phosphorus in the soil is the biomass that is burned after cutting. The phosphorus that is incorporated in the soil after burning makes it more fertile for a few years after pastures are established. After about 10 years, this phosphorus is transformed into more stable, recalcitrant forms that are difficult for plants to use. These transformations occur without a change in the total amount of phosphorus in the soil.

The forms that phosphorus takes in the soils of pastures created from former rain forests influence several important aspects of pasture ecology and nutrient cycling. Many Amazonian pastures show declines in grass productivity anywhere from two to 20 years after clearing. Although the rate at which phosphorus moves between different fractions is an important aspect of fertility in these soils, we currently know little about these complex transformations in many of the regions where pastures are widespread. In Rondônia, we are finding declines in the productivity of pastures greater than 10 years old. These results fit with the declines we observe in the most available soil phosphorus. In the long run, sustainable management of land as pasture in this region will require periodic additions of phosphate fertilizer.

We also want to understand how the forms of phosphorus in pasture soils influence the nutrients that flow into adjacent streams. Our findings suggest that the potential for movement of the most available forms of inorganic phosphate into streams is higher in younger, vigorously growing pastures where these forms are more abundant. Older pastures contribute less available phosphorus to streams, as long as all other factors are equal. We are currently exploring the contributions these variations make to the differences in chemistry between streams moving through recently cleared land and streams draining older, established pastures. These findings will help us predict the forms and variety of nutrients that will eventually end up in the larger rivers of the region, including the Amazon itself, as an ever-increasing portion of its watershed is transformed from forest to agricultural uses.
Located at the interface between the land and the ocean, the estuaries of rivers provide vital habitat for many fish and shellfish species of commercial and recreational value. Estuarine marshes support both migratory and resident birds. These areas also offer a wide variety of recreational opportunities, such as boating, swimming, fishing, bird-watching and hiking. Because of its commercial, recreational and scenic value, coastal land is highly valued. The population density of coastal regions is double that of the United States as a whole, and population growth in these areas is three times the national growth rate. Landmargin ecosystems are thus under increasing stress from alterations in local land-use patterns as well as changing climate on the global scale.

Since 1993, scientists at The Ecosystems Center have been conducting laboratory and field experiments in Plum Island Sound on the northeastern shore of Massachusetts (Figure 1) and developing models of its ecosystem processes and properties. Our goal is to understand and predict the impact of changes brought about by human activity on estuarine ecosystems. This research, carried out by center researchers Linda Deegan, Robert Garratt, Anne Giblin, John Hobbie, Charles Hopkinson, Bruce Peterson and Joe Vallino, is part of the Land Margin Ecosystem Research (LMER) program of the National Science Foundation (NSF).

The LMER project at Plum Island Sound includes studies of both the estuary and its watershed. The watershed research focuses on how changes in land use, such as clearing of forests for agriculture or residential use, affect the quantity and seasonal variation in the dissolved inorganic nitrogen (DIN) and organic matter that flows into the estuary as well as the quality, or biological useability, of the organic matter. The estuarine research focuses on how the DIN and organic matter from the watershed affect the food web of the estuary, from the microorganisms at the base to the fish at the top.

The ecology of the estuary, however, is not simply a function of the material that flows into it. Physical factors, such as the influx of fresh water, mean sea level and the amplitude of the tides, the salinity of the water, nutrients, light intensity and temperature, all affect how and where organisms grow and material is transformed in the estuary. These physical forces operate on a variety of time scales, ranging from hours to days for storms, months to years for seasonal changes, and years to decades or centuries for changes in climate.

In our effort to investigate the effects of changes in physical factors, we are developing models that combine estuarine hydrodynamics with ecosystem processes and properties. The hydrodynamic interplay between freshwater discharge from the watershed and salt-water intrusion from the ocean determines many of the basic characteristics of an estuary, including salinity levels throughout the system.

Salinity, in turn, affects the development and distribution of organisms throughout the estuary. Although some organisms can survive in the full range from fresh water to ocean salt water, most can only tolerate small changes in salinity. For these organisms, the magnitude of freshwater flux into the estuary limits the locations in which they can survive. For example, in the spring many species of fish spawn and grow in low salinity water. Thus the magnitude

Figure 1: False-color infrared aerial photograph of Plum Island Sound and the Parker River on the northeastern coast of Massachusetts. Plum Island, on the right, separates the sound from the Gulf of Maine.

Linda Deegan
Figure 2: Modeling simulations of salinity distributions in the Parker River and Plum Island Sound during spring 1965 and spring 1994. The higher discharge of fresh water from the watershed into the estuary in 1994 increases the low-salinity area in the upper Parker River (purple and blue colors on salinity scale).
of the spring freshwater discharge from the watershed dictates the area of spawning habitat and possibly the size of the fish population in a given year.

In 1993-94, LMER scientists measured fish abundance in the Plum Island Sound estuary and found it to be 10 times greater than that measured in 1965 by the U.S. Fish and Wildlife Service. Curious about the cause of this difference in fish abundance, we used our hydrodynamic model to simulate the expected salinity distribution in the estuary for the springs of 1965 and 1994, based on the long-term data set on stream discharge (Figure 2). We found that the higher freshwater discharge in 1994 produced a much larger area of habitat for juvenile fish for those years than that produced in 1965 (purple and blue regions in Figure 2).

Another topic of study is the relationship between plankton abundance and water movement. These tiny organisms, which form the base of the food chain, move freely with the movement of water and can easily be washed out of the estuary into the ocean. Phytoplankton, the simplest plants, use DIN, carbon dioxide and sunlight to build their tissues via the process of photosynthesis. They grow best or "bloom" where DIN is high and water movement is low. These conditions exist in the Parker River, in the upper part of the Plum Island Sound estuary, where DIN input from the land is high and transport out of the river is low, at least during times of low freshwater discharge.

We have used our coupled hydrodynamic-ecosystem model to look at the effect of freshwater discharge on phytoplankton blooms. We carried out a simulation of phytoplankton growth that showed how the bloom of these organisms was washed out of the estuary during the rapid increase in freshwater discharge associated with the passage of Hurricane Bertha through the area in July 1996 (Figure 3). Although the DIN concentration in the upper Parker River was quite high during the period of high freshwater discharge (days 9-15), the high rate of transport removed the phytoplankton faster than they could grow. As the discharge diminished, however, the bloom was reestablished (days 20 and after).

Many of the physical forces that affect estuarine ecology change over long time periods. An example is the rise in sea level that is associated with warming of the atmosphere. It

Figure 3: Modeling simulation of the impact of freshwater discharge on the phytoplankton bloom over 15 kilometers of the upper Parker River. This simulation is based on the observed freshwater discharge in the Parker River, shown in the upper panel, during the passage of Hurricane Bertha over the area in July 1996. The lower panel is a simulation of the phytoplankton bloom, measured in milligrams of carbon per cubic meter, over 30 days in July 1996.

Figure 4: Production of salt marsh grass in kilograms per square meter per year at North Inlet, South Carolina, at different sea levels. Each data point represents a year of growth at the sea level for that year. Sea level is expressed relative to the mean sea level at Charleston, SC. (Figure courtesy of James Morris, University of South Carolina.)
is difficult, however, to obtain funding for long-term studies that make it possible to understand how such changes in the physical environment affect estuarine ecosystems. To address the need for long-term data sets to address a number of complex ecological questions, the NSF established the Long-Term Ecological Research (LTER) program in 1980. This program has grown to include some 20 research sites in a variety of ecosystems.

In June 1997, the NSF selected our project, the Plum Island Sound Comparative Ecosystem Study (PISCES), as the newest LTER project. Thus our LMER study is continuing with additional participants and similar goals under a new umbrella. New components are the long-term perspective and comparative activities of the LTER program, the establishment of long-term field experiments, and the addition to the project of two auxiliary estuarine research sites, located in Maine and South Carolina, to facilitate comparative research. In addition, we will focus more closely on understanding ecosystem processes and characteristics at the interface between marshes and the open water.

Long-term observations of watershed and estuarine processes will give us a better understanding of the effects of change in the physical environment on estuarine ecosystems. Had long-term monitoring in Plum Island Sound been initiated in 1965, for instance, we would have a much better understanding of the importance of the spring freshwater discharge for fish abundance and could determine whether the differences in fish abundance between 1965 and 1993-94 were associated with salinity levels in the upper Parker River. Long-term monitoring will also allow us to understand the effects of short-lived events, such as storms and hurricanes, on the long-term functioning of the estuary.

We are currently inaugurating three long-term experiments in Plum Island Sound. Two of them will focus on the effects of increased nutrient fluxes from the land into the marshes and tidal creeks. These experiments will allow us to determine the response of marsh ecosystems to the eutrophication that often accompanies an increase in the flow of nutrients from the land into an estuary.

The third experiment will examine the importance of detritus, or decaying vegetation, from the marshes as a source of organic matter in estuaries. This experiment will take advantage of salt marsh haying, an activity that has continued since Colonial times. By comparing sites where marsh grass is cut for hay with ones where it is not, we hope to be able to sort out some of the roles of marsh detritus in estuarine ecosystems.

One of the difficulties of conducting ecological research at a single site is determining which characteristics are unique to that site and which are not. To find out whether the knowledge we have gained from studying Plum Island Sound is applicable to other estuaries, we have established additional research sites at North Inlet, South Carolina, and Wells, Maine. Both sites are National Estuarine Research Reserves with active research and monitoring programs. One of the long-term physical factors we are particularly interested in is sea-level rise and its effects on marsh and estuarine ecosystems. Scientists working at North Inlet have observed that marsh productivity increases as sea level rises (Figure 4). We are also interested in understanding the effects of change in freshwater inputs on estuarine ecosystems. The Wells site, which has a higher level of freshwater discharge into the estuary than Plum Island Sound does, offers us a useful opportunity for comparison.

By working at several research sites with different physical characteristics, we will be able to broaden our understanding of estuarine ecosystems as well as gaining expertise in areas beyond our original LMER study. Long-term monitoring and experiments coupled with our whole-system ecological modeling efforts will allow us to develop a better understanding of the response of estuarine systems to changes, both short and long term, brought about by human activities.
Global climate models predict that warming associated with rising levels of "greenhouse" gases such as carbon dioxide (CO₂) in the atmosphere will have significant effects on the Arctic during the coming century. Researchers are attempting to answer a number of key questions about these effects: Will climate change induce increased plant growth and thus an increase in the uptake of CO₂ from the atmosphere? If soils get warmer, will increased microbial activity release carbon stored in the soil? Will warmer temperatures increase the production of methane, another greenhouse gas, in regions where wetlands expand? To answer these questions on an Arctic-wide basis, we need to develop a new generation of computationally efficient models that can link physical and biological processes and operate at the regional scale.

As a first step toward this goal, Anne Giblin, John Hobbie and Marc Stieglitz of The Ecosystems Center, together with George Kling of the University of Michigan, are carrying out an exercise designed to test such a model against data from a small, well-studied creek near Toolik Lake, Alaska. We have coupled a simple soil microbial respiration model with a physical land surface model. The physical model was developed by Stieglitz and validated with data from a Vermont watershed. By calculating the respiration of soil microbes with simulated ground temperatures and soil moistures, we are able to simulate soil-atmosphere fluxes of CO₂ in both current climate conditions and altered ones.

The correct simulation of soil moisture throughout a watershed is the key step. Fortunately, the spatial distribution of soil moisture within a watershed is somewhat predictable. Lowlands tend to be regions where water flows converge and soil moisture is high. Soils in the upland regions of a watershed tend to be drier. One approach to modeling the spatial distribution of soil moisture is to work with the details of the watershed topography, modeling the movement of water from the hillsides to the valleys explicitly. Although this approach works well for small watersheds, it requires too much computer power for studies at the regional scale.

We have taken a different approach, treating the watershed as the fundamental hydrologic unit. This approach is compatible with the computational demands of global and regional climate models. In it we combine two ways of modeling the flow of water within a watershed. The first makes use of a soil column model that simulates the vertical movement of water and heat within the soil and from the surface of the soil and vegetation to the atmosphere. The second makes use of the statistics of the topography and allows us to track the horizontal movement of shallow groundwater from the uplands to the lowlands (a TOPMODEL or topographic approach). By combining these two approaches, we can produce a three-dimensional picture of soil moisture distribution within a watershed. This model also allows us to predict the portion of the watershed that is saturated with water, the watershed runoff and ground temperatures throughout the year.

Having simulated the distribution of soil moisture for the watershed, we are able to calculate the evaporation from the soil into the atmosphere, the plant transpiration and the microbial respiration in both the wet lowlands and the drier uplands. Decomposition is aerobic and microbial respiration relatively rapid in the unsaturated uplands; in saturated zones along creeks, decomposition is likely to be anaerobic and microbial respiration thus slower.

To test the model, we used two and a half years' worth of hourly meteorological data, measurements of daily runoff and daily soil temperature data collected by Larry Hinman and Douglas Kane of the University of Alaska at Innawaiit Creek in Alaska. Our modeled hydrological and thermal processes appear to agree well with results from field mea-

![Figure 1: Average daily soil temperatures observed at Innawaiit Creek, Alaska (blue line) and generated in a modeling simulation (black line) over one annual cycle.](image-url)
measurements, such as the soil temperature data shown in Figure 1.

We have been examining the hypothesis that warming of the soil in the Arctic could increase plant productivity by increasing the depth of the summer thaw and the release of soil nutrients. Field experiments at Toolik Lake have shown that increased nutrient availability leads to increased plant growth and a dramatic increase in the thickness of the litter layer on the surface of the soil. In these experiments, however, we observed that summer thaw depth actually decreased as a result of the increased insulation provided by the thicker layer of plant litter.

Does increased litter decrease microbial decomposition and therefore act as a negative feedback by inhibiting further plant growth? To examine this hypothesis, we conducted two exercises with our coupled biological-physical model. One exercise simulated a control plot with a 2-centimeter litter layer and the other, a fertilized plot with a 4-centimeter litter layer. Both simulations included tundra vegetation and peat with a mineral soil underneath.

We conducted the modeling exercises using actual meteorological data from Inninavik Creek. The results show that the increased insulation produced by the 4-centimeter litter at the fertilized plot does indeed yield shallower summer thaw depths and cooler summer temperatures in the peat soil, as we observed in the experiments at Toolik Lake. However, the annual microbial respiration in the simulated fertilized plot is greater than that in the control plot (Figure 2). This difference occurs because the slightly warmer soil temperatures in the fertilized plot induce respiration during the long winter months that more than compensates for the reduced respiration resulting from lower summer temperatures. Our modeling results suggest a positive feedback situation; if climate changes stimulate plant growth, soil microbial respiration and decomposition may promote rather than discourage further plant growth.

It is interesting to note, furthermore, the overall shift that favors winter microbial respiration over summer respiration in our simulation of a fertilization experiment. How well did the model predict the effect of increased nutrient availability in the fertilized experiments at Toolik Lake? Ground temperatures in these plots are indeed colder than in control plots in the summer, in agreement with our model. But the soil temperatures in winter do not agree with the model; we did not observe warmer temperatures in the fertilized plots at Toolik. A possible explanation is that, with fertilization, the increase in plant biomass and change in the mix of species on the plots produced more foliage and altered the exchange of heat between the atmosphere and the surface soil and plants. We do not, as yet, understand fully what is bringing about this change.

By combining modeling exercises like the one described above with long-term field experiments, we can begin to understand some of the complex ways in which hydrological, thermal and biological processes interact. The approach we are taking allows us to link these processes in a unified and natural framework. In the near term, we plan to use this approach to simulate fluxes of methane between soils and the atmosphere. We also plan to model the flux of CO₂ produced by microbial respiration, in soil water as it moves from the uplands into stream systems. In the long term, we hope to use models such as this to predict the effects of climate change on the Arctic as a region.

Figure 2: Results from a modeling simulation of carbon dioxide (CO₂) flux from arctic soil into the atmosphere over one annual cycle. The blue line shows the flux from a simulated control plot with two centimeters of plant litter. The black line shows the flux from a simulated fertilized plot with four centimeters of litter.
What Does El Niño Have to do with Carbon Cycling in the Amazon?

Many regions of the earth experience fluctuations in climate as temperatures, winds and patterns of rainfall vary from year to year as well as season to season. In recent years, scientists have become increasingly interested in the effects of interannual variation on biogeochemical processes at regional and global scales. Among the questions they are attempting to answer are how changes in temperature and precipitation affect the amount of carbon dioxide (CO₂) plants take up from the atmosphere during photosynthesis, the amount of CO₂ returned to the atmosphere through plant and soil respiration, and the capacity of terrestrial ecosystems to store carbon.

One of the most important catalysts for short-term climate variations in many parts of the world is a cyclic phenomenon of the central Pacific Ocean known as ENSO, for El Niño-Southern Oscillation. ENSO is the result of a complex interaction between ocean and atmosphere that involves dramatic changes in pressure gradients, the strength and direction of trade winds, sea-surface temperature and ocean upwelling. El Niño conditions, which occur roughly every three to four years, represent one extreme of the ENSO cycle; the other extreme is called La Niña. El Niño conditions alter climate in different ways in various parts of the world. They bring heavy rains to the western coast of both North and South America and drought to Australia, the Indian subcontinent, parts of Southeast Asia and the Amazon Basin.

Ecosystems Center scientists are studying the influence of climate variation on carbon cycling in a variety of terrestrial ecosystems from the Arctic to the tropics. Together with colleagues from the University of New Hampshire, the University of Alaska and the Max-Planck Institute in Hamburg, Germany, John Helfrich, David Kicklighter, Jerry Melillo and Hanqin Tian are investigating the relationship between interannual climate variation and the carbon budget of the Amazon Basin.

The Amazon Basin, covering about 7.2 million square kilometers, contains almost half of the world's undisturbed rain forest as well as large areas of tropical savanna. The forests of the basin are important in the global carbon cycle; they account for about 10% of the plant production in terrestrial ecosystems as well as a similar percentage of the carbon stored in the terrestrial biosphere. Based on results from short-term measurements of net carbon exchange between the atmosphere and the forest at a site in the western Amazon, a team of European and Brazilian scientists have suggested that this region is functioning as an important sink in the global carbon budget. This extrapolation of carbon storage capacity from a single field site to a whole basin requires an assumption that all ecosystems in this region function in the same way.

We have been using our biogeochemical process model, the Terrestrial Ecosystem Model (TEM), to see how interannual climate variability and ecosystem differences across the Amazon Basin have affected carbon storage over the 15 years between 1980 and 1994. TEM focuses on how ecosystems function. With it, we use information on climate, elevation, soils and vegetation to make monthly estimates of significant carbon and nitrogen fluxes and pools in terrestrial ecosystems. This information is organized into a grid with a resolution of half a degree of latitude by half a degree of longitude. At the equator, each cell of the grid is about 55 kilometers on a side.

The carbon fluxes calculated by TEM include gross primary production, plant respiration, net primary production, microbial respiration and net ecosystem production (NEP). Gross primary production represents the uptake of atmospheric CO₂ during photosynthesis and is influenced by light availability, CO₂ concentration in the atmosphere, temperature and the availability of water and nitrogen. Plant respiration is calculated as a function of temperature and the mass of carbon in vegetation. Net primary production is calculated as the difference between gross primary production and plant respiration and represents the rate of carbon accumulation by living plants.

Microbial respiration takes place as microorganisms decompose organic matter. It is influenced by the amount of soil organic matter available to the microbes, by temper-
nature and by soil moisture. The movement of carbon between an ecosystem and the atmosphere is calculated as the difference between net primary production and microbial respiration. The annual NEP of an ecosystem is equivalent to the net amount of carbon stored in it during a year.

Results from our TEM simulations suggest that annual NEP in the undisturbed ecosystems of the Amazon Basin over the 15-year period of our study varied between -0.2 petagrams (10^15 grams) of carbon in 1987 and 1992 and 0.7 petagrams of carbon in 1981 and 1993 (Figure 1). A negative NEP indicates that the ecosystems of the Amazon are releasing CO₂ into the atmosphere, while a positive NEP indicates that these ecosystems are taking up CO₂ and storing it as carbon compounds in plants and soils.

Year-to-year variations in net primary production appear to be mainly responsible for the interannual variation in NEP. Annual net primary production shows much greater variation than does microbial respiration (Figure 2). A major factor controlling net primary production in the Amazon Basin, even in areas covered in rain forest, appears to be soil moisture, which is a function of both precipitation and temperature. Soil moisture, an index of the availability of water for plants, controls many plant and soil processes.

Our conclusion that soil moisture is a key control on carbon exchange between terrestrial ecosystems and the atmosphere agrees with results from a study of Amazonian forests by a team that includes Ecosystems Center scientists Matthew Williams and Edward Rastetter as well as scientists from Brazil and Europe. These researchers measured net carbon exchange between the forest and the atmosphere at a site north of Manaus in the western Brazilian Amazon. They then interpreted the field measurements using a detailed model of carbon and water exchange. They concluded from their study that an increase in soil water stress in the dry season introduces a significant seasonal cycle to carbon exchanges between the atmosphere and the forest.

We conclude from our TEM project that year-to-year variations in carbon storage in the Amazon Basin parallel shifts among three phases of the ENSO cycle: El Niño, La Niña and neutral. Amazonian ecosystems released CO₂ into the atmosphere (negative NEP) during three El Niño episodes, occurring in 1982-83, 1987-88 and 1991-92 (Figure 1). El Niños bring about drier and warmer weather condi-

![Image of two individuals](Image)

*Figure 1: Interannual variations in net ecosystem production (NEP) for the Amazon Basin as simulated by the Terrestrial Ecosystem Model (TEM). A negative NEP indicates that these ecosystems release CO₂ into the atmosphere, while a positive NEP indicates that these ecosystems take up CO₂ from the atmosphere. Negative NEP levels occur during El Niño conditions in 1982-83, 1987-88 and 1991-92.*

![Graph showing relationship between temperature and NPP](Image)

*Figure 2: The relationship of annual mean temperature and precipitation to annual net primary production (NPP) and microbial respiration (R_m) or heterotrophic respiration, which is dominated by microbial respiration. Annual NPP is negatively correlated with annual mean temperature and positively correlated with annual precipitation. Annual microbial respiration is positively correlated with temperature but not with precipitation.*

*John Helfrich, Andy Ricca*
tions in the Amazon Basin. Both drier weather and warmer temperatures decrease net primary production in these ecosystems. In addition, warmer temperatures increase microbial respiration (Figure 2). As a result, NEP decreases during El Niño events.

Our TEM simulations suggest that the ecosystems of the Amazon Basin took up CO$_2$ from the atmosphere (positive NEP) during the La Niña event of 1989. La Niñas bring with them wetter and cooler conditions in the basin. In neutral years as well, when conditions in the Pacific are at neither extreme of the ENSO cycle, our modeling efforts suggest that the ecosystems of the basin act as a carbon sink.

Figure 3 shows the spatial patterns of NEP in the Amazon Basin derived from our model simulations for the three phases of the ENSO cycle. It is interesting to note that a substantial portion of the area exhibiting carbon loss during El Niño episodes is covered by rain forest (Figure 3D). We do not normally associate water stress with this form of ecosystem.

Figure 3: Net ecosystem production (NEP) in grams of carbon per square meter per year across the Amazon Basin during three phases of ENSO: A) El Niño, B) neutral, C) La Niña. D) Tropical rain forest, a type of vegetation not usually associated with water stress, covers most of the Amazon Basin.
The Ecosystems Center offered its innovative Semester in Environmental Science (SES) for the first time in the fall of 1997. Held on the campus of the Marine Biological Laboratory (MBL), the 15-week program attracted 16 students from 11 colleges.

The SES program is designed to introduce undergraduates from small liberal arts colleges and universities to environmental science from the perspective of ecosystems ecology. It draws on the collective expertise of the center’s terrestrial and aquatic ecologists, biogeochemists, microbial ecologists and mathematical modelers to present a comprehensive and rigorous program of ecosystems studies that includes lectures, laboratories and field work.

The semester in Woods Hole will be offered each fall. It is intended to supplement the curricula at small colleges, which often do not address topics in biogeochemistry and global element cycles in their courses. The 28 institutions that have joined the MBL in an Environmental Science Consortium grant a full semester’s credit to students who complete the course successfully.

Administered by Kenneth Foreman, the SES is organized around two core courses, Aquatic Ecosystems and Terrestrial Ecosystems. In 1997, the former was led by Charles Hopkinson, and the latter by Knute Nadelhoffer. Center staff members present lectures and supervise the laboratory work of the students. In addition, each student is expected to take an elective in either the mathematical models of ecosystems or microbial methods in ecology, to attend two seminar series and to carry out an independent research project.

No one investigator can master all the techniques and knowledge required to solve complex environmental problems. For this reason, SES faculty members stressed the importance of teamwork throughout the 1997 semester. In the core courses, the students worked in field teams of four, learning not only about ecosystems but also about the art of collaboration and cooperation. Students teamed up again for independent project research.

The students who attended the first semester had the opportunity to build a basic understanding of ecosystem structure and dynamics as they participated in field projects at two local sites on Cape Cod, a mixed oak/pine forest and a coastal bay. As part of their course work, they studied the major biogeochemical processes occurring in all ecosystems and examined the effects of both anthropogenic and natural changes on these processes. Topics included the global carbon cycle, fossil fuel emissions and increased concentrations of greenhouse gases in the environment as well as eutrophication, acid deposition, deforestation, fisheries, invasions of exotic species, and the effects of changes in biodiversity on ecosystem function.

In the laboratory, students used sophisticated methods of analysis and equipment, including gas and ion chromatography, elemental analysis, high-precision titration, dataloggers, nutrient and gas flux measurements, and both stable and radioactive isotope analysis.

Members of the MBL Environmental Science Consortium

- Allegheny College
- Bates College
- Bard College
- Bowdoin College
- Brandeis University
- Bryn Mawr College
- Carleton College
- Colgate University
- Connecticut College
- Dickinson College
- Franklin & Marshall College
- Gettysburg College
- Grinnell College
- Hamilton College
- Hampshire College
- Harvey Mudd College
- Haverford College
- Lafayette College
- Middlebury College
- Mount Holyoke College
- Sarah Lawrence College
- Skidmore College
- Trinity College
- Vassar College
- Wellesley College
- Wesleyan College
- Wheaton College
- Williams College

Ken Foreman, Marsha Chandler

Peter Siver
Each week, students attended a seminar conducted by a distinguished visiting scientist. The students met and talked with the speakers at meals before and after the lectures. The 1997 SES guest speakers and their topics are listed in Seminars at The Ecosystems Center.

Students also participated in a seminar series that emphasized developing science-writing skills. Boyce Rensberger, science editor for The Washington Post, served as science writer-in-residence for 1997. Other participants in the science-writing seminars were: Steven Nadis, a freelance science writer from Boston; Charles D. Hollister, vice president of Woods Hole Oceanographic Institution; Ellen Ruppel Shell, co-director of the Science Journalism Program, Boston University, and James T. Detjen, director of the Environmental Journalism Program, Michigan State University School of Journalism.

During the final five weeks of the course, the students applied their analytical skills and knowledge to designing and carrying out independent research projects. Topics ranged from cedar swamp and bog ecology to the effects of irrigation with sewage effluent on plant diversity, soil properties and groundwater quality. At the end of their independent projects, students gave oral presentations at a day-long symposium for the whole laboratory.

By the end of the 1997 semester, students had acquired a basic understanding of biogeochemistry, not only through lectures but also through hands-on experience measuring the fundamental processes and properties of ecosystems. But SES students gained more than scientific knowledge. One student observed that "I learned to really enjoy learning."

The SES program offers a fellowship each fall to a professor from a participating college or university. Peter Siver, Silfen Professor of Botany and director of the Environmental Studies Program at Connecticut College, was the recipient of the first SES Faculty Exchange Fellowship. A paleolimnologist interested in reconstructing the history of pH and other changes in lake ecosystems from the sedimentary record of small algae, scaled chrysophytes and diatoms, Peter also received a Lucy B. Lemann Environmental Fellowship at the MBL in the summer of 1997. He regularly attended the SES courses and provided advice to both faculty and students during the semester. He and Ecosystems Center scientist Anne Giblin are collaborating on a study of the interactive effects of acid deposition and eutrophication on softwater lakes.

Total support for the Semester in Environmental Science from foundations and individual donors has reached $2.66 million. In 1997, the program received an additional award from the Andrew W. Mellon Foundation, as well as grants from The Starr Foundation and the Charles E. Culpeper Foundation and a gift for scholarships from Phoebe Speck. Other donors include the Davis Educational Foundation and the Burroughs-Wellcome Fund as well as the Osterhout, Edison and Sears families, who have endowed a scholarship fund.

"SES is special in that it is a program that combines field studies and traditional classroom learning. I think that is what makes the program so valuable, that and the chance to work with top scientists in ecosystems studies."

Sophie Parker
Wellesley College

Research assistant Pat Micks and SES student Amy Townsend-Small measure respiration in forest shrubs as part of an exercise in estimating carbon balance in the forest ecosystem.
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 the 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.

Ecosystems Center staff members also participate in MBL’s summer Science Writing Fellowships Program, teaching in workshops for the visiting journalists and introducing them to research projects at arctic and coastal field sites. Marguerite Holloway of Scientific American and Lynne Cherry, a freelance writer from Washington, D.C., spent part of the field season with center staff members at the Long-Term Ecological Research (LTER) site at Toolik Lake, Alaska. John Fleischman of Yankee magazine joined center researchers at Plum Island Sound on the northeastern coast of Massachusetts for a week to participate in the Land Margin Ecosystems Research (LMER) project there.

Semester in Environmental Science

Many staff members participated in the center’s first Semester in Environmental Science (SES), described in detail elsewhere in this report. Chuck Hopkinson and Knute Nadelhoffer led the core aquatic and terrestrial courses. Ed Rastetter taught a class in ecosystem modeling as an elective, while John Hobbie 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 and Matt Williams gave lectures for the core courses, and Michele Bahr, Hap Garritt, Bonnie Kwiatkowski, Pat Micks, Jane Tucker and Nat Weston were teaching assistants. Associate director Ken Foreman and executive assistant Marcia Chandler kept the program running, solving problems that arise in any new venture. Many other staff members became involved in unofficial ways, helping students with field work or lab assignments.

Postdoctoral Research Associates

Robert Holmes came to The Ecosystems Center in 1995 from Arizona State University, where he received his doctorate for research on nitrogen cycling in stream ecosystems. At the center, Bob has worked with Bruce Peterson and others on a study of the nitrogen cycle of the Parker River estuary in northeastern Massachusetts. The study used an isotopic tracer to follow the flow of nitrogen through various biogeochemical transformations as it moved through the estuary. He is beginning to work on a project examining hydrological and nutrient flux from the pan-arctic watershed to the Arctic Ocean, focusing on the biogeochemical aspects of the study. In addition, he and Bruce are beginning a collaboration with a team of European scientists, headed by Gilles Pinay and Girard Gruau of the University of Rennes, France, that is investigating nitrogen retention in agricultural landscapes.

Hanqin Tian is working with Jerry Melillo and other members of the center’s terrestrial ecosystem modeling group on the development and application of the Terrestrial Ecosystem Model (TEM). Hanqin received his doctorate in 1996 from the College of Environmental Science and Forestry at the State University of New York at Syracuse, where he studied with Charles A.S. Hall. For his thesis, he developed models of land-use change and ecosystems dynamics and investigated the effects of changing land use on carbon fluxes and storage. Hanqin came to the United States in 1992 after finishing a master’s degree in China and working at the Chinese National Rice Research Institute for two years. At the center, his major focus is on the understanding of how interannual climate variability, increasing atmospheric carbon dioxide (CO₂) concentrations and land-use change affect ecosystem processes and terrestrial carbon storage at various scales.

Darrell Herbert joined The Ecosystems Center in 1996 after completing his doctorate at the University of Hawaii, where he studied with Jim 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 model (MEL) to look at plant species competition and the effect on element cycles in ecosystems. The object of his work is to understand how species characteristics are important in the functioning of ecosystems.
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 postdoctoral appointment at Rutgers University with Sam Wainright, studying bacterial response to sediment resuspension. Jeff is currently working with Linda Deegan on using a model of nitrogen loading in coastal bays to predict effects on juvenile fish and the quality of fish habitat.

Laura Gough joined The Ecosystems Center in 1996 after completing her doctorate at Louisiana State University in the Department of Plant Biology, where she studied with James Grace. She conducted her thesis research on the diversity of plants species in a southern coastal marsh, investigating the effects of physical factors such as flooding and salinity and biological factors such as herbivory on community structure. Laura is currently focusing on factors that affect the structure of plant communities in arctic tundra. She has collected data on species diversity and spatial heterogeneity of tundra plant communities in landscapes of different ages near the Arctic LTER site at Toolik Lake, Alaska. She has also been participating in an LTER cross-site comparison on the relationship between diversity and productivity at different spatial scales and in different habitats.

Anne Hartley finished her doctorate in 1997 at Duke University, where she worked with Bill 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 center scientists Jerry Melillo, Chris Neill and Frank Bowles of Research Designs, Woods Hole, on two global change simulation experiments in the subarctic tundra of northern Sweden. Anne completed a soil warming experiment last summer and will investigate the potential interactive effects of elevated CO2 and air warming on soil nutrient cycling and plant growth in the summer of 1998.

Diana Garcia-Montiel joined The Ecosystems Center in 1997 to work with Jerry Melillo, Paul Steudler and Chris Neill on a study of 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 Dan 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 center, Diana is investigating the relative availability of different forms of phosphorus for plants as well as measuring trace-gas fluxes in forests and pastures in Brazil.

**Student Research Opportunities**

Students participating in the National Science Foundation's Research Experience for Undergraduates (REU) program worked with Ecosystems Center staff members at several field sites last summer. Chris Catricia and Kathy Newkirk served as mentors for Jon Sanderman of Brown University and Nina Wurzburger of the University of California at Davis and at the Harvard Forest LTER site in Peterham, Massachusetts.

Dana Royer of the University of Pennsylvania and Jenny Carroll of Tulane University worked with Laura Gough at the Alaska LTER site at Toolik Lake. They completed posters on their work there, and Jenny is using her data for her senior honors thesis. Cate O'Keefe of Hampshire College worked on a project with Linda Deegan at Toolik Lake.

Fiona Boyer came from Sterling University in Scotland to work with Anne Giblin in August. She sampled the same plots in a salt marsh in West Falmouth that Anne had sampled for her doctoral thesis. For her undergraduate honors thesis, Fiona is looking at how the metal content of the sediment has changed over the past 15 years.

Jeff Hughes and Linda Deegan advised two REU participants, KaTina Chiavarella from Coastal Carolina University and Rob Javonillo from Boston University, who took part in projects at the Plum Island Sound LTER site. Chuck Hopkinson, Anne Giblin and Jane Tucker also supervised two students at Plum Island. Summer Morlock of Duke University and Dave Taylor of North Carolina State University worked on the salinity effects of benthic nutrient fluxes.

Diana Garcia-Montiel, Paul Steudler and Chris Neill worked with Marciano Brito, a student at the Centro de Energia Nuclear na Agricultura (CENA) of the University of São Paulo in Piracicaba, Brazil, to analyze the fate of phosphorus soils following tropical deforestation. Marciano collected samples before and after the clearing and burning

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*Bonnie Kwiatkowski, Darrell Herbert*  
*TOM ALEXANDER*  
*Michele Bahr*  
*COURTESY OF MICHELE BAHR*
of an experimental forest plot as part of a joint MBL-CENA research project in the Amazon. Marciano will use the data in his doctoral thesis.

With support from the National Science Foundation, a high-school staff member and two high-school students spent several weeks at the arctic LTER research site at Toolik Lake working with center staff members. Terry Lashley, an administrator in the Oak Ridge, Tennessee, school system, studied the behavior of white-crowned sparrows. High school seniors Thuy Lam from Chesapeake, Virginia, and Alisha Moreland from Portland, Oregon, worked with Linda Deegan and Karie Slavik on a study of young-of-the-year grayling in streams.

Science Education on the Local Scene

Chris Catricala, Chuck Hopkinson, Kathy Newkirk, Debbie Scanlon and Jane Tucker judged projects at science fairs in the Falmouth public schools and at Falmouth Academy in March. Kathy, Wil Wollheim, Pat Micks and Michele Bahr volunteered to help students plan their science fair projects. Kathy and Karie Slavik also talked with junior high school students about opportunities for women in science.

Keri Holland volunteered on weekends for the New England Aquarium in Boston, conducting educational outreach programs at community events and cultural fairs. In September, Jeff Hughes presented a lecture on invertebrates of the marsh and beach on a Massachusetts Audubon Society field trip to Wellfleet. Kama Thielert volunteered for the environmental education program at the Waquoit Bay National Estuarine Research Reserve. Joe Vallino helped the North and South Rivers Watershed Association develop their World Wide Web page on the Internet.

The MBL was host to a three-day workshop in early February for high school teachers enrolled in Southern Connecticut State University’s Institute for Science Instruction and Study (ISIS). Chris Neill talked to the participants about the effects of deforestation on streams in the Amazon, and Mat Williams discussed the exchange of CO₂ between arctic tundra and the atmosphere. Yude Pan described modeling efforts to describe and predict global climate change, and Joe Vallino talked about modeling estuarine food webs.

Chris Neill writes a column on birding and natural history for The Falmouth Enterprise, a regional newspaper.
Ecosystems Center Events and Activities

Highlights of 1997

Appointments and Awards

Jerry Melillo returned to The Ecosystems Center at the end of August after 16 months in Washington, D.C., as associate director of the Environment Division of the Office of Science and Technology Policy. He was subsequently appointed to the design committee for the Report Card on the Health of the Nation’s Ecosystems, which is charged with designing a report to the nation on how well the major ecosystems of the country are functioning. With both public and private sponsorship, this project is being coordinated by the H. John Heinz Center for Science, Economics and the Environment.

In October, Jerry received the Award for Excellence in Ecosystem Ecology, sponsored by the Natural Resources Ecology Laboratory (NREL) at Colorado State University. He is the first recipient of the award, which was presented to him at the celebration of NREL’s 30th anniversary.

Colleagues and former students honored John Hobbie at a special symposium and banquet, held during the annual meeting of the American Society of Limnology and Oceanography (ASLO) in Santa Fe in February. The session featured talks by John’s former graduate students and post-doctoral associates from both The Ecosystems Center and North Carolina State University.

Knute Nadelhoffer returned to the center in August after a year as a Fulbright Research Fellow at the Norwegian Institute for Water Research in Oslo and the Norwegian Forest Research Institute in Ås. He worked with European colleagues on an interdisciplinary study of nitrogen enrichment and carbon storage in temperate forests.

Gus Shaver began his second year on leave from the center to serve as a program officer in the Ecosystem Studies Program at the National Science Foundation (NSF) Division of Environmental Biology. He will return to Woods Hole in August 1998.

Chuck Hopkinson was promoted from associate to senior scientist. He came to The Ecosystems Center in 1989 from the University of Georgia Marine Station at Sapelo Island, where he was a member of the scientific staff for 10 years.

Joe Vallino, Mat Williams and Chris Neill joined the senior staff as assistant scientists. Chris was appointed a postdoctoral research associate at the center in 1991 after completing his doctorate at the University of Massachusetts at Amherst. Joe received his doctorate from Massachusetts Institute of Technology in 1991 and came to the center as a postdoctoral research associate in 1993. Mat joined the center as a postdoctoral research associate in 1994 after receiving his doctorate from the University of East Anglia in the United Kingdom.

Hanqin Tian received the Technical Communication Award from the Society for Technical Communications at Oak Ridge National Laboratory for his work on spatially-explicit models of land-use change.

LTER Workshops and Meetings

Chris Catricala, Bill Currie, Pat Micks and Kathy Newkirk attended the eighth annual Harvard Forest Long-Term Ecological Research (LTER) Symposium, held Feb. 4 in Petersham, Massachusetts. Chris presented an update on research at the forest on microbial and root respiration.

John Hobbie and Kathy Regan organized the annual planning meeting for the Arctic LTER program at Toolik Lake, Alaska, which was held at the MBL in March. Other center staff members attending were Neil Bettez, Michele Bahr, Dave Bryant, Anne Giblin, Laura Gough, Anne Hartley, Bethanie Hooker, Bonnie Kwiatkowski, Jim Lauandre, Knute Nadelhoffer, Bruce Peterson, Ed Rastetter, Gus Shaver, Karie Slavik, Mat Williams and Wil Wollheim.

In August, John Helfrich attended an LTER data managers meeting in Albuquerque, New Mexico, preceding the Ecological Society of America annual meeting.

Laura Gough attended an LTER workshop at the National Center for Ecological Analysis and Synthesis (NCEAS) in Santa Barbara, California, in October. Focus of the meeting was on analysis of the relationship between diversity and productivity at LTER sites.

In November, Gus Shaver attended the annual meeting of the international LTER program in Taipei, Taiwan.
LMER Workshops and Meetings

Sixty scientists from four Land Margin Ecosystems Research (LMER) sites attended the LMER All Scientists Meeting, held during November in Solomons, Maryland. John Hobbie served as chairman for the event, which was organized by Debbie Scanlon. Chuck Hopkinson presented an overview of the systems ecology of the Plum Island Sound estuary and adjacent watersheds, while Bruce Peterson talked about an intersite study of nitrogen cycling in streams. Chuck, John and Bruce presented the posters for the Plum Island Sound Comparative Ecosystems Study (PISCES) team. These included a poster prepared by Nat Weston on estimating denitrification in the sediments of the Parker River estuary and one by Linda Deegan and Hap Garett summarizing results of food-web research at the Plum Island site. The PISCES team also presented a poster on the effect of salinity on the transformations of inorganic nitrogen in Parker River sediments.

Arctic System Science workshops

In January, Bruce Peterson participated in a workshop in Seattle, Washington, that was responsible for producing a plan for the Arctic System Science (ARCSS) program.

Dave Kicklighter and John Helfrich attended the ARCSS Land-Atmosphere-Ice Interactions (LAI) meeting in Seattle in March. They presented a talk, in cooperation with Jerry Melillo and Dave McGuire of the University of Alaska, on the simulation of historical patterns of net ecosystem production in high latitude ecosystems.

Laura Gough presented a paper on plant species diversity responses to artificial and natural productivity gradients in Alaskan arctic tundra at the eighth annual meeting of the ARCSS International Tundra Experiment (ITEX) in London in April. Gus Shaver also presented a paper at the ITEX meeting.

John Hobbie, John Helfrich, Dave Kicklighter, Jerry Melillo, Ed Rastetter and Xiangming Xiao traveled to Martha’s Vineyard in October to participate in an ARCSS workshop on the role of high-latitude ecosystems in the global carbon cycle. The meeting was organized by Dave McGuire.

IGBP Workshops

Gus Shaver attended a steering committee meeting for Focus 1: Ecosystem Physiology and Global Change of the Global Change and Terrestrial Ecosystems (GCTE) program in Salt Lake City, Utah, in March. GCTE is a core project of the International Geosphere-Biosphere Programme (IGBP). Later that month he traveled to Montpellier, France, for an GCTE workshop on terrestrial primary productivity. In July, he attended a GCTE NETFLUX workshop in Palo Alto, California.

Xiangming Xiao participated in a seminar on the integrated assessment of global climate change at an IGBP Global Change System for Analysis, Research and Training (START) meeting in Beijing, China, during July. He also gave a talk on sustainable development and integrated assessment of climate change at a symposium for young scientists on sustainable development that followed the START meeting.

Calendar of Other Conferences and Workshops

In January, Dave Kicklighter and Xiangming Xiao participated in the Global Change Forum at the Massachusetts Institute of Technology; Jerry Melillo gave the keynote address.

Darrell Herbert visited Biosphere 2 outside Tucson, Arizona, in March for a workshop on improving links between CO2 models and experiments. He participated in a series of ecosystem model intercomparisons at the meeting.

Ed Rastetter and Mat Williams attended a workshop on carbon budgets of boreal and arctic ecosystems at NCEAS during April. Later that month Mat visited the University of Edinburgh in Scotland to continue collaboration on a project investigating canopy processes in tropical forests and to make a presentation.

In May, Anne Hartley presented a poster at the International Workshop on Dissipation of Nitrogen from the Human Nitrogen Cycle and its Role in Present and Future N2O Emissions to the Atmosphere in Oslo, Norway. Haoning Tian and Dave Kicklighter attended a public briefing on the Vegetation/Ecosystem Modeling and Analysis Project (VEMAP) at the National Science Foundation in Washington, D.C.

Anne Giblin presented one of the keynote talks at BIOGEOMON, a biogeochemistry society, at Villanova University in June. Her talk was titled "Controls on Methane emission in Alaskan Arctic Tundra: Results of Long-term Field Manipulations of Temperature and Nutrients." Jerry
Melillo gave a plenary address on science and policy. In July, Jane Tucker gave a talk in Boston on benthic metabolism and nutrient cycling in Boston Harbor as part of a 10-year review symposium on management issues and scientific studies in Massachusetts Bay and Boston Harbor. Xiangming Xiao presented an update on the MIT integrated global system model at the Climate Change Impacts and Integrated Assessment Workshop in Snowmass, Colorado, in August.

As a member of the Arctic Research Commission, John Hobbie took part in meetings in Seattle, Alaska and Washington over the year. During August, commission members attended the 50th anniversary celebration of the Naval Arctic Research Laboratory at Point Barrow, Alaska, where John presented an overview of limnological studies at the laboratory.

Dave Kicklighter presented a poster comparing analyses of the effects of CO₂ fertilization on the global carbon budget from four terrestrial biosphere models at the Fifth International Carbon Dioxide Conference in Cairns, Australia, in September.

Michele Bahr participated in a workshop titled "Evolution: A Molecular Point of View" at the MBL Center for Advanced Studies in the Space Life Sciences in October.

In November, Linda Deegan served as chairman for a workshop on higher trophic levels sponsored by the Interagency Florida Bay Science Program at the National Oceanic and Atmospheric Administration's Atlantic Oceanographic and Meteorological Laboratory in Miami. Later that month she participated in a workshop sponsored by the Public Service Electric and Gas Company on fish production by tidal marshes that was held in Newark, New Jersey.

Jerry Melillo chaired the U.S. Climate Forum, held in Washington, D.C., during November, and presented one of its keynote speeches. Focus of the conference was on the potential consequences of climate change for the nation's ecosystems. Sponsored by the Office of Science and Technology Policy and the U.S. Global Change Research program, the forum attracted 400 participants.

In December, Chris Neill attended a meeting of the National Aeronautics and Space Administration (NASA) Large-Scale Biosphere Atmosphere Study team to plan international research in the Amazon. Also that month Chris gave a paper on the effect of deforestation for pasture on soil carbon in the Amazon at a workshop titled "Carbon Stocks and Fluxes in Tropical Ecosystems" in Belem, Brazil.

Michele Bahr, Neil Bettez and John Hefrich also attended the ASLO meeting.

Jeff Hughes presented papers on the Nitrogen Isotope Tracer Experiment (NISTREX) to the Benthic Ecology Society meeting in Portland, Maine, in April, and to the American Fisheries Society meeting in Monterey, California, in August.

Linda Deegan attended the spring meeting of the New England Estuarine Research Society in May in Wells, Maine, where she presented an overview of the Plum Island Sound LMER project. In June, she attended the Estuarine Coastal Shelf Association meeting in Lisbon, Portugal.

In May, Ed Rastetter and Mat Williams went to a meeting of the American Geophysical Union in Baltimore. Mat discussed the application of his tree canopy model to data from a research site near Manaus, Brazil.

Several Ecosystems Center scientists participated in the annual meeting of the North American Benthological Society in San Marco, Texas, in June. Bob Holmes spoke on investigating the fate of watershed-derived nitrogen in estuaries with an isotopic tracer. Bruce Peterson gave a talk on the impact of scale on nitrogen dynamics in streams in Arctic Alaska. Karie Slavik presented a poster on the community structure of moss epiphytes in the fertilized reach of the Kuparuk River, Alaska. Wil Wollheim gave a paper on the impact of nitrogen regeneration on estimates of travel distance.

Paul Steudler traveled to Melbourne, Australia, in July to present a paper on consequences of the conversion of forest to pasture for fluxes of nitrous oxide and methane in the Brazilian Amazon. His paper was a contribution to a symposium on trace-gas budgets at a meeting of the International Association of Meteorology and Atmospheric Sciences.

The Ecological Society of America (ESA) annual meeting in Albuquerque, New Mexico, in August had its share of Ecosystems Center presentations. Jerry Melillo was the keynote speaker at a special session on communication and interaction among long-term ecological projects. Suzanne Thomas presented a poster on soil phosphorus fractions in a pristine, old-growth coniferous forest in the Cordillera de Pinchul in Chile. Chris Neill spoke on changes in nitrogen cycles and trace-gas emissions following deforestation in the tropics. Hanqin Tian gave a paper on continental-scale responses of the terrestrial carbon system to changes in atmospheric CO₂ and temperature between 1854 and 1990.

Meetings
At the ASLO symposium in honor of John Hobbie, held in Santa Fe during February, Bruce Peterson gave a talk on whole ecosystem nitrogen isotope additions. Former Ecosystems Center postdoctoral research associates Jon Cole and George Kling spoke as well. John spoke on whole-system experiments in limnology at another ASLO session. As chairman of the Future of ASLO Committee, he also reported on the findings of that group. Joe Vallino presented a paper titled "Synthesis of Whole System Metabolic Measurements with an Estuarine Model to Assess Heterotrophic Processes." Bob Holmes made a presentation on the processing of riverborne nitrate in an estuary, while Chuck Hopkinson gave a talk on stoichiometry of dissolved organic matter dynamics on the continental shelf.

(Beth Hooker, Courtesy of Beth Hooker)
Dave Kicklighter presented a poster on the role of nitrogen in transient responses of net primary production and carbon storage to changes in CO₂. Xiamingming Xia gave a talk on climate change and net terrestrial ecosystem production. Darrell Herbert, Ed Rastetter and Mat Williams also attended the meeting.

Many center scientists participated in the Estuarine Research Federation (ERF) meeting, held in October in Providence, Rhode Island. Jeff Hughes chaired a session on oligohaline zone ecology and made a presentation on the NISOTREX project. Linda Deegan gave a paper on food web support of higher trophic levels in the oligohaline zone of the Plum Island Sound estuary. Posters presented included one by Hap Garrit, titled "Comparison of Estuarine Carbon and Nitrogen Food Web Economies: Is Nitrogen a Better Indicator of Important Organic Matter Sources than Carbon?" Jane Tucker also presented a poster on using stable isotopes to trace sewage-derived material through Boston Harbor and Massachusetts Bay. Bob Holmes made a presentation on nitrogen cycling in the oligohaline zone of the Plum Island Sound Estuary, while Bruce Peterson gave a talk on how nitrogen dynamics in rivers affect the oligohaline zone of estuaries. Joe Vallino gave a paper on deriving seasonal patterns in estuarine metabolism from whole-system measurements of oxygen. Also attending the ERF meeting were Anne Giblin and Chuck Hopkinson, who led a workshop group on controls on estuarine metabolism.

Chris Catricala, Jerry Melillo, Kathy Newkirk and Paul Steudler made presentations at the annual meeting of the Soil Science Society of America in Anaheim, California, in late October. Jerry delivered the opening talk as part of a symposium on soil respiration. Paul gave a paper describing patterns of soil respiration in Brazilian forests and pastures. Chris spoke on the effects of soil warming on microbial and root respiration, and Kathy discussed interannual variation in soil respiration at the soil warming experiment at Harvard Forest.

Lectures and Seminars

In January, Hanqin Tian gave a seminar titled "Understanding the Metabolism of the Biosphere in the Changing Global Environment: Scaling Down vs. Scaling Up" at Harvard University. Gus Shaver spoke at the Smithsonian Environmental Research Laboratory in Edgewater, Maryland. Laura Gough gave a paper on plant species richness and productivity in coastal Louisiana marshes and Alaskan tundra at Kellogg Biological Station, Michigan State University.

Knute Nadelhoffer presented a seminar on how rates and forms of nitrogen deposition affect forest nitrogen retention at the Norwegian Institute for Forest Research in As in February and the Swedish Agricultural University in Uppsala in April. He also gave a seminar titled "Linking Research at Local and Global Scales: Perspectives on the U.S. LTER Program" in As in May.

Bob Holmes spoke at the Institute of Ecosystem Studies in Millbrook, New York, in March on the fate of watershed-derived nitrogen in estuaries. He spent the summer as a visiting scientist at the University of Rennes, France, working on nitrogen cycling in agricultural landscapes. While there, he presented two seminars, one on surface-subsurface interactions in streams and the other on whole-ecosystem isotope tracer experiments. In December, he gave a talk on hydrological control of nitrogen cycling at the interface of rivers and estuaries at Arizona State University.

Hanqin Tian gave a seminar on integrating simulation models with remote sensing and geographical information systems for land-sea linkages at Woods Hole Oceanographic Institution in March. In June, he was invited by the U.S. Geological Survey’s Earth Resources Observation Systems Data Center to speak about modeling land-use changes in the tropics.

Jerry Melillo presented the H.J. Oosting Memorial Lecture at Duke University in April. Focus of his talk was on climate change and environmental policy-making on the global scale. Later that month, Bruce Peterson gave a lecture at the University of Waterloo in Ontario, Canada, on tracer studies of nitrogen cycling in watersheds.

In May, Anne Giblin gave a Boston University Marine Program seminar titled "Lake Victoria: From Fish to Mud." Darrell Herbert spoke at the University of New Hampshire on nutrient limitation, resource use efficiency and resistance to disturbance in Hawaiian rain forests.

On July 18, Jerry Melillo gave an MBL Friday Evening Lecture titled "Ecological Research and Global
Environmental Policy: New Challenges for an Essential Partnership." John Hobbie introduced his co-director.

In September, Bruce Peterson traveled to St. Petersburg, Russia, to speak on modeling Arctic watershed hydrology. He gave a seminar at Princeton University the next month on nitrogen cycling in watersheds.

Jeff Hughes lectured on invertebrates of the marsh and beach to participants in a Massachusetts Audubon Society field trip to Wellfleet in September.

Chuck Hopkinson gave a lecture on sources, fates and effects of materials exported from watershed to estuary at Old Dominion University, Norfolk, Virginia, in November.

Procter & Gamble Company invited Bruce Peterson to Cincinnati, Ohio, in December to speak on the use of stable isotope tracers in stream research.

Committee Memberships
Jerry Melillo serves on a committee of the President's Council of Advisors on Science and Technology. The committee's charge is to review and make recommendations about federal research and development programs concerned with biodiversity and ecosystem management. Its report, *Teaming with Life*, was submitted in January 1998.

As part of John Hobbie's duties as a member of the National Research Council's Ocean Studies Board, he was appointed chairman of a study committee reporting on the effectiveness of the Community Development Quota (CDQ) program of the National Marine Fisheries Service. The CDQ program uses a percentage of the Bering Sea fishery quota for economic and social development in 55 Alaskan coastal communities.

As a member of the Arctic Research Commission, John participated in survey of logistic capabilities for research support in the Canadian Arctic during August. Commission members flew via Twin Otter from Fairbanks, Alaska, to Tuktoyaktuk on the McKenzie River, Resolute Bay, Eureka and Alert at 82° N, a farthest north record for John.

Anne Giblin became president-elect of ERF in October. She is also the ASLO representative to the American Association for the Advancement of Science (AAAS) and a member of the biological section of the AAAS Council of Delegates.

Knute Nadelhoffer served as an external member of the Appointments Board at the Swedish Agricultural University in Uppsala from October 1997 to March 1998. He is also an editorial board member of *Oecologia*.

Gus Shaver serves on the interdisciplinary advisory board of the Arctic and Alpine Research Committee of the University of Colorado.

Chuck Hopkinson serves as an advisory panelist for the Florida Department of Environmental Protection. The panel's charge is to overview and evaluate Everglades nutrient threshold research. He is also editor in chief of *Mangroves and Salt Marshes*.

Chris Neill is a member of the NASA Large-Scale Biosphere Atmosphere Science team.

Kathy Newkirk is chairman of the executive committee of the Association of Women Soil Scientists, a member of the Women in Agronomy committee of the American Society of Agronomy, chairman of the Soil Science Applied Research Award committee and a member of the strategic planning committee of the Soil Science Society of America.

MBL Boards and Committees
Bruce Peterson is a 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. Linda Deegan currently chairs the Year-round Scientists' Forum.

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.

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. Chuck Hopkinson is chairman of the radiation safety committee. Ed Rastetter heads up the computer network committee. Paul, Jerry Melillo and Ken Foreman are members of the research services and space committee.

Knute Nadelhoffer served on the search committee for the director of the MBL Office of Research Administration and Education.
<table>
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<tr>
<th>Month</th>
<th>Title</th>
<th>Author/Institution</th>
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<tbody>
<tr>
<td>January</td>
<td>Xingming Xiao, Marine Biological Laboratory, &quot;Linking TEM to the MIT Global System Model for integrated assessment of global change.&quot;</td>
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<td>Bradley Eyre, Southern Cross University, Lismore, Australia, &quot;Impacts of acid runoff from acid sulphate soils in the Lower Richmond River catchment, Australia.&quot;</td>
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<td>Laura Gough, Marine Biological Laboratory, &quot;Plant species richness and productivity in coastal Louisiana marshes and Arctic tundra.&quot;</td>
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<td>Edward Rastetter, Marine Biological Laboratory, &quot;Will terrestrial ecosystems gain carbon or lose carbon when warmed?&quot;</td>
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<td>Yadvinder Mahli, Institute of Ecology and Resource Management, University of Edinburgh, &quot;Trace gas exchange in tropical rainforests.&quot;</td>
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<td>March</td>
<td>Donna Francis, Harvard Forest, &quot;Land-use and lake ecosystems: Paleolimnological studies in Michigan and New England.&quot;</td>
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<td>Joseph Vallino, Marine Biological Laboratory, &quot;Estuarine metabolism: Coupling models with observations.&quot;</td>
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<td>Sam Wainright, Institute of Marine and Coastal Studies, Rutgers University, &quot;Stable isotopes as tracers of sewage and seabird guano in riverine and coastal estuaries.&quot;</td>
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<td>Theresa Theodore, University of Southern Maine, &quot;Plant community dynamics in alpine tundra.&quot;</td>
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<td>April</td>
<td>Tadashi Yoshinari, Department of Environmental Health and Toxicology, School of Public Health, University of Albany, State University of New York, &quot;Application of isotope tracer techniques on the study of microbial activity in ground water systems.&quot;</td>
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<td>Steven Hamburg, Center for Environmental Studies, Brown University, &quot;Land-use history, chronosequences, and ecosystem processes: Does it all go together?&quot;</td>
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<td>Michael Shiaris, Biology Department, University of Massachusetts, Boston, &quot;Aromatic hydrocarbon degradation in estuarine environments: Microbial diversity.&quot;</td>
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<td>Robert Holmes, Marine Biological Laboratory, &quot;Nitrogen cycling in an oligohaline estuary: Results of whole-system 15N tracer addition.&quot;</td>
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<td>May</td>
<td>William Salas, Complex Systems Research Center, University of New Hampshire, &quot;Remote sensing of tropical deforestation and secondary growth dynamics.&quot;</td>
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<td>Gordon Wallace, Environmental, Coastal and Ocean Sciences Program, University of Massachusetts, &quot;Sediment-water column interactions of metals: Can life be that simple?&quot;</td>
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<td>Mark Altabet, Woods Hole Oceanographic Institution, &quot;New insights into the marine nitrogen cycle, present and past.&quot;</td>
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<td>September</td>
<td>Robert Naiman, University of Washington, &quot;Rivers as ecosystems.&quot;</td>
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<td>Robert Howarth, Cornell University, &quot;Why nitrogen often limits primary production.&quot;</td>
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<td>James Elser, Arizona State University, &quot;Biogeochemistry and the ribosome: Biological stoichiometry in ecosystems.&quot;</td>
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<td>October</td>
<td>John Hedges, University of Washington, &quot;The global carbon cycle and all that rot.&quot;</td>
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<td>Greg Retallack, University of Oregon, &quot;The interplay between primary and secondary production over geological time scales.&quot;</td>
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<td>Steven Murawski, NOAA/NMFS, &quot;Sustainable fisheries: An oxymoron?&quot;</td>
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<td>Samuel McNaughton, Syracuse University, &quot;Ecology of grassland ecosystems and large grazing mammals.&quot;</td>
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<td>November</td>
<td>Jerome Nriagu, University of Michigan, &quot;Historical changes in global cycles of toxic metals.&quot;</td>
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<td>Kathleen Weathers, Institute for Ecosystem Studies, &quot;A Catskill conundrum: Why is nitrate leaking from Catskill Mountain watersheds?&quot;</td>
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<td>December</td>
<td>Anne Hartley, Marine Biological Laboratory, &quot;Nitrogen dynamics in the Chihuahuan desert.&quot;</td>
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<td>Suzanne Thomas, Marine Biological Laboratory, &quot;Soil phosphorus fractions in a pristine temperate rainforest, Isla de Chiloe, Chile.&quot;</td>
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<td>Just Cebrian, Boston University Marine Program, &quot;Plant turnover rate as a predictor of ecosystem properties.&quot;</td>
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Staff at The Ecosystems Center during 1997

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
Dorothy J. Berthel
Administrative Assistant
Marsha J. Chandler
Administrative Assistant, Semester in Environmental Science
Boston University
Suzanne J. Donovan
Executive Assistant
Massachusetts College of Art
Guillermo Nuñez
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B.S., Texas A & M University
Mary Ann Seifert
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B.A., Alfred University
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Executive Assistant, LMER Coordination Office
B.A., Syracuse University

Scientific Staff
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Charles S. Hopkinson, Senior Scientist
Ph.D., Louisiana State University
Jerry M. Melillo, Senior Scientist
Ph.D., Yale University
Bruce J. Peterson, Senior Scientist
Ph.D., Cornell University
Gaius R. Shaver, Senior Scientist
Ph.D., Duke University
Anne E. Giblin, Associate Scientist
Ph.D., Boston University
Knute J. Nadelhoffer, Associate Scientist
Ph.D., University of Wisconsin
Linda A. Deegan, Associate Scientist
Ph.D., University of Wisconsin
Edward B. Rastetter, Associate Scientist
Ph.D., University of Virginia
Christopher Neill, Assistant Scientist
Ph.D., University of Massachusetts at Amherst
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
Yude Pan, Research Associate
Ph.D., State University of New York, Syracuse
Xiangming Xiao, Research Associate
Ph.D., Colorado State University

Educational Staff Appointments
William Currie, Visiting Postdoctoral Scholar,
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Ph.D., University of New Hampshire
Diana C. Garcia-Montiel, Postdoctoral Research Associate
Ph.D., Colorado State University, Fort Collins
Laura Gough, Postdoctoral Research Associate
Ph.D., Louisiana State University
Anne E. Hartley, Postdoctoral Research Associate
Ph.D., Duke University
Darrell A. Herbert, Postdoctoral Research Associate
Ph.D., University of Hawaii
Robert M. Holmes, Postdoctoral Research Associate
Ph.D., Arizona State University
Jeffrey E. Hughes, Postdoctoral Research Associate
Ph.D., University of Rhode Island
Marc Stieglitz, NOAA Global Climate Change Postdoctoral Fellow
Ph.D., Columbia University
Hanqin Tian, Postdoctoral Research Associate
Ph.D., State University of New York, Syracuse
Melissa J. Weaver, Postdoctoral Research Associate
Ph.D., University of Wisconsin-Madison

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Michele P. Bahr, Research Assistant
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Neil D. Bettez, Research Assistant
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David M. Bryant, Research Assistant
M.A., University of Colorado
Jana D. Canary, Research Assistant
M.S., University of Washington
Christina E. Catricala, Research Assistant
M.S., University of New Hampshire
Tamara Clark, Research Assistant
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Mark M. Dornblaser, Research Assistant
M.S., SUNY-Stony Brook
Martha R. Downs, Research Assistant
B.S., Cornell University
Robert H. Garritt, Senior Research Assistant
M.S., Cornell University
John V. K. Helfrich III, Senior Research Assistant
B.S., St. Mary's College of Maryland
Keri J. Holland, Research Assistant
B.A., Trinity College
Bethanie A. Hooker, Research Assistant
M.S., University of Connecticut
David W. Kicklighter, Senior Research Assistant
M.S., University of Montana
Bonnie L. Kwiatkowski, Research Assistant
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James A. Laudre, Senior Research Assistant
M.S., University of Connecticut
Patricia Micks, Research Assistant  
M.S., University of New Hampshire  
Kathleen M. Newkirk, Research Assistant  
M.S., Virginia Polytechnic Institute  
Amy L. Nolin, Research Assistant  
B.A., Wheaton College  
Sarah E. Pratt, Research Assistant  
B.A., University of Pennsylvania  
Kathleen M. Regan, Research Assistant  
Cleveland State University  
Andrea Ricca, Research Assistant  
B.A., University of Hartford  
Carol Schwamb, Laboratory Assistant  
University of Connecticut  
Karie A. Slavik, Research Assistant  
M.S. Bowling Green State University  
Lori A. Soucy, Research Assistant  
B.S. University of Lowell  
Kama K. Thieler, Research Assistant  
M.S. Duke University  
Kristin S. Tholke, Research Assistant  
M.S. University of Connecticut  
Suzanne M. Thomas, Research Assistant  
M.S. University of Pennsylvania  
Jane Tucker, Senior Research Assistant  
M.S., University of North Carolina  
Nathaniel B. Weston, Research Assistant  
M.S. Hampshire College  
Wilfred M. Wollheim, Research Assistant  
M.S., University of Wyoming  

Heidi E. Golden, Research Consultant  
M.S., University of Massachusetts  
Robert Golder, Graphics Consultant  
Rhode Island School of Design  

Visiting Scientists and Scholars  
George Kling, Visiting Scientist  
University of Michigan, Ann Arbor  
Wendy Loya, Visiting Graduate Student  
Kansas State University  
Gabriel Seifert, Council on International Educational  
Exchange Intern  
Technical University of Wismar, Germany  
Alexander Igorevich Shiklomanov, Visiting Scientist  
The State Scientific Center of the Russian Federation  
Arctic and Antarctic Research Institute (AARI),  
St. Petersburg, Russia  
Peter Siver, SES Faculty Fellow  
Connecticut College

Consultants  
Francis P. Bowles, Research Systems Consultant  
Principal, Research Designs  
Ph.D., Harvard University  
Margaret C. Bowles, Administrative Consultant  
B.A., Bryn Mawr College

Bob Holmes  
Luc Claessens

Mardi Bowles  
Dixie Berthel  
Mary Ann Seifert


In Press


Currie, W. S., K. J. Nadelhoffer and J. D. Aber. Soil detrital processes controlling the movement of 15N tracers to forest vegetation. *Ecological Applications*.


Hall, R. O., Jr., B. J. Peterson and J. L. Meyer. Testing a nitrogen cycling model of a forest stream using a 15N tracer addition. *Ecosystems*.


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Gus Shaver


GRANTS FOR RESEARCH AND EDUCATION IN EFFECT DURING 1997

I. National Science Foundation

NSF-ATM-9529836
"Inter-American Institute (LAI) Workshop: Biogeochemical Consequences of Land Use Change in the Amazon Basin"
January 1996 - June 1998
Investigators: Melillo, Steudler, Neill $50,000

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

NSF-DEB-9211775
"The Arctic LTER Project: Terrestrial and Freshwater Research on Ecological Controls"
Investigators: Hobbs, Peterson, Shaver, Deegan, Giblin, Nadelhoffer, Rastetter $3,913,750

NSF-DEB-9307888
"Recovery of Terrestrial Ecosystems from Major Disturbance: Constraints Due to Carbon/Nutrient Interactions"
August 1993 - July 1997
Investigators: Rastetter, Melillo, Shaver $849,999

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 15N Tracers"
July 1994 - June 1998
Investigator: Nadelhoffer $400,000

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"
November 1994 - October 1998
Investigator: Giblin $200,000

NSF-DEB-9411975
"Harvard Forest: Long-Term Ecological Research" (subcontract from Harvard University)
January 1995 - January 2001
Investigators: Melillo, Nadelhoffer, Steudler $746,130

NSF-DEB-9509613
"Multiple Resource Interactions and Ecosystem Function"
June 1995 - September 1998
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 1998
Investigator: Giblin $149,965

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

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

NSF-OCE-9214461
"LMER: Plum Island Sound Comparative Ecosystems Study (PISCES): Effects of Land Use and Organic Matter-Nutrient Interactions on Estuarine Trophic Dynamics"
September 1992 - September 1998
Investigators: Hopkinson, Hobbs, Giblin, Deegan $1,780,000

NSF-OCE-9416294
"Coordination for Land Margin Ecosystems Research (LMER)"
September 1994 - February 1998
Investigator: Hobbs $543,936

NSF-OCE-9419078
"SCOPE Workshop on Estuarine Synthesis"
September 1994 - February 1998
Investigator: Hobbs $55,000

NSF-OPP-9318529
"Attaining Ecological Understanding at the Regional Level: The Kupark River as a Model Arctic System"
June 1994 - May 1998
Investigator: Hobbs $569,642

NSF-OPP-9400722
"Controls of Structure and Function of Aquatic Ecosystems in the Arctic"
June 1994 - May 1998
Investigators: Hobbie, Peterson, Deegan, Rastetter $2,726,000

NSF-OPP-9415411
"Primary Production in Arctic Ecosystems: Interacting Mechanisms of Adjustments to Climate Change"
April 1995 - March 2000
Investigator: Shaver $752,316
II. U.S. Department of Energy

DOE-901214
Investigators: Melillo, Nadelhoffer, Steudler
$920,525

DEFG02-92ER61438
Investigators: Hopkinson
$1,316,891

DEFG02-95ER62108
Investigator: Melillo
$50,000

DEFC03-90ER61010
Northeast Regional Center of the National Institute for Global Environmental Change (NIGEC) "Integrating an Ecosystem Model into a Global Change Impact Assessment." (subcontract from Harvard University) July 1996 - June 1998
Investigator: Hobbie
$10,500

III. National Aeronautics and Space Administration

NASA-9208/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-NAGW-3752
"Land Use Change, Soil Processes and Trace Gas Fluxes in the Brazilian Amazon Basin" June 1993 - August 1997
Investigators: Melillo, Steudler
$963,700

NASA-NAGW-5160
"A Comparison of Three Canopy Models against Eddy Covariance Data from the Amazon." May 1996 - September 1997
Investigator: Rastetter
$99,975

NASA-NAGW-3859
Investigator: Melillo, Steudler, Neill
$800,000

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

IV. National Oceanic and Atmospheric Administration

NOAA Sea Grant R/P-56
Investigators: Giblin, Hopkinson
$149,000
V. U.S. Environmental Protection Agency

CR-823606-01
"Testing the Estuarine Biotic Integrity Index Across Biogeographic Regions"
October 1994 - September 1997
Investigator: Deegan
$406,557

CR-823713-01-0
"Interaction of Factors that Control Greenhouse Gas Fluxes: A Transect Study"
June 1995 - June 1998
Investigators: Melillo, Steudler
$532,944

CR-824767-01-0
"Tracing the Fate of Nitrogen Inputs from Watersheds to Estuaries"
January 1996 - December 1998
Investigators: Deegan, Peterson
$232,323

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

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)
March 1995 - February 1997
Investigator: Melillo
$60,000

29-1299
"PNET-IIS/TEM Model Comparison and Expansion"
August 1995 - February 1997
Investigator: Melillo
$36,000

95-37101-1879
"Influences of Above- and Belowground Litter on Forest Soil Organic Matter Dynamics"
August 1995 - August 1998
Investigator: Nadelhoffer
$316,000

97-35101-4318
"Is Forest Productivity of Old Forests Limited by Tree Hydraulics"
October 1997 - September 2000
Investigators: Rastetter, Williams
$56,102

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

VII. Electric Power Research Institute

RP3316-04
"Vegetation/Ecosystem Modeling and Analysis Project"
September 1993 - December 1998
Investigator: Melillo
$906,703

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

WO8020-17
"The Effects of Climate Change on Ecosystem Structure and Function"
June 1996 - May 1997
Investigators: Hobbie, Neill
$100,000

WO8020-18
"VEMAP Phase II"
June 1996 - May 1997
Investigator: Hobbie
$169,347

VIII. Other Research Grants

Texaco Foundation
"Texaco Fellowships in Environmental Research"
September 1990 - December 1998
Investigators: Melillo, Steudler
$460,000

Sweet Water Trust
"Operation of a Field Station"
January 1993 - December 1997
Investigator: Hopkinson
$23,250

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

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

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

Exxon Corporation
"Global Change Research"
April 1994 - December 1997
Investigator: Melillo
$150,000
Swedish Nature Protection Agency 802-116-94-FF
"Ecological Responses to Increases in Carbon Dioxide
Concentration and Temperature: A Global Change Study at
Hälsingland, Sweden"
July 1994 - June 1998
Investigator: Melillo
$155,904

The Haken Foundation
"Studies of Sediments in Lake Victoria"
July 1996 - December 1997
Investigator: Giblin
$11,179

Bermuda Biological Station for Research
"Investigate the Cycling of Natural and Man-made
Nitrogen Compounds Between the Atmosphere, the Land
Environment and the Ocean"
January 1997 - December 1998
Investigator: Melillo
$55,000

CR Environmental
"New York City Department of Environmental Protection
Catskill Reservoir Study"
May 1997 - April 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
$1,500,000

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

Ann Osterhout Edison/Theodore Miller Edison and Olga
Osterhout Sears/Harold Bright Sears Endowed Scholarship
Fund
"Semester in Environmental Science"
December 1996
$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

Phoebe Speck Scholarship for the Semester in Environmental
Science
April 1997
$100,000
Sources of Support for Research and Education

The annual operating budget of The Ecosystem Center for 1997 was $6,768,585, almost 7% higher than the previous year. Roughly 70% of the income of the center comes from grants for basic research from government agencies. The other 30% comes from gifts and grants from private foundations, corporations and individuals, as well as from institutional support for administration and income from the center's reserve and endowment funds. This includes support for the Semester in Environmental Science.

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 1997.

The combined total value of the center's reserve fund and endowment at the end of 1997 was $6,518,534, an increase of a little more than 11% over the 1996 year-end value of $5,836,594. 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.
The Starr Foundation
Surdna Foundation, Inc.
Sweet Water Trust
Texaco Foundation
Wingwalker Initiatives
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