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Cover Photography: Background: The Alyeska pipeline carries oil across Alaska from Prudhoe Bay in the north to Valdez in the south. Here the pipeline crosses the Athabasca River in the Brooks Range. Photo by John Hobbie.

Inset left: Experimental mesocosms in Woods Hole harbor contain typical populations of phytoplankton, zooplankton, bacteria and larval fish. Treatments with organic matter and inorganic nutrients enable researchers to study the way that changing inputs from watersheds affect the trophic structure of coastal waters. Photo by Hap Garritt.

Inset upper right: Ecosystems Center consultant Frank Bowles and Rose Crabtree of Sheffield University, United Kingdom, test flow characteristics of experimental chambers in plots at the Abisko Naturvetenskapliga Station in northern Sweden. The chambers are used for carbon dioxide enrichment and environmental warming experiments. Photo by Mardi Bowles.

Inset lower right: Agricultural worker monitors controlled burn of three hectares of forest at Fazenda Nova Vida in Rondônia. Using this experimental plot, researchers will study the effects of burning forest vegetation and establishing pasture on soil carbon balance, nutrient cycles and emission of trace gases from soils. The plot was cut in June, burned in September and sown with grass in January, approximating customary practice for making pasture throughout the Amazon Basin. Photo by Chris Neill.

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Top: Chris Catricala, photo by Frank Bowles. Bottom: Jane Tucker, photo by Linda Deegan.
Introduction to The Ecosystems Center

The Ecosystems Center, located at the Marine Biological Laboratory in Woods Hole, Massachusetts, is dedicated to the study of ecological systems and to the application of knowledge gained through research to the problems of sustaining and managing natural resources. The center, which will celebrate its 20th anniversary in 1995, operates as a collegial association under the leadership of co-directors John Hobbie and Jerry Melillo. Although funding for research projects comes primarily from competitive government grants, support for administration, research and educational activities also comes from grants and gifts from private foundations, corporations and individuals.

Investigators at The Ecosystems Center study the structure of ecological systems and the way they function. Ecosystems vary greatly in size and complexity: some are defined by natural boundaries, some by the questions researchers ask. But each system encompasses both species and their physical environment, linked through a variety of biological, chemical and physical processes. Among the ecosystems in which we conduct our research are boreal, temperate and tropical forests, lakes and streams, arctic tundra and coastal estuaries.

Ecosystem structure is defined both by the type and abundance of species and by the distribution of such elements as carbon or nitrogen among components of the system. Ecosystem function is defined by the patterns and rates of processes, such as predation or photosynthesis, that control species variety and abundance as well as transferring energy and materials among components of systems and across boundaries. The processes that govern the way ecosystems function are themselves controlled by a variety of factors, such as the presence and absence of certain plant or animal species, temperature or the availability of water and nutrients.

Studying the Effects of Change on Ecosystems

Describing the complex set of interactions among species, processes and controls is essential to understanding the way ecosystems work and predicting their response to changing environmental conditions. Such information provides insight into questions about the effect of human activities on the functioning of ecosystems. How does the deposition of acidic compounds derived from factory and automobile emissions affect biological and chemical processes in forests, lakes and streams of the northeastern United States? How do changes in land use affect the flow of nutrients and organic matter into New England estuaries and thus the food web in coastal waters?

We ask similar questions about the effects of change in other parts of the world. How will the clearing of tropical rain forests change the amount of carbon dioxide released into the atmosphere? What will be the effect on global climate? Will deforestation affect the flows of sediment and nutrients into streams and rivers and alter aquatic systems? How will soil organic matter change? Will these changes determine whether agriculture can be sustained over the long term?

At the other end of the temperature spectrum, how would warmer temperatures affect arctic ecosystems? Will an increase in the depth of thaw above 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 plants and animals that are part of them. The plants and animals are likewise important to the processes that constitute ecosystem functioning. We can ask some general questions: What species are most important? If certain species disappeared, would ecosystems remain intact and 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 actively functioning ecosystems? If the loss of one species does not result in measurable change, would the loss of 10? Or 100?

Although we undertake studies in diverse environments and on different scales, we are primarily 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 mathematical models we employ to predict the effects of environmental change over long periods of time and on the large scale. Basic processes are common to all ecosystems; knowledge gained from one system is applicable to others. By studying one process, such as the decomposition of soil organic matter, in a wide range of temperature and moisture conditions, we can predict its rate in an unstudied system with some level of confidence.

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, mathematics and computer modeling. One of the strengths of The Ecosystems Center is the ability of its scientists to interact closely; the constant challenge and stimulation is invaluable.

Facilities and Research Sites

The center's facilities in Woods Hole include two mass spectrometers for stable isotope analyses, chemical analytical laboratories and experimental chambers. Researchers prepare field samples for chemical analysis and carry out experiments on plant or microbial growth in the aquatic and terrestrial laboratories. In the chemistry laboratory, samples are analysed for variables such as nutrient content or rates of microbial growth and release of trace gases. The stable isotope facility is used to measure amounts of nitrogen, carbon or sulfur transferred in aquatic and terrestrial food webs.

Center scientists also conduct research in a wide range of field sites. Coastal studies are carried out at the Essex County Greenbelt Association's station on Plum Island Sound and in Woods Hole harbor. Studies of temperate forests are conducted at Harvard Forest in Massachusetts and at the Bear Brooks Watersheds site 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 a field site 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.

Ecosystems Center scientists share a commitment to the importance of both long-term research and comparative studies. Staff members 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 also participates 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 near northeast of Boston. In addition to its participation in the LMER field program, The Ecosystems Center is host to the LMER coordinating office.

Support for Research and Education

Support for research at The Ecosystems Center comes from a number of federal agencies, including the National Science Foundation (NSF), the Department of Energy (DOE), the Environmental Protection Agency (EPA), the National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA) and the Department of Agriculture's Forest Service (USFS). The center has also received funds for research from the Massachusetts Water Resources Authority (MWRA), the Electric Power Research Institute, the Exxon Corporation, the Texaco Foundation and the Conservation, Food & Health 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 Cox Foundation is supporting a study of links between land use and the health of fisheries in the coastal zone, and Wingwalker Initiatives is supporting a collaborative study between The Ecosystems Center and the Lloyd Center in South Dartmouth, Massachusetts.

Private funding is making a number of innovative educational activities possible. The Texaco Foundation is providing support for three Brazilian graduate students who are working with Ecosystems Center staff members on a study of the effects of converting forested lands into pasture in the Amazon. With support from the A.W. Mellon Foundation, the staff of the center is developing an educational program in environmental sciences for undergraduates. The center also works with the MBL's Science Writing Fellowships Program, creating opportunities for journalists to participate in environmental field research.

Applying Ecological Knowledge to Practical Problems

One of the reasons to carry out research in ecology is to provide a sound foundation for environmental policy and management. Basic research conducted at The Ecosystems Center will help answer questions with practical applications: How will changes in land use in the coastal zone affect the flow of nutrients into the ocean and thus the production of fish and shellfish? How rapidly do the sediments of Boston Harbor break down nitrates and other compounds found in sewage? Will excess nitrogen from acidic deposition leach out of forest ecosystems and affect the quality of water in streams and rivers?

Staff members at The Ecosystems Center share their knowledge in a number of ways, including briefing legislators and administrators on environmental issues and advising resource managers. Output from a terrestrial ecosystem model developed at the center will be included in reports of the Intergovernmental Panel on Climate Change (IPCC) that will serve as a resource for agreements on gas emissions into the atmosphere. This model is also part of an integrated assessment activity developed jointly by the natural and social sciences faculties at Massachusetts Institute of Technology. The purpose of this activity is to provide leadership in understanding both the environmental and the economic aspects of global change and combining them in policy assessments that assist the ongoing discussion of national and international needs.

One center scientist is serving on a review committee for EPA's Environmental Monitoring and Assessment (EMAP) program. Several center investigators have conducted studies in Massachusetts Bay that are providing valuable information for state officials responsible for assessing the possible effects of the new Boston sewer plant and offshore outfall. And one staff member writes a monthly column on natural history for the local newspaper.

Center scientists serve on a wide variety of governmental and non-governmental committees, including boards and panels of the NSF, NASA, NOAA, EPA, DOE, Department of Agriculture and National Research Council. One senior staff member is vice chairman of the International Geosphere-Biosphere Programme (IGBP) Scientific Committee and a lead author for the chapter on terrestrial ecosystems of the 1995 IPCC assessment volume. Another is secretary of the board of the Arctic Research Consortium of the U.S. (ARCUS) and chairman of the LMER Coordinating Committee. Yet another is a member of the executive committee of the Estuarine Research Federation. Several serve on committees of the Ecological Society of America and the American Society of Limnology and Oceanography. Members of the staff serve on many committees of the MBL, including the Scientific Council of the laboratory.
The mission of The Ecosystems Center has encompassed research, education and public policy in varying degrees since the center was formed two decades ago. Research, the systematic inquiry into the structure and functioning of ecological systems, is the primary business of the center. We ask how ecosystems work and how they respond to disturbance. Our research is intellectually rewarding; it is also essential to the other two parts of our mission. The knowledge we gain from research brings special insight and excitement to our teaching, and it gives us credibility in our interactions with policymakers and resource managers.

The proportional effort that we devote to research, education and policy has changed over the center's first 20 years. Shifts in the balance have resulted from changes in personnel, in our interests and in the kinds of opportunities available to us. As the center enters its third decade, we are once again evaluating the mix of our activities. While research continues to be our main business, we are considering expanding both our educational program and our contributions to policymaking.

Exploring a New Initiative in Education

Although we offer undergraduate internships for work at research sites at Toolik Lake, Alaska, and at Harvard Forest and Plum Island Sound in Massachusetts, the educational program at The Ecosystems Center focuses at present on the graduate and post-graduate levels. We are currently considering ways to increase our commitment to undergraduate education. With support from the A.W. Mellon Foundation, we are exploring the possibility of launching a semester in environmental sciences for undergraduates in the spring of 1997. The aim of the proposed program is to introduce students from liberal arts colleges and small universities to various aspects of environmental science.

Although many undergraduates today are interested in environmental issues, few small schools can afford to offer a variety of courses in the environmental sciences. One way that such institutions will be able to meet the needs and interests of their students is by sharing resources. In an effort to promote this sharing, we are working on developing a magnet program in environmental science at the Marine Biological Laboratory. We envision bringing up to 40 sophomores and juniors to Woods Hole for one semester each year for environmental science courses and a science-writing seminar.

The courses would include intensive field and laboratory experiences that stress the identification and articulation of important research questions, the design of experiments, the use of state-of-the-art instruments and the analysis of data. The science-writing seminar would focus on communicating complex scientific concepts and results to the public in an understandable way. A number of students would also be eligible for summer internships at Ecosystems Center research sites around the world.

We would like to include faculty members as well as students in our program at the MBL. We are considering offering two faculty fellowships each spring semester to professors from participating colleges and universities.

These fellowships would give the visiting faculty a chance to interact with the course instructors and other ecologists in Woods Hole and to work on their own projects.

Contributions to Environmental Policymaking

Clear communication of relevant information to policymakers and resource managers is essential to the formulation of effective environmental policies. Policy questions must be matched with plain-language answers derived from our knowledge of ecological processes and relationships. The contributions of Ecosystems Center staff members to the dialogue on policy include informal discussions with policymakers, testimony before committees from government, industry and environmental organizations, and long-term research projects with policy-related goals. As an example of the latter, several center staff members are participating in an interdisciplinary project in partnership with Massachusetts Institute of Technology (MIT) that is intended to provide an integrated assessment of the potential effects of global change. In this project, we are coupling models of oceanic and atmospheric chemistry and physics with models of ecological and economic systems to yield a holistic view of global change.

A theme that underlies many policy-related activities is the need to develop an understanding of the Earth's capacity, globally or regionally, to sustain human beings. The concept of carrying capacity and its application to human populations was much debated in the 1970s. From that debate we learned that defining carrying capacity is a
two-part problem. The first part involves quantifying the resources, both renewable and non-renewable, that are available to support human beings. The second part involves defining the amount of resources allocated to each individual.

Scientists can make a contribution to the quantification of resources. But defining resource allocation is, in the end, an ethical problem that involves judgments about quality of life. Our contribution is likely to be in helping to define the “goods and services” that ecosystems provide for human society. Ecosystems process and store carbon and nutrients. They provide food, fiber and energy. They regulate water runoff, controlling floods and soil erosion. They assimilate wastes and purify water. And they provide opportunities for recreation. Changes in climate, in land use and in the chemistry of the atmosphere and the precipitation will alter the systems that provide these sorts of goods and services.

In their studies of arctic, temperate and tropical ecosystems, researchers from The Ecosystems Center are documenting some of the effects of a changing environment. In this annual report, Anne Giblin and Gus Shaver each describe a comparative research project, one a study of the flux of nutrients from sediments into the water column in lake ecosystems and the other a study of primary production in the tundra ecosystems of the Arctic. Both are designed to broaden our understanding of what controls the response of ecosystems to change, whether it be in climate or in the availability of nutrients.

In their joint essay, Knut Nadelhoff and James Galloway discuss the effects of human activity on the global nitrogen cycle and describe the impact of the atmospheric deposition of nitrate on temperate forest ecosystems. In a report on a mesocosm experiment conducted in Woods Hole harbor, Linda Deegan discusses the consequences of changing land use for the food web in New England coastal waters. In a report on tropical forest research, Paul Steudler describes the effects of converting forested lands to pasture in Brazil on the exchange of trace gases between the soils and the atmosphere.

In addition to our field studies, we are using a variety of models to evaluate potential effects of changes in climate and the availability of nutrients on ecosystems at various scales. In an article in this report, Bruce Peterson describes the use of models in conjunction with field experiments to study the flow of nitrogen through watersheds. A long-term goal of this project is to develop models able to predict the response of streams and rivers to changes in nutrient loading. In his report on the Vegetation/Ecosystem Modeling and Analysis Project, Jerry Milillo summarizes progress to date in a study that is integrating ecosystem models of different types in an effort to improve our ability to describe and predict the long-term, large-scale responses of terrestrial ecosystems to changes in the global environment. We anticipate that the combination of field studies with modeling efforts will enhance our ability to inform the process of formulating environmental policies.
What Feeds the Fish?
Understanding the Links Between Land Use and Coastal Food Webs

Home to diverse communities of plant and animal species, coastal zones are among the most biologically productive areas in the world. Coastal waters are linked to the upland basins that drain into them by the flow of water carrying sediments, organic matter and inorganic nutrients. Changes in human activity have an impact on these links; the removal of forests to make way for agriculture or residential development, for instance, tips the balance between organic matter and inorganic nutrients in the flux from the uplands into the coastal waters. Members of The Ecosystems Center's Land Margin Ecosystems Research (LMER) group are interested in understanding the effects of these changing inputs on the trophic structure of coastal food webs, especially the production of higher trophic levels such as fish or shellfish.

Working with Meredith Hullar of Harvard University and Mark Benfield and Ee Lin Lim of Woods Hole Oceanographic Institution, center staff members Linda Deegan, Anne Giblin, John Hobbie, Chuck Hopkinson, Joseph Vallino, Ishi Buffam, Robert Garratt and Jane Tucker carried out a field experiment during 1994 that was designed to test our understanding of how changing inputs of nutrients and organic matter influence the trophic structure of coastal waters. We were interested in determining how different levels of dissolved organic matter and dissolved inorganic nutrients altered food web dynamics and how much of the dissolved organic material supported higher trophic levels.

The experiment was set up in Woods Hole Great Harbor, where an old stone pier in front of the National Marine Fisheries Service facility provided a sheltered location. We submerged and filled four large transparent bags (roughly two meters across and three deep) with harbor water, creating mesocosms with typical populations of phytoplankton, bacteria, zooplankton and a larval fish called Atlantic silversides (Menidia menidia). The fish were added; the rest of the organisms were present in the harbor water. We excluded large fish and other predators from the mesocosms.

We designed several experimental treatments to examine the interaction of the microbial and planktonic food chains in the coastal food web. Inputs into coastal waters from natural terrestrial systems, such as forests, contain primarily organic matter. Organic matter must be consumed by bacteria before it can contribute to the production of higher trophic levels. Inorganic nutrients, on the other hand, bypass the microbial food chain and stimulate blooms of phytoplankton, which provide high-quality food for zooplankton, small invertebrates and shellfish. As forested lands in coastal watersheds are converted to farms and residential developments, the input of inorganic nutrients increases relative to the input of organic matter.

Each of the four mesocosms was treated differently. We added dissolved organic matter (DOM) to one bag, dissolved inorganic nutrients (DIN) to another and both DOM and DIN to a third. The fourth mesocosm served as a control. The added DOM was in the form of a strong, tea-colored solution, derived from soaking leaves in seawater for two weeks. Some dissolved nutrients were present in this solution. We added enough of this solution to bring the DOM concentration in the first and third bags up to a level that is typical of inputs from forested watersheds during spring runoff. For the DIN treatments, we added a solution containing nitrate, phosphate and silicate each day.

One of our major interests was in tracing the different sources of carbon from one trophic level to another. To do so, we used the ratio of carbon-13 (13C), a stable but rare isotope of carbon, to carbon-12 (12C), the common form of the element, as a means of tracing the passage of carbon from various sources through the food web. In order to describe this ratio, we use the delta (δ) notation, in which the ratio of two isotopes in a sample is expressed as a per mil (‰) deviation from an agreed-upon standard value. Plankton in seawater and DOM from forested watersheds both have δ13C values around -22‰ to -30‰. Organisms at higher trophic levels have δ13C values that are roughly the same as their sources of food. In order to increase our ability to differentiate carbon derived from phytoplankton from carbon derived from forest runoff, we added enough inorganic carbon enriched in 13C to all the experimental bags to elevate the δ13C value of the dissolved inorganic carbon in the water to +120‰. We anticipated that the phytoplankton in each of the mesocosms would take up the enriched inorganic carbon and exhibit δ13C values around +100‰.

If the zooplankton in the mesocosms consumed only the enriched phytoplankton, we would expect them to have δ13C values similar to their food. If they consumed only organisms that were dependent solely on the forest DOM, their δ13C value would remain around -30‰. Intermediate values would indicate that the zooplankton were consuming food derived from both sources.

The results of the experiment confirmed some of our hypotheses about the way estuarine food webs function. Phytoplankton biomass and production were highest in the two mesocosms with DIN and lowest in the control (Figure 1). During the first seven days, phytoplankton bloomed in...
all three experimental mesocosms. The nutrients, such as ammonium, that were added with the DOM were exhausted within the seven days, and phytoplankton biomass and production declined in the DOM mesocosm, although low levels of production were sustained throughout the experiment as the microbes released DIN during decomposition of DOM and the initial plankton bloom.

In the two mesocosms with daily additions of DIN, phytoplankton biomass and production remained high throughout the experiment in comparison with the control and DOM mesocosms. A second increase in biomass occurred at around 20 days in the DIN mesocosm, but not in the one with both DIN and DOM additions. We suspect that a second bloom did not occur in the latter mesocosm because the high level of zooplankton consumed the phytoplankton and kept their numbers down.

We observed that large phytoplankton cells were the primary producers under high nutrient conditions. In both of the mesocosms with added DIN, more than 50% of the primary production consisted of large-celled phytoplankton such as diatoms. In the control mesocosm and the one to which we added only DOM, on the other hand, small-celled algae made up most of the primary production.

We found that additions of both DOM and DIN, alone or together, stimulated the microbial food chain. Bacterial production was between seven and 20 times higher in the treated mesocosms than in the control, and biomass was between two and eight times higher. Bacterial biomass and production were highest in the two mesocosms with DIN additions. Phytoplankton production and biomass were greatest in these two mesocosms, indicating that particulate and dissolved organic matter from the phytoplankton provide a high-quality source of food for the bacteria.

Zooplankton also responded to the increased food available in the mesocosms with the added nutrients as compared to the control or DOM-only mesocosms. Respiration measurements showed that zooplankton biomass was greatest in the two mesocosms that included DIN, intermediate in the DOM-only mesocosm and very low in the control mesocosm. The large-celled phytoplankton provide high-quality food for the zooplankton directly.

Figure 1: Response of phytoplankton to experimental addition of dissolved inorganic nutrients and organic matter. Phytoplankton biomass, shown in panel A, and primary productivity, shown in panel B, were stimulated in all mesocosms during the first week, but they were sustained at high levels only in the bags with continuous additions of nutrients (DIN, DIN and DOM). Panel C shows that nutrients added with the DOM treatment were consumed in the first week of the experiment.
whereas the smaller-size phytoplankton enter a longer food chain that wastes far more energy.

Surprisingly little carbon from the DOM made it to the higher trophic levels. The larval fish tripled in weight in all the mesocosms over the course of the three-week experiment, which indicates that they were not limited by the availability of food (Figure 2a). As they grew, their δ13C values changed from -20 o/oo to around +50 o/oo (Figure 2b). During the same period, the δ13C values of the zooplankton in the DOM mesocosm also shifted from -20 o/oo to +50 o/oo. Although we do not have all the results yet, these shifts toward the δ13C value of the phytoplankton in the experiment (+100 o/oo) indicate that the efficient production of higher trophic levels in coastal ecosystems depends heavily on phytoplankton, which depend, in turn, on the supply of inorganic nutrients.

We confirmed our expectation that inorganic nutrients stimulate the type of production that provides more nourishment more readily to organisms at higher trophic levels and that organic matter alone is insufficient to stimulate “efficient” production. But this conclusion does not entitle us to say that high inputs of nutrients into coastal waters will increase fish production. If the level of nutrient inputs is too high, it can stimulate so much algal production that the zooplankton cannot consume enough to control the stand-

![Menidia Dry Weight and δ13C](image)

**Menidia Dry Weight and δ13C**

- Control
- DOM
- DIN
- DIN+DOM

**Figure 2:** Phytoplankton production provided most of the support for the growth of fish. Fish tripled in weight in all mesocosms over three weeks (panel A). Delta 13C values for fish changed from -20 o/oo at the beginning of the experiment to +50 o/oo at the end, indicating a strong dependence on phytoplankton as a source of food (panel B).

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Staff members at The Ecosystems Center conduct a variety of studies, such as the one described in this report, in ponds, estuaries and near-shore ocean waters. Participants are Ishi Buffam, Linda Deegan, Deirdre Dugan, Todd Drummey, Brian Fry, Robert Garritt, Anne Giblin, David Giehlbrock, John Hobbie, Charles Hopkinson, Amy Nolin, Bruce Peterson, Kathleen Regan, Leslie Redmond, Deborah Scanlon, Kristin Tholke, Jane Tucker and Joseph Vallino.
The Long-Term Ecological Research (LTER) program, funded by the National Science Foundation (NSF), allows investigators to observe and measure organisms and processes over decades rather than the two or three years characteristic of most NSF-supported projects. Access to a series of measurements collected over many years at a single site improves our understanding of the ways in which ecosystems function and respond to changes in factors such as climate or nutrient availability. Valuable as these long-term measurements are, however, they are not sufficient to allow us to generalize our knowledge from one site to others. We need to compare processes at a number of sites to see whether ecosystems are behaving in similar ways.

NSF has recently provided support for several comparative studies of large data sets from different sites. A group of researchers led by Ecosystems Center scientist Anne Giblin is carrying out one of these studies, an investigation of the controls on the flux of nitrogen and phosphorus from lake sediments. Giblin is working with Jonathan Cole and Nina Caraco of the Institute of Ecosystem Studies, David Armstrong of the University of Wisconsin, George Kipphut of Murray State University, and Dominic Di Toro of Manhattan College. The data sets to be compared include long-term records collected in seven lakes located at the Hubbard Brook Experimental Forest, Northern Temperate Lakes and Arctic Tundra LTER sites as well as shorter-term records collected from about 50 temperate and arctic lakes.

The investigators will begin by comparing the ratios of elements such as oxygen, carbon, sulfur, nitrogen and phosphorus in the fluxes from lake sediments. Their aim is to clarify the factors that control the regeneration of nitrogen and sulfur in the sediments and their release into the water column. They will use these data to determine whether a model based on decomposition processes can be used to describe benthic fluxes in a wide variety of lakes.

We know that the release of nutrients from sediments is important in determining the productivity of lake ecosystems. Primary production in most water bodies is limited by the supply of either nitrogen or phosphorus. These nutrients are taken up by small aquatic plants (phytoplankton) and converted into organic form through photosynthesis. When the plants die and sink to the sediments, bacteria decompose the organic matter, and the nitrogen and phosphorus are remineralized and released. In this form, these nutrients can be used again by plants.

The release of nitrogen and phosphorus from sediments is regulated by a number of factors. One is the ratio of carbon to nitrogen to phosphorus in the organic matter that reaches the sediments. Another is the conversion of mineral nitrogen into biologically unavailable N₂ gas. Yet another is the trapping of phosphorus by minerals in the sediments. These factors, in turn, are controlled by other factors such as the iron content in the sediments, oxygen levels in the overlying water and temperature.

The process-based model that the investigators will be testing was developed by Di Toro and James Fitzpatrick of HydroQual, Inc. It has already been used for managing nutrient inputs in Onondaga Lake, New York, and in Long Island Sound. The comparative study will extend the application of the model by measuring differences in processes from lake to lake and determining whether these differences should be incorporated into the model. A single model that is able to describe nitrogen and phosphorus fluxes under a wide variety of conditions would be of considerable use to resource managers. The information gained will be invaluable for predicting the results of various approaches to reducing nutrient inputs in both fresh and marine waters.

Kathy Regan, Jane Tucker and Marty Downs

Anne Giblin and Ed Rastetter
Dramatic increases in industrial activity and large-scale changes in agricultural practices during the twentieth century have greatly altered the global nitrogen cycle. Although nitrogen comprises about 78% of the atmosphere as an inert gas (N₂), most organisms cannot use it until it is transformed into a biologically or chemically reactive form. Recent studies show that human activities are now converting as much atmospheric nitrogen into reactive forms as are all the natural terrestrial processes of conversion, such as lightning or fixation by bacteria, combined. As a result, the production and redistribution of reactive nitrogen through human activity is an increasingly important "global change" issue.

The conversion of atmospheric N₂ into nitrogen oxides in high-temperature combustion reactions, such as occur in automobile engines and electric power generating plants, is one process by which humans are increasing the inputs of reactive forms of nitrogen into ecosystems world-wide. Other human activities that transform nitrogen are the production of fertilizer, the cultivation of legumes and wet rice farming. Bacteria associated with legumes fix nitrogen, converting it into forms that can be used by plants. Wet rice cultivation creates anaerobic conditions that also favor nitrogen fixation.

In recent years, the use of fertilizer and legume and rice cultivation have released roughly 120 million tons of biologically usable nitrogen a year into the environment, some six times the amount converted into reactive form through the combustion of fossil fuels (roughly 20 million tons). The natural rate of nitrogen fixation by terrestrial ecosystems is about 110 million tons a year, significantly less than the 140 million tons a year transformed through human activities. The size of the anthropogenic contribution has increased dramatically since the early 1950s, when human activity converted only about 30 million tons of nitrogen a year. And projections indicate that anthropogenic mobilization of nitrogen per year will double between 1990 and 2020.

Once nitrogen is converted through combustion, production of fertilizer or fixation by crops, it is transformed through a variety of biological and chemical processes into a number of forms. On a global basis, emissions of ammonium from the use of fertilizer yield about 47 million tons a year, whereas nitrogen oxide emissions from fossil fuel combustion yield about 20 million tons a year and from fertilized soils, about 10 tons a year. Once in the atmosphere, nitrogen in various forms can be transported hundreds of kilometers and deposited in regions far from the original source.

Given the magnitude of nitrogen mobilization, its redistribution about the earth's surface and the many ecosystem processes that it affects, we need to know more about where it goes and what it does. One of its most likely fates is storage in terrestrial reservoirs, such as groundwater, soils and forests. While storage in terrestrial reservoirs reduces the global distribution of reactive nitrogen, it can have significant impacts on soil biota and forest vegetation.

We do not know how much nitrogen deposition these reservoirs can absorb, or what role plants, soil microbes and physical and chemical processes play in retaining nitrogen in terrestrial ecosystems. The following article describes one promising means of obtaining this information, the use of isotopic tracers to identify the potential for nitrogen storage in different components of ecosystems.

Using Stable Isotopes to Trace Nitrate Retention in a Northern Hardwood Forest

Anthropogenic emissions of nitrogen oxides react with water vapor in the atmosphere to form nitric acid (HNO₃), which is deposited on ecosystems located downwind of industrialized regions. Unlike the atmospheric nitrogen (N₂) from which it is derived, nitrate (NO₃⁻) is biologically reactive. Plants and microbes can use it to synthesize enzymes that regulate their growth and metabolism. Therefore an increase in the flux of nitrate into ecosystems can increase the rates of growth and activity of forest organisms, at least over the short term.

Although nitrate can enhance plant growth and microbial activity, the long-term effects of increased nitrate inputs are not yet well understood. If the nitrate supply in a terrestrial ecosystem exceeds the capacity of organisms to take it up, the excess is leached from the soil into the groundwater and ultimately into streams and lakes. Nitrate leaching can lead to eutrophication of downstream water bodies or to contamination of the groundwater. Because nitrate serves as a strong acid anion, leaching can also deplete soils of important cations such as potassium (K⁺), calcium (Ca²⁺) and magnesium (Mg²⁺). Cation leaching, in turn, can lead to impoverishment of the soil and the eventual export of acidic ions such as H⁺ and elemental aluminum into streams, degrading water quality in aquatic ecosystems.

Knute Nadelhoffer
Forest ecosystems occupy much of the landscape in temperate regions where industrial activity and nitrate deposition rates are high. For this reason, it is important that we improve our understanding of how forests respond to chronically elevated nitrate inputs. We need to know how much nitrate deposition forests can retain before nitrate is exported into the groundwater. Furthermore, we need to identify the ecosystem components that assimilate nitrate and to understand what biogeochemical processes are responsible for the retention of nitrate in forests.

Ecosystems Center researchers Knute Nadelhoffer, Martha Downs, Brian Fry and Jerry Melillo have been collaborating with colleagues at the University of New Hampshire and the University of Maine on an interdisciplinary study of the effects of nitrate deposition on forest ecosystems at a site near the Bear Brooks Watershed in eastern Maine. We have been adding nitrate enriched in $^{15}$N, a naturally rare isotope of nitrogen, to plots in a relatively pristine forest of beech, maple and red spruce in order to trace the movement of the nitrate into components of the ecosystem. Because the abundance of $^{15}$N in nature is low, less than half a percent of the total nitrogen in both plant tissues and soils, small amounts of this stable isotope can be used to trace the movements of nitrogen through ecosystems.

In this study, we increased the $^{15}$N content of nitrate added to each forest plots from background values of 0.3663% $^{15}$N to 0.4945% $^{15}$N by adding small amounts of nearly pure $^{15}$N tracer ($^{15}$NO$_3$) to the treatment solutions. Variations in natural nitrogen isotope composition can be described by using the “delta” ($\delta$) notation, in which $^{15}$N contents are expressed as parts per thousand or per mil (o/oo) deviations from a standard of 0.3663% $^{15}$N in the atmosphere. The $\delta^{15}$N value of the nitrate we added to the forest plots was +344 o/oo. Because $\delta^{15}$N values of forest plant tissues and soils range between -4 o/oo and +10 o/oo, we were able to measure the assimilation of our labeled nitrate additions into different forest ecosystem compartments. We found, for example, that $\delta^{15}$N values of beech leaves on plots treated with additions of either 28 or 56 kilograms of NO$_3$ per hectare per year increased throughout four seasons of treatment (Figure 1).

We were able to identify similar shifts in the $^{15}$N content of growing wood, decomposing litter and both organic and mineral soil horizons during the course of the experiment. These shifts show where in the forest the nitrate additions were being assimilated. In order to estimate the amounts of nitrate assimilated into different components of the ecosystem, we used mass balance techniques that incorporate information on shifts in $\delta^{15}$N values, together with the $\delta^{15}$N value of the added nitrate and measurements of total nitrogen contents. The results of our calculations showed that about one-fourth of the nitrate we introduced could be accounted for in the components we measured (Figure 2). We also found that plant and microbial processes were equally important in retaining nitrate; similar amounts of nitrate were assimilated into growing vegetation (foliage plus wood) and soils. Some nitrate was probably assimilated into other components, such as fine roots and deeper soils.

![Graph showing δ15N values of beech foliage in August for each year of a four-year experiment with adding nitrate enriched with 15N to plots in a northern temperate forest near the Bear Brooks Watershed in eastern Maine. Symbols show mean values and vertical bars show standard errors of δ15N values in control plots with no nitrate additions, low-nitrogen plots with applications of 28 kilograms (kg) of nitrate (NO$_3$) per hectare per year and high-nitrogen plots with applications of 56 kg NO$_3$ per hectare per year. The δ15N value of nitrate applied to all experimental plots was +344 o/oo during all four years.](image1)

![Graph showing percentages of nitrate (NO$_3$) assimilated into compartments of a northern temperate forest after four years of additions of nitrate enriched in 15N. Figures are shown for two treatments, 28 and 56 kilograms NO$_3$ per hectare per year.](image2)
Our analyses indicate, however, that forests subjected to rates of nitrate deposition similar to those occurring in highly polluted regions do not retain all the nitrate that comes into the system.

This “budgeting” approach to tracking the fate of isotopically-labeled nitrate additions has yielded important new information on the capacity of forests to retain nitrogen. Field studies with $^{15}$N tracers can be used in other ways as well to improve our understanding of the way forest ecosystems function. For example, the $^{15}$N distributions in our previously treated plots now differ markedly from the $^{15}$N distributions in untreated forest. The $^{15}$N values found in leaf litter and soils in the treated plots have increased by about 4 o/oo, and values for the wood and foliage of red spruce and beech trees have increased by 20 o/oo to 63 o/oo (Figure 3). We will continue to sample materials from these plots after the experiment is completed in order to measure the rates at which $^{15}$N is redistributed among plant tissues and soils. These longer-term measurements will provide data for testing and improving the simulation models that are used to predict responses of forests to changes in nutrient availability and climate.

In an effort to extend our findings, we are conducting nitrogen tracer studies in oak and pine forests at the Harvard Forest Long-Term Ecological Research (LTER) site in central Massachusetts. We also plan to compare the results of our studies in the northeastern United States to those of our European counterparts, who have been applying fertilizers labeled with $^{15}$N to forests in Denmark, Germany, Holland, Sweden, and the United Kingdom as part of the Nitrogen Saturation Experiment (NITREX). These large-scale $^{15}$N tracer studies will yield data on nitrate retention in four forest types on two continents. The information that will emerge from these studies should greatly improve our understanding of the controls on nitrogen cycling and related biogeochemical processes in terrestrial ecosystems.

Figure 3: Distributions of $^{15}$N values in components of forest ecosystems in experimental plots located near the Bear Brooks Watershed, Maine, before and after nitrate (NO$_3^-$) additions. Solutions of HNO$_3$ with a $^{15}$N value of +344 o/oo were applied to three plots at a rate of 56 kilograms NO$_3^-$ per hectare per year with a spray irrigation system. The treatment was continued over four growing seasons. Deciduous species (at left in each group) assimilated more NO$_3^-$ than red spruce did. The $^{15}$N values increased in all ecosystem compartments: forest floor, mineral soils, bolewood and foliage. The $^{15}$N contents of plant tissues and soils will continue to change as litter is shed from trees and as nitrogen is taken up from soils.

Ecosystems Center staff members are undertaking a variety of studies, such as the one described here, in forests and lakes of the temperate zone. Participants are Mark Castro, Christina Catricala, Mark Dornblaser, Martha Downs, Brian Fry, Anne Giblin, David Kicklighter, Jerry Melillo, Knute Nadelhoffer, Kathleen Newkirk, Bruce Peterson, Kathleen Regan, Andrea Ricca, Paul Steudler and Jane Tucker.
Changing Land Use in the Amazon Basin: Consequences for Trace Gas Emissions

Tropical ecosystems make a major contribution to the exchange of "greenhouse" gases between the biosphere and the atmosphere. These gases, which include methane (CH₄) and nitrous oxide (N₂O), absorb outgoing infrared radiation and help to trap heat in the atmosphere. Changes in land use in the tropics, such as the widespread clearing of forests for agriculture and pasture, can potentially alter the exchange of greenhouse gases and thus their atmospheric concentrations in such a way as to affect global temperature.

Forest clearing is occurring at a rapid pace in many parts of the Amazon Basin in Brazil. Studies using satellite imagery have estimated that between 6% and 10% of the primary forest in the basin was cleared by 1991. The major impetus for clearing in the basin is conversion to pasture; nearly 70% of the cleared land becomes pasture sooner or later. Since 1991, scientists from The Ecosystems Center and colleagues at the Centro de Energia Nuclear na Agricultura (CENA) of the University of São Paulo in Brazil have been collaborating on studies aimed at answering questions about the consequences of changes in land use for the release of greenhouse gases into the atmosphere.

Center researchers Paul Steudler, Jerry Melillo and Christopher Neill are working with Carlos Cerri, director of CENA, and his associates Brigitte Feigl and Marisa Piccolo on a project that is designed to evaluate the effects of converting forest to pasture on the fluxes of N₂O and CH₄ from soils. We began making gas flux measurements in June 1992, using our static chamber sampling technique to address three questions: What are the seasonal patterns of gas flux in natural forests? Do patterns of gas flux in pastures differ from those in forests? Does the age of the pasture (the time since the land was first cleared) affect the exchange of gases with the atmosphere?

We are studying these three questions in two chronosequences, a series of plots in forests or pastures of various ages, at Fazenda Nova Vida, a cattle ranch in located in the western part of the Amazon Basin in the state of Rondônia (Figure 1). Both series of plots are located on the same type of soil and include pasture sequences that range in age from four to 80 years. We found that forest N₂O emissions were greatest during the wet season and decreased more than six-fold in the dry season. Pastures also showed seasonal emission patterns, with dry-season releases comparable to those of forested plots. Gas fluxes from pastures increased during the wet season, but not as much as they did in the forest. The youngest pasture, cleared in 1989, yielded higher gas emissions than any of the older pastures (Figure 2a).

When we examined the factors controlling N₂O emissions from forest and pasture sites, we found that soil moisture, expressed as percent of water-filled pore space, and ammonium pools in the top five centimeters of the soil were strong predictors of N₂O emission levels in the forest sites. When these two factors were combined, we were able to explain 97% of the N₂O emissions. We did not detect this relationship in the pasture sites.

Two microbial processes in soil, nitrification and denitrification, are responsible for the production of N₂O. Ammonium is converted to nitrate (NO₃⁻) in the process of...
nitrification, and NO is given off. Denitrification, the conversion of NO\textsuperscript{-} to N\textsubscript{2}O or nitrogen gas (N\textsubscript{2}) under anaerobic conditions, may also contribute to the emission of N\textsubscript{2}O when soils are wetter. We are currently trying to determine which process is the dominant one for N\textsubscript{2}O production at our sites.

We estimated the mean annual N\textsubscript{2}O emissions from forest sites to be 2.2 kilograms of nitrogen per hectare (kg N/ha). These rates are comparable to results obtained by Brazilian scientists in Manaus from a forest site in the central part of the Amazon Basin. Annual N\textsubscript{2}O emissions from the pasture sites were generally similar to or less than emissions from forests, except for the oldest pasture, which emitted nearly 3.5 kg N/ha (Figure 2a). Our results suggest that at Nova Vida the change from forest to pasture does not substantially alter the emission of N\textsubscript{2}O from the soil into the atmosphere.

Turning to CH\textsubscript{4}, we found that forest soils took up this gas from the atmosphere at all times of year. The highest rates of consumption were in the dry season, decreasing two-fold in the wet season. Pasture soils also took up CH\textsubscript{4} during the dry season but less, in general, than the forest soils took up. We were surprised to find, on the other hand, that pasture soils emitted CH\textsubscript{4} into the atmosphere during the rainy season.

When we looked for the factors that controlled the consumption or emission of CH\textsubscript{4} in forest and pasture sites, we found a strong relationship between the direction of the CH\textsubscript{4} flux and the percent of water-filled pore space in the top five centimeters of the soil (Figure 3). Pasture soils appear to switch from consumption of CH\textsubscript{4} to emission of this gas when the water-filled pore space reaches a critical value of approximately 45%. Some soil microbes produce CH\textsubscript{4} as they decompose plant tissues, and others consume it. When the percentage of water-filled pore space is greater than the critical value, the balance between production and consumption shifts, and CH\textsubscript{4} is released into the atmosphere.

We estimated that the forest sites in both chronosequences had a mean consumption rate of 469 milligrams of CH\textsubscript{4} per square meter per year (mg CH\textsubscript{4}-C/m\textsuperscript{2}/yr) (Figure 2b). The pastures, on the other hand, were a net source of

![Chris Neill](image)

**Figure 2**: Estimates and standard errors for annual flux of N\textsubscript{2}O and CH\textsubscript{4} from forest sites and pastures of different ages at Fazenda Nova Vida. Data on forest sites are shown at 0 year in each panel.

**Figure 3**: The relationship between daily average CH\textsubscript{4} flux and percent water-filled pore space at 0-5 centimeters depth for all sampling times in 1992 and 1993. The figure includes flux data from forest (F) and pasture (P) sites for both chronosequences at Fazenda Nova Vida.
CH₄ for the atmosphere, with a mean emission rate of 271 mg CH₄-C/m²/yr. Using the mean forest and pasture exchange rates, we estimate that the conversion of tropical forests into pasture results in a net release of nearly 1 gram CH₄/m²/yr from the soil. Our findings thus suggest that the soils of land converted from forest to pasture in the tropics serve as a source of CH₄ for the atmosphere with an annual emission rate similar to that of low boreal wetland sites in Canada, which are important sources of CH₄.

We are currently constructing gas flux models based on these findings, which we plan to combine with satellite data on land cover collected over time throughout the Amazon Basin. Our goal is to be able to describe the N₂O and CH₄ fluxes between forest and pasture lands and the atmosphere for the whole basin from the early 1970s to the present. We hope that this extrapolation from our small-scale study to the regional scale will allow us to assess the effects of land-use change in the basin on global levels of N₂O and CH₄ in the atmosphere.

Ecosystems Center staff members who participated in studies of tropical ecosystems during 1994 are Jerry Melillo, Christopher Neill, Paul Steudler and Linda Deegan.

Brazilian graduate student Marciano Brito carries soil samples.

Linda Deegan removes bioassay experiment from tropical pasture stream.

Early stages of secondary growth in Brazilian forest.
Ecosystem research is often carried out at a single site, especially when field experiments are involved. The advantage of the single-site approach is that it makes possible the comparison and analysis of information about individual species or processes in the context of a whole system. The disadvantage is that it is difficult to know how broadly this information can be applied when only one or a small number of sites are studied. Ecologists spend all too much of their time arguing over whether their particular study site is typical of some larger area or region.

One way to avoid this trap is to identify a few key processes that can be measured inexpensively and precisely at a large number of sites. These key processes should be well enough understood so that variation in results from one site to another can be interpreted as indicating widespread patterns of control over element cycling, productivity or species composition.

Under the leadership of Gus Shaver, researchers from the Ecosystems Center are joining in a major international, multi-site study in the Arctic, designed to advance our understanding of controls over primary production throughout a major region of the earth. Participants in this study, called the International Tundra Experiment or ITEX, come from a dozen countries and work at about 25 different sites (Figure 1). The focus of ITEX research is on processes of plant growth and flowering. Researchers are making a few simple measurements with identical methods on the same species of plants at each site. The species under study were carefully chosen, not only for their wide distribution within the Arctic but also for minimum genetic variability, helping to ensure that measurements are made on homogeneous plant material.

In addition to annual monitoring of plant growth and flowering at many arctic sites, ITEX researchers are observing responses to a simple experimental treatment that is applied to the study species at each site. Plants are exposed to increased air temperature, which investigators achieve by enclosing small areas of tundra in open-topped plastic chambers or greenhouses. This simple experiment allows researchers to compare responses, not only to annual variation in climate but also to one specific experimental manipulation, among sites that differ widely in average temperature and other features of climate.

We consider plant growth and flowering to be key ecosystem processes because a great deal is already known about their controls and their relationship to primary production. Both processes have been studied intensively at several arctic sites. One such site is Toolik Lake, located on the North Slope of the Brooks Range, where Ecosystems Center researchers have been working for nearly 20 years. One of the benefits of participating in ITEX is that it helps us find out how typical the Toolik Lake region is and thus how broadly useful our past results are.

Our field greenhouse experiments illustrate this benefit. We have maintained these greenhouses for many years as part of a larger experiment testing the effects of warming, fertilizer and shade and combinations of these treatments on various plants. For Eriophorum vaginatum, one of the most common arctic sedge species, we have documented leaf growth in response to these treatments using the methods adopted by ITEX. Our results show a large increase in leaf elongation in response to the increased temperatures in our greenhouses (Figure 2), which suggests that low temperatures limit leaf growth, at least within a single growing season. ITEX researchers have obtained similar results for the same species at several other sites, allowing us to conclude that our experiments may be useful in predicting responses to temperature over much of the Arctic.

![Gus Shaver](image)

*Figure 1: Circumpolar map of ITEX field sites, compiled by Giles Marion of the U.S. Army Cold Regions Research Laboratory.*

*Figure 2: Leaf elongation per tiller per day (the sum of the increases in length of all growing leaves on an individual shoot) in Eriophorum vaginatum at Toolik Lake, Alaska. Treatments include fertilization with nitrogen and phosphorus, increased air temperature in a field greenhouse, fertilizer plus increased air temperature and a 50% reduction in light intensity by shading.*
One way to understand how ecosystems function is to look at the cycles of key elements such as carbon, nitrogen and phosphorus. Since all living things require these elements, they are taken up, used and recycled over and over again. In many terrestrial and aquatic ecosystems, the growth and abundance of plants is controlled by the availability of phosphorus and nitrogen, which are present in limited quantities. Human activities often increase the supply of these nutrients, however, causing increased plant growth. We refer to the process of overfertilization and excess plant production in aquatic systems as eutrophication. Awareness of the prevalence and consequences of eutrophication in fresh waters and coastal marine areas has stimulated us to try to improve our understanding of how these ecosystems respond to changing nutrient inputs.

Modeling is among the tools we use in our efforts to understand the impact of change on ecosystems. Models of ecosystems allow us to lay out in simplified form how we think a system is structured and how its different parts interact. For example, we know that nitrate (NO₃⁻) leaching into arctic rivers from the tundra is taken up by algae and that the algae are eaten by insects. The insects, in turn, are eaten by fish. Thus we diagram with boxes and arrows the flow of nitrogen from NO₃⁻ to algae to insects to fish. Some of the nitrogen taken up is returned to the water as dissolved organic nitrogen (DON), fine particulate organic nitrogen (FPON) and ammonium (NH₄⁺).

Since even the relatively simple ecosystems of arctic rivers have several different types of plants, insects and fish, these diagrams become complicated. We modeled the nitrogen cycle of the Kuparuk River, located on the North Slope of the Brooks Range in Alaska; the result required 17 compartments to describe the major pathways of nitrogen flow in the food web (Figure 1). The diagram is organized with nutrients and detritus on the bottom, primary producers in the middle and consumers on the top. Thus the assimilation of nitrogen tends to move upward in the diagram, while regeneration and excretion move downward. Since most compartments are connected via flows of nitrogen in various forms to several other compartments, the number of pathways needed to illustrate these fluxes is well over 100; we have shown only one in Figure 1.

If we try to include all possible compartments and fluxes, models of ecosystems can become overly complex and confusing. We need to simplify models without losing the ability to describe essential attributes and behavior of ecosystem components. And we need to demonstrate that whole-ecosystem models do indeed represent accurately at least the dominant pathways of element cycles. But how can we be sure how nitrogen actually moves through natural ecosystems?

Building an ecosystem model frequently requires use of most of the relevant information about the ecosystem. Thus it is difficult to find enough information to perform a

Figure 1: The structure of the river nitrogen cycle model, showing the distribution of nitrogen among different components of the food web in the Kuparuk River. The numbers refer to the maximum δ¹⁵N values observed in each component after we added ammonium chloride enriched in ¹⁵N, a naturally scarce stable isotope of nitrogen, to the system. Natural δ¹⁵N values are given in parentheses. Variations in nitrogen isotope composition are described using the "delta" notation, in which δ¹⁵N contents are written as parts per thousand deviation from an atmospheric standard for ¹⁵N of 0.3663%. The arrows show the flux of nitrogen in the form of ammonium (NH₄⁺) into algae attached to rocks (diatoms), which are consumed by insects (Baetis), which are consumed, in turn by fish.

Bruce Peterson
rigruous independent test of the appropriateness of the model structure and functioning. Ecosystems Center scientists Knute Nadelhoffer, Brian Fry and Bruce Peterson, together with George Kling of the University of Michigan, have been leaders in the design of whole-ecosystem experiments that use stable isotopes of elements as tracers to obtain data on the flow of nitrogen through forest, lake and river ecosystems. The addition to an ecosystem of nitrogen that is rich in the naturally rare isotope $^{15}$N allows researchers to follow the transfer and determine the fate of nitrogen entering the system. The $^{15}$N content of nitrogen fluxes and ecosystem compartments changes over space and time as the tracer moves through the system.

The first experiment of this type to focus on stream processes was conducted at the Toolik Lake Long-Term Ecological Research (LTER) site in Alaska during July and August 1991. We added NH$_4^+$ enriched in $^{15}$N to the river continuously for six weeks. Most of the components of the Kuparuk River food web except adult grayling contained measurable tracer levels within a few days and reached maximum $^{15}$N values within three to four weeks. After we stopped adding the tracer, we continued to sample selected ecosystem components for two more summers. We were amazed to find that the $^{15}$N tracer was still measurable in samples of mosses and insects from near the tracer addition site even after two years. Because the productivity of the Kuparuk River is primarily limited by phosphorus, we had expected the nitrogen to be flushed downstream more rapidly.

The $^{15}$N tracer data can be used to find out whether a mathematical model of nitrogen flow is a reasonable representation of nitrogen-cycle compartments, pathways and rates of flow in the river. The model calculates the movement of the $^{15}$N tracer over space and time for any specified set of compartments, pathways and fluxes. Since the $^{15}$N data were not used to estimate nitrogen stocks and fluxes in the model, they are independent and can serve as a valid test. In order to come close to matching the field data, however, we had to include several initial observations from the tracer study in the model. One was the different degree of preference for NO$_3^-$ versus NH$_4^+$ of the different groups of

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**Figure 2:** Model calculations of the predicted spatial and temporal distribution of $^{15}$N values for selected components of the Kuparuk River nitrogen model. Each box illustrates the pattern of $^{15}$N values for one component over five kilometers and 50 days. Boxes are keyed by component, maximum $^{15}$N value achieved and percent of the maximum value (red highest, light blue lowest) according to the key on right. NH$_4^+$ = ammonium, DIA = diatoms, BAE = Baetis, GRA = adult grayling, PON = particulate organic nitrogen, BLK = black flies.

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**Figure 3:** Comparisons of modeling simulations with field data: $^{15}$N values for black flies, mayflies (Baetis) and filamentous algae in the Kuparuk River after five weeks of continuous addition of nitrogen enriched in $^{15}$N. Locations are in kilometers downstream from the site of the $^{15}$N addition.
primary producers (diatoms, filamentous algae and moss). Another was the use of two compartments to represent the microbial film on the rocks in the river, one for microbes, which cycle nitrogen rapidly, and one for detritus, which cycles nitrogen slowly.

Figure 2 shows some of the results of our efforts to model the flow of nitrogen over time and space in the Kuparuk River. The model output assumes that the nitrogen cycle was in a steady state during the seven weeks of 15N tracer addition. Field data from the summer of 1991, on the other hand, show that a number of factors, such as river discharge, nitrate concentrations and temperature, vary over time. Although any of these factors could affect the flow of nitrogen in the experimental reach of the river, we did not include these variations in this modeling exercise. In spite of this oversimplification, we have found a very high correlation between the 15N content of our field samples and the 15N content calculated from the nitrogen model (Figure 3). The overall correlation coefficient for all field samples versus model predictions was 0.97, but the 815N values in the model were a bit low on average.

Several important features of the ecosystem became apparent as we worked with the model and the tracer data. One factor was the surprising importance of mosses in the nitrogen cycle. Although mosses appear sparse in this stretch of the river, their uptake of nitrogen from the water is a major, perhaps dominant, factor in the nitrogen cycle. If we exclude mosses from the model, both ammonium and nitrate uptake rates are too low to agree with the tracer data. Mosses have been widely ignored in stream studies. Our results suggest that they may be much more important in stream biogeochemistry than currently believed.

A second surprise was the prolonged storage of nitrogen in the detritus of the epilithon (film on the rocks). As noted above, we found it necessary to create two compartments rather than one in order to model the nitrogen uptake and storage of the epilithon adequately. One compartment represents diatoms, which obtain all their energy through photosynthesis (autotrophic), with a rapid nitrogen turnover rate; the other represents heterotrophic microbes plus epilithic detritus with a slow turnover rate.

The third surprise was the distribution of 15N in the filter-feeding black flies. Black flies had low 15N values near the point at which we added the tracer and reached maximum values almost one kilometer downstream from the dripper (figures 2 and 3). This distribution suggested that the fine particulate nitrogen assimilated by the black flies was produced, on average, about a kilometer upstream of the point where it was ingested. This result was important because the travel distance for fine particles in rivers is difficult to determine directly and thus poorly known.

The stream nitrogen model is now being used to study nitrogen cycling in other Arctic streams, in forested streams at the Coweeta LTER site in North Carolina and in coastal salmon rivers in British Columbia. The use of 15N tracer experiments in conjunction with modeling promises to contribute greatly to our understanding of the role of streams and rivers in nitrogen flow through watersheds. One proposed use of this approach is to determine how nitrogen fertilizer additions can be optimized to promote the production of salmon and trout in Canadian rivers. Another is to perform a comparison among LTER sites to see how nitrogen cycles in streams differ in different regions. The long-term goals are to improve our understanding of rivers and to develop river models that are generally applicable and able to predict how flowing waters respond to changes in nutrient loading and climate.

Ecosystems Center staff members carried out a variety of arctic research projects, such as the ones described in this report, during 1994. They are Michele Bahr, Neil Bettez, Mark Castro, Nancy Castro, Linda Deeghan, Anne Giblin, Christopher Harvey, John Hobbie, Loretta Johnson, David Jones, Bonnie Kwiatkowski, James Laundre, Robert McKane, Jerry Melillo, Georgia Murray, Knute Nadelhoffer, Bruce Peterson, Edward Rastetter, Gus Shaver and Wilfred Wolheim.
The combustion of fossil fuels and other human activities are bringing about changes in the atmospheric concentrations of greenhouse gases, such as carbon dioxide (CO₂), methane or nitrous oxide, and of aerosols, which include particles derived from sulfur dioxide emissions and the burning of vegetation. These changes have an impact on features of climate such as temperature, cloudiness and precipitation patterns. We are increasingly aware that changes in climate and atmospheric composition are likely to stimulate a variety of changes in the structure of terrestrial ecosystems and in the way they function.

Structural responses are likely to include changes in the distribution of plant species and in a variety of vegetation characteristics such as canopy height and rooting depth. Functional responses are likely to include changes in the cycling of water, carbon and nutrients, such as nitrogen, phosphorus and sulfur. In order to understand and predict the ways in which terrestrial ecosystems will respond to changing atmospheric conditions, we need to ask how these structural and functional responses are likely to influence each other.

Among the tools available to address this question are two types of models, one of which focuses on ecosystem structure (biogeographical or vegetation distribution models), and the other of which focuses on function (biogeochemical or dynamic process models). Both types of model have been used in recent years to simulate response on regional and global scales under various climate change scenarios. Although the development of these two kinds of model has, for the most part, proceeded independently, a serious attempt to assess the impact of changes in climate and atmospheric composition on particular regions must take into account both structural and functional responses. While we are not yet able to link specific biogeochemical and biogeo graphical models in a way that produces a true interaction between functional and structural responses, an international, multi-institutional research initiative currently underway is making progress in using the results of biogeo graphical modeling exercises as input for biogeochemical modeling efforts.

Ecosystems Center researchers Jerry Melillo, Yude Pan, David Kicklighter and David McGuire are participating in the Vegetation/Ecosystem Modeling and Analysis Project (VEMAP), which involves modeling teams from six research institutions. Teams from Lund University in Sweden, Sheffield University in England in cooperation with the University of Virginia, and the United States Forestry Service in Corvallis, Oregon, have contributed biogeography models to VEMAP; while teams from the University of Montana, Colorado State University and The Ecosystems Center have contributed biogeochemistry models.

The group from The Ecosystems Center is working with the Terrestrial Ecosystem Model (TEM). With this model, we use information on soils, vegetation and climate from a variety of sources to make monthly estimates of the major components of the carbon and nitrogen budgets of ecosystems, such as forests, grasslands and deserts.

VEMAP participants had two objectives for the first phase of the project. The first was to compare the sensitivity of the six models to changes in climate and atmospheric CO₂, and the second was to evaluate the coupled response of these two types of model to altered conditions. A team of scientists from the National Center for Atmospheric Research (NCAR) in Boulder, Colorado, worked with the six modeling teams to develop a common set of initial conditions, such as vegetation and soil distribution, and controlling variables, such as temperature and precipitation, so that differences in results could be attributed to the models and their implementation rather than to different initial inputs. The study region for the first phase of VEMAP was the contiguous United States, divided into parcels with a spatial resolution of 0.5° longitude by 0.5° latitude.

In order to evaluate the individual and joint effects of altered climate and doubling of CO₂ levels on simulated biogeography and biogeochemistry, we linked models in every possible combination and looked at the different combinations of changes in the controlling variables. The first set of modeling simulations was carried out with the three biogeography models, Biome2, DOLY (short for Dynamic Global Phytogeography Model) and MAPSS (Mapped...
Atmosphere-Plant-Soil System. We used the current atmospheric CO2 concentration of 355 parts per million volume (ppmv) and monthly or daily versions of contemporary climate conditions for the control runs. We then carried out three simulations of ecosystem response to altered conditions: change in climate under three scenarios derived from general circulation models (GCMs), a doubling of atmospheric CO2 levels to 710 ppmv, and change in both climate and CO2 levels. We then analysed the biogeochemistry models for their representation of vegetation under current and altered conditions.

The second set of simulations was carried out with the three biogeochemistry models, TEM, Biome-BGC (biogeochemistry) and Century. Control runs with these models used the same CO2 concentration and contemporary climate data as were used for the biogeography models. We also carried out simulations of response to climate change, doubled CO2 levels, and the combination of climate and CO2 changes.

In a third set of simulations, we examined the effects of biogeographical changes on biogeochemical responses. We ran each biogeochemistry model using the vegetation distribution generated by each of the three biogeography models. We carried out these "coupled" simulations both for contemporary (control) conditions and for the combined effects of altered climate and doubled atmospheric CO2. The controls for the coupled runs differed from those for the independent experiments in that the vegetation distributions we used were based on the output from the biogeography model control runs rather than generated from independent sources.

We evaluated the results of the coupled experiments in terms of a number of measures of ecosystem response, including change in the total amount of carbon stored in vegetation and soils for the contiguous United States (Table 1). The coupling of TEM with each of the three biogeography models yielded increased carbon storage under all three GCM climate-change scenarios with elevated CO2 levels. The largest increases in total carbon storage resulted from the combination of TEM with Biome2 (Table 1 and Figure 1b), and the smallest increases resulted from the combination of TEM with MAPSS. We found that the main reason for this difference was the differential sensitivity of the two biogeography models to the effect of drought on vegetation. Biome2 is less sensitive to drought stress than MAPSS.

Not all of the model couplings yielded increases in total carbon storage for the climate change scenarios. When Biome-BGC, the most drought-sensitive biogeochemistry model, was combined with MAPSS, total carbon storage was reduced between 8.3% and 39.4% (Table 1 and Figure 1a). These early results from the model intercomparisons have caused us to look more closely at how different models represent the water cycle and how the biogeochemistry models link the water cycle with the carbon cycle.

One of our goals for future VEMAP work is to develop a modular structure for each of the models that would facilitate future comparisons and pairings. Each "module" would

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<th>Models</th>
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<td>114</td>
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<td>MAPSS</td>
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Table 1: Total carbon stored in vegetation and soils of the contiguous United States as predicted by linked pairs of ecosystem models under contemporary conditions (CON) and scenarios for climate change derived from three general circulation models (GCMs), Oregon State University (OSU), Geophysical Fluid Dynamics Laboratory (GFDL) and United Kingdom Meteorological Office (UKMO). Biogeochemistry models (BGC) are Biome-BGC (BBGC), Century (CEN) and the Terrestrial Ecosystem Model (TEM). Biogeochemistry models (VEG) are Biome2 (BIOME2), the Dynamic Global Phytoecology Model (DOLY) and Mapped Atmosphere-Plant-Soil System (MAPSS). CON is calculated at an atmospheric CO2 level of 355 ppmv. The GCM climate scenarios are calculated at an atmospheric CO2 level of 710 ppmv.
contain a component of the overall model that deals with some particular ecosystem process or structure. For biogeochemistry models, for example, a modular structure would make it possible to exchange modules describing key ecosystem processes such as photosynthesis or transpiration between models. We could thus pinpoint the conceptual differences among models and explore the system-level consequences of these differences.

A modular approach would also improve our ability to pair models from different classes. Currently the pairing of MAPSS with TEM, for example, presents a conceptual problem. In response to climate change, the predicted vegetation distribution reflects a high sensitivity to water stress, whereas the predicted biogeochemical cycling reflects a low sensitivity to water stress. An ideal coupling of these models would involve a common hydrology module.

Our efforts to resolve these conceptual differences among models will enhance our ability to describe and predict the large-scale and long-term responses of terrestrial ecosystems to changes in the global environment. These improved ecological models can then be coupled to models of atmospheric chemistry and physics as well as to economic models. These integrated models will allow us to evaluate more completely the linked responses of natural and socioeconomic systems to global environmental change.

Investigators from The Ecosystems Center are working with colleagues from Massachusetts Institute of Technology to carry out this kind of integrated assessment.

**Total Carbon Storage, Change from Contemporary**

a.) UKMO/MAPSS/Biome-BGC

b.) GFDL-R30/BIOME2/TEM

**Figure 1:** Change in total carbon stored in vegetation and soils of the contiguous United States predicted by coupled biogeography and biogeochemistry models for future climate scenarios and atmospheric CO2 levels of 710 ppmv. The change is from current climate conditions and an atmospheric CO2 level of 355 ppmv. Figure 1a describes the results of coupling MAPSS with Biome-BGC under a climate scenario generated by a United Kingdom Meteorological Office (UKMO) general circulation model (GCM). Figure 1b describes the results of coupling BIOME2 with the Terrestrial Ecosystem Model (TEM) under a climate scenario generated by a Geophysical Fluid Dynamics Laboratory (GFDL) GCM. Blue indicates high carbon storage; brown indicates low.

*Staff members at The Ecosystems Center participated in a number of modeling studies, such as the one described in this report, during 1994. They include David Fernandes, David Kicklighter, David McGuire, Robert McKane, Jerry Melillo, Knute Nadelhoffer, Yude Pan, Susan Pennington, Bruce Peterson, Edward Rastetter, Gus Shaver, Mathew Williams and Xiangming Xiao.*
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 lead workshops and participate in courses given at MBL. Senior staff members supervise the work of postdoctoral research associates at the center. Visiting scientists and students come to work on projects, some for a week or two and some for a year or more.

Anne Giblin and John Hobbie hold adjunct professorships at Boston University. Gus Shaver is a senior research associate at the Institute of Arctic Biology of the University of Alaska. Linda Deegan is an adjunct associate professor at the University of Massachusetts at Amherst, where she serves regularly on graduate thesis committees.

The Ecosystems Center also participates in MBL's Science Writing Fellowships Program each summer. In June 1994, Richard Stone of Science magazine accompanied center investigators to the Long-Term Ecological Research (LTER) site at Toolik Lake in Alaska for a first-hand look at ecological field research in the Arctic. Freelance science writer Yvonne Baskin and David Zimmerman of Probe magazine talked with scientists at the center and visited field sites at Harvard Forest in Petersham, Massachusetts, and at Plum Island Sound northeast of Boston. Anne Giblin, Bruce Peterson, Jerry Melillo and Ed Rastetter made presentations during the science writers workshop at MBL in June, and Linda Deegan led a field trip to the Waquoit Bay Estuarine Research Reserve.

Postdoctoral Research At The Center

Robert McKane was appointed a research associate at The Ecosystems Center in July. He came to the center initially as a postdoctoral research associate in July 1990 after receiving his doctorate in soil sciences from the University of Minnesota, where he studied nitrogen and carbon cycling in old-field succession. He has worked on the General Ecosystem Model (GEM) project with Ed Rastetter, Jerry Melillo and others, using GEM to predict the effects of changes in atmospheric carbon dioxide and climate on the storage of carbon in the vegetation and soils of ecosystems ranging from arctic tundra to tropical forests. Bob has also worked with Gus Shaver and Loretta Johnson on an experiment in Alaska that uses stable isotopes to show how differences in sources of nitrogen for plant species promote biodiversity in arctic tundra.

Christopher Neill was also promoted to research associate in July. He received his doctorate in forestry and wildlife management at the University of Massachusetts at Amherst and joined the center as a postdoctoral research associate in November 1991. For his thesis, Chris examined ways in which flooding controls nitrogen cycling and primary production in prairie marshes in Manitoba. He currently works with Jerry Melillo, Paul Steudler and Brazilian researchers from the Centro de Energia Nuclear na Agricultura (CENA) on the effect of deforestation and pasture agriculture on soil fertility and trace gas fluxes in the Amazon Basin. On one field trip to Brazil this year, he teamed up with Brazilian scientist Marisa de Càssia Piccolo to collect soil and gas samples along a transect across 700 kilometers of rapidly changing territory in the state of Rondônia in the western Amazon. Later in the year, Chris helped organize an experimental cut and burn of three hectares of forest, where researchers from MBL and CENA will study changes in soil organic matter and measure gas emissions over the next few years.

Loretta Johnson joined the staff of The Ecosystems Center as a postdoctoral research associate in May 1992 after a semester of teaching at the University of Connecticut, where she received her doctorate in 1991 in ecology and environmental biology. For her doctoral research, Loretta studied decomposition in peatlands in northeastern Maine and in Sweden. She has been working with Gus Shaver and Bob McKane on a stable isotope experiment, using nitrogen-15 to trace the partitioning of nitrogen compounds between vegetation, soils and soil microbes. She is also studying the effects of temperature and nutrients on carbon dioxide exchanges in wet sedge tundra at the arctic LTER site at Toolik Lake, Alaska. Loretta has participated for the last two years in the Young Investigator Program in Arctic Ecology, sponsored by the Russian National Academy of Sciences and...
its U.S. counterpart. During 1993, she and nine other Americans visited Russian arctic research institutions. The following year the American ecologists and 10 Russian specialists in arctic ecology met for two weeks in Alaska to visit field sites and to plan future collaborative efforts.

Postdoctoral research associate Joseph Vallino came to The Ecosystems Center in July 1993 as MBL's first Lakian Postdoctoral Scholar to work with Chuck Hopkinson and other members of the center's aquatic group on modeling and field studies of the microbial food web in estuaries. Joe received his doctorate in chemical engineering from Massachusetts Institute of Technology, where he pursued both modeling and experimental approaches to the study of metabolic pathways in microorganisms. After completing his doctorate in 1991, he undertook two years of postdoctoral research at Scripps Institution of Oceanography on microbial degradation of dissolved organic carbon. Joe is currently working on developing models of the energetics of microbial growth and on incorporating them into models of advection and dispersion in estuaries.

David Fernandes joined The Ecosystems Center as a postdoctoral research associate in February 1994 after completing a previous postdoctoral project at the University of Denver on the relationship between land use and phosphorus dynamics, species diversity and succession in tropical forests in Costa Rica. He received his doctoral degree in astrophysics from Stanford University in 1992. Interested in using models to address questions of environmental policy as well as in combining field studies with modeling, Dave is working with Ed Rastetter on the General Ecosystem Model (GEM) project. The focus of his effort is on developing a better model of how plants allocate nutrients among stems, roots and leaves. His goal is to be able to describe systems that are changing rapidly and to predict their future directions.

Mathew Williams comes to The Ecosystems Center from the University of East Anglia in the United Kingdom, where he received his doctorate in 1994 in ecology in the School of Environmental Science. During his undergraduate career at Oxford University, he spent a summer at the Woods Hole Oceanographic Institution as a student fellow. For his doctoral research, he collected data on tree structure and distribution in old-growth forests in the Adirondacks of New York and developed a three-dimensional model of forest succession. At the center, Mathew is also working with Ed Rastetter on the GEM project. He is developing a photosynthetic canopy model that describes the transport and loss of water and the uptake of carbon. His ultimate goal is to develop a model that describes a continuum from soil to plant to atmosphere.

Yude Pan completed her undergraduate degree in applied mathematics and masters degree in plant ecology in the Peoples Republic of China before coming to the United States to continue her studies. She received her doctorate in 1993 in plant ecology from the State University of New York at Syracuse, where she developed an individual tree growth model as part of a study of the relationship between tree ring growth and climate. As a postdoctoral research associate at The Ecosystems Center, Yude is working with Jerry Melillo, Dave Kicklighter and Dave McGuire on the Vegetation/Ecosystems Modeling and Analysis Project (VEMAP). She is becoming familiar with the MBL Terrestrial Ecosystem Model (TEM) and is participating in comparisons of results from TEM with the output of other biogeochemistry models used in VEMAP.

Xiangming Xiao joined The Ecosystems Center as a postdoctoral research associate in September 1994 after receiving his doctorate from Colorado State University (CSU), where he was a graduate student in the Department of Rangeland Ecosystem Science and the Natural Resource Ecology Laboratory. He received his undergraduate degree in biology and his masters degree in ecology in the Peoples Republic of China before coming to CSU, where he participated in both field and modeling studies of the carbon balance in the grasslands of Inner Mongolia, a province of China. Xiangming has a joint appointment at Massachusetts Institute of Technology and at The Ecosystems Center, where he works with Jerry Melillo, Dave Kicklighter and Dave McGuire on modeling projects associated with the MIT Joint Program on the Science and Policy of Global Change. He is using TEM, a process-based ecosystem model, to assess the impact of climate changes predicted by a general circulation model on net primary productivity and carbon storage.

Training Students In Brazil
With support from the Texaco Foundation and the

Mark Dornblaser and Loretta Johnson

Bob McKane

Deb Cades
Conservation, Food & Health Foundation, Jerry Melillo, Paul Steudler and Chris Neill are collaborating with colleagues in Brazil to train students in the methods and principles of ecosystem ecology. During 1994, the Texaco Fellowship Program provided support for three graduate students at the University of São Paulo at Piracicaba, where The Ecosystems Center has a close working relationship with the Centro de Energia Nuclear na Agricultura (CENA). Texaco fellows are working with center staff members in both the laboratory and the field; two of them have also visited the center and other research facilities in the U.S. to learn new techniques.

Brigitte Feigl received her doctorate during 1994. Her thesis is titled “Dynamics of soil organic matter in forest to pasture succession in Amazonia.” She has worked with scientists at The Ecosystems Center on methods for analyzing organic matter in tropical soils. She also received her bachelor’s degree in biology and her master’s degree in agronomy from the University of São Paulo.

Marisa de Cássia Piccolo, who also received her doctorate during 1994, earned her undergraduate degree in industrial chemistry from the Universidade Metodista de Piracicaba and her master’s degree from CENA. The topic of her thesis is “Behavior of nitrogen in forest to pasture chronosequences in Rondônia.” She has worked with Ecosystems Center researchers on experiments to determine methods of measuring patterns of soil nitrogen availability.

Marciano de Medeiros Pereira Brito received his undergraduate degree in agricultural sciences from the Federal University of Paraiba in 1987 and his master’s degree in soil and plant nutrition from the Luiz Queiroz Agricultural College of the University of São Paulo, where he is currently a doctoral candidate. His research focuses on factors influencing soil fertility in pastures of the Amazon Basin, especially the roles of phosphorus availability and microbial biomass and their relationship to soil carbon stocks.

Former Texaco fellow Jener Leite de Moraes is currently finishing his doctorate at CENA. His work links groundwater-based measurements of soil classification and carbon content to satellite images of changes in land use in Rondônia. Ecosystems Center staff members introduced Jener to techniques for using a Geographic Information System (GIS) for data management and analysis and helped him set up such a system at CENA.

Other Educational Activities

Students participating in the National Science Foundation’s Research Experiences for Undergraduates (REU) program worked with Ecosystems Center staff members at several research sites last summer. Duke University undergraduate Deborah Cades joined Loretta Johnson and Gus Shaver at the Toolik Lake site in Alaska for a study of the effects of elevated temperature and nutrients on leaf photosynthesis in wet sedge tundra. Mark Waldrop of New Mexico State University worked with Gus, Anne Giblin, Knute Nadelhoffer and Ed Rastetter at Toolik Lake on controls on methane fluxes in tundra ecosystems. He presented a poster on his project at the Soil Science Society meeting in November.

Eileen Monaghan, a student at the University of Massachusetts at Amherst, worked with Anne, Chuck Hopkinson and Jane Tucker on a study of the effects of coupling between the oxic and anoxic layers of sediment on the release of nutrients in the Plum Island Sound estuary in northeastern Massachusetts. A short report on Eileen’s work was published in the Biological Bulletin. She also presented her work at the New England Estuarine Research Society meeting in October. Lawrence University undergraduate Amy Uhlenhopp worked with Joe Vallino, John Hobbie and Hap Garrott on determining the availability for microbes of organic carbon transported by rivers into the estuary.

At the Harvard Forest site in central Massachusetts, Ecosystems Center staff members Kathy Newkirk and Chris Catrical supervised the work of REU student Kaelyn Stiles of Oberlin College and National Institute for Global Environmental Change (NIGEC) fellow Gwen Stephens, an undergraduate at Allegheny College. Kaelyn and Gwen assisted with the collection of samples and the analysis of trace gas fluxes from forest plots. High school science teacher David Hoyt also assisted Kathy and Chris with collecting and analyzing soil and gas samples as part of his internship for Southern Connecticut State University’s Institute for Science Instruction and Study (ISIS) program.

Camille Lecat, an undergraduate in chemical engineering at the Université de Technologie de Compiègne, France, spent six months at The Ecosystems Center becoming acquainted with various analytical methods as well as with the processes of experimental design and data analysis. She worked with Jerry Melillo on the question of how changes in temperature affect the rates of microbial respiration and nitrogen mineralization in arctic soils. As part of this project, she conducted a series of laboratory incubations with soils collected at field sites in northern Sweden.

Ecosystems Center staff members also share their expertise with Falmouth’s public and private schools. Debbie Scanlon, Kathy Regan, Knute Nadelhoffer, Marty Downs and Kathy Newkirk served as judges for 1994 science fairs at Falmouth Academy and Falmouth High School. Others participate in activities sponsored by the Woods Hole Science and Technology Education Partnership, a consortium of area schools, research institutions and businesses. As part of the partnership’s Women in Science program this year, Marty Downs and center consultant Beth Schwarzmnan spoke to Falmouth school system students about their work and how they chose careers in science.

Camille Lecat
Ecosystems Center Events and Activities

Highlights of 1994

GCTE Conference at MBL
Scientists from 34 countries gathered at the Marine Biological Laboratory (MBL) May 23 to 27 for the first scientific conference of the Global Change and Terrestrial Ecosystems (GCTE) program, a core project of the International Geosphere-Biosphere Programme (IGBP). The aim of the conference was a comprehensive assessment of current research on the interactive effects of changes in climate and atmospheric composition with the responses of terrestrial ecosystems.

Jerry Melillo organized the meeting and served as co-host with GCTE chairman Brian Walker of the Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia. Susan Pennington handled the local logistics. With nearly 400 participants, the conference filled MBL's auditoriums, classrooms, beds and dining facilities to capacity. One of the first large-scale global change conferences for terrestrial ecologists, the four-day event featured plenary sessions each morning and poster sessions, concurrent oral presentations and workshops in the afternoons and evenings.

Jerry gave a keynote talk on global change and resource interactions in terrestrial ecosystems. Other contributors of papers and posters from The Ecosystems Center were Mark Castro, Linda Deegan, Marty Downs, Brian Fry, Anne Giblin, John Hobbie, Loretta Johnson, David Jones, Dave Kicklighter, Jim Laundre, Dave McGuire, Bob McKane, Georgia Murray, Knute Nadelhoffer, Chris Neill, Yude Pan, Bruce Peterson, Ed Rastetter, Gus Shaver, Paul Steudler, Joe Vallino, Mathew Williams and Xiangming Xiao.

LTER Workshops and Meetings
Participants in the Harvard Forest Long-Term Ecological Research program met in Petersham April 25 for their fifth annual symposium. Kathy Newkirk made a presentation on time-domain reflectometry and the results from the soil-warming project. Mark Castro discussed the problem of extrapolating methane consumption rates from chamber experiments to regional scales. Knute Nadelhoffer attended both the Harvard Forest symposium and the annual meeting of the National Institute for Global Environmental Change (NIGEC) Northeast Project, which followed it.

Participants in the Arctic LTER program met in Woods Hole in March for their annual three-day workshop. Attending from the center were Michele Bahr, Neil Bettez, Nancy Castro, Linda Deegan, Brian Fry, Anne Giblin, John Hobbie, Loretta Johnson, Bonnie Kwiatkowski, Jim Laundre, Bob McKane, Georgia Murray, Knute Nadelhoffer, Bruce Peterson, Ed Rastetter and Gus Shaver. During the meeting, Michele gave an update on molecular microbial ecology research underway in collaboration with the MBL Center for Molecular Evolution.

Bruce Peterson and Linda Deegan participated in a trip to British Columbia during the last two weeks of July. The purpose of the expedition, sponsored by the LTER program, was to conduct stable isotope studies of nitrogen flow in rivers where other fertilization projects are going on.

LTER Workshops and Meetings
Plum Island Sound was the host site for the annual All Scientists' Meeting of the Land Margin Ecosystems Research (LMER) program in October. Eighty scientists and agency representatives attended the meeting in Gloucester, Massachusetts, organized by LMER coordinating committee chairman John Hobbie and executive assistant Debbie Scanlon.

Chuck Hopkinson, principal investigator for the Plum Island LMER, led participants on a field trip through the watershed of the rivers that feed the sound. John convened the working group on organic matter, and Bruce Peterson, the group on coupling land use with GIS and modeling to predict inputs into coastal zone. Linda Deegan was a co-leader of the working group on food-web structure and function in estuarine systems. Also participating from the center were Ishi Buffam, Hap Garritt, Anne Giblin, Jane Tucker and Joe Vallino.

Chuck Hopkinson and John Hobbie attended an LMER Coordinating Committee meeting at the National Science Foundation (NSF) in Washington, D.C. in March.
IPCC Working Group Meetings
Jerry Melillo traveled to Fortaleza, Brazil, in mid October to attend a meeting of the Intergovernmental Panel on Climate Change (IPCC) Working Group II, where he gave a talk on global change and natural ecosystems. Later in the month, he attended a meeting of lead authors for the IPCC Working Group I 1995 Assessment. Jerry is serving as convening lead author for the 1995 chapter on terrestrial ecosystems: responses to global environmental change and feedbacks to climate.

Calendar of Other Conferences and Workshops
Ed Rastetter attended “Science Camp 5,” a workshop on carbon and nitrogen cycles in terrestrial ecosystems held at Captiva Island, Florida, in mid January. In April, he participated in a modeling workshop for the Long-Term Intersite Decomposition Experiment Team (LIDET) project in Fort Collins, Colorado.

In February, Knute Nadelhoffer participated in a workshop in Athens, Georgia, sponsored by the Environmental Protection Agency. The topic was trace gas fluxes in the Arctic.

Joe Vallino traveled to Sofia, Bulgaria, in March to attend a NATO workshop on ecosystem modeling for the Black Sea where he gave a talk titled “A Bioenergetic Approach to Modeling Microbial Food Webs.” He made a similar presentation at Harvard University in April.

Linda Deegan was invited to speak at the New England Environmental Conference on the future of New England fisheries, held at Tufts University in March.

Gus Shaver attended the annual workshop of the International Tundra Experiment, which was held in St. Petersburg, Russia, in March. He gave a talk on short-term versus long-term controls on primary production in arctic ecosystems.

Anne Giblin participated in an interdisciplinary meeting on constructing a nitrogen budget of the North Atlantic, held on Block Island in May. Sponsored by the Scientific Committee on Problems of the Environment, the workshop will result in a special issue of Biogeochemical Cycles.

During May, Jerry Melillo helped to organize a planning workshop in Manaus, Brazil, for ecological programs in the Amazonian Basin. The workshop was sponsored by the U.S. National Aeronautics and Space Administration (NASA) and Brazilian federal and state agencies. He also presented an overview of the effects of deforestation on biogeochemical cycles. Earlier in the month, he gave a talk on modeling the response of terrestrial ecosystems to global change at the Earth Systems Modeling Symposium in Washington, D.C., sponsored by the U.S. Office on Global Change.

During June, Jerry traveled to Venice, Italy, to attend a meeting of the Massachusetts Institute of Technology Joint Program on Climate Change, where he gave an overview talk on modeling the response of terrestrial ecosystems to global change.

Dave Kicklighter attended the first Net Primary Production Modeling Comparison Workshop in Potsdam, Germany, during July, where he made a presentation on the MBL Terrestrial Ecosystem Model (TEM). The workshop was held under the auspices of the IGBP Global Analysis, Interpretation and Modelling (GAIM) project.

Knute Nadelhoffer traveled to Göttingen, Germany, in September to participate in a meeting of the International Nitrogen Saturation Experiment (NITREX). During the same month, Jerry Mellilo attended a meeting of the Swedish Nature Protection Board in Abisko, where he gave a lecture on soil warming and CO₂ fertilization in arctic ecosystems.

Ed Rastetter attended a NATO Advanced Research Workshop on forests and the carbon cycle, held in Banff, Alberta, during September. In October, he participated in a workshop at the Desert Research Institute in Reno on fostering collaboration among modelers and between modelers and field researchers interested in responses of terrestrial ecosystems to changes in CO₂ and climate.

Bruce Peterson gave a lecture on the impact of climate change on the coastal zone at the International Petroleum
Institute's Environmental Conservation Association meeting in October. The three-day workshop was held at Woods Hole Oceanographic Institution. Jerry Melillo, a member of the association's steering committee, made a presentation on global change and natural ecosystems at the meeting.

Xiangming Xiao, Dave Kicklighter and Dave McGuire participated in Global Change Forum VII at Massachusetts Institute of Technology in October. The focus of the three-day conference was on economic components of climate policy analysis.

John Hobbie attended a workshop on global change in the Arctic, held in Stockholm, Sweden, in October. The workshop was sponsored by the International Arctic Science Council. During November, John attended a workshop on dissolved organic carbon, ultraviolet-B exposure and freshwater systems in Jasper National Park in Canada.

Bruce Peterson gave a lecture on riverine processes at a workshop on modeling the delivery of terrestrial materials to freshwater and coastal ecosystems at the University of New Hampshire in December. Dave Kicklighter made a presentation on the structure and uses of the Terrestrial Ecosystem Model. John Hobbie contributed an overview of the NSF ITER and LMER programs.

Contributions to Policymaking
Jerry Melillo was invited to the White House in February to brief Vice President Gore and other government officials on climate change, ecosystem responses and biodiversity. Later in the spring, he visited Washington, D.C. twice to make presentations on the response of terrestrial ecosystems to climate change before the President's Council on Sustainable Development.

Anne Giblin participated in a National Forum on the Environment and Natural Resources Research and Development held in Washington, D.C. in March. Sponsored by the National Academy of Sciences, the forum brought together scientists, social scientists, federal administrators and representatives of industry and non-profit organizations to discuss priorities for policy-related research. Anne served on the subcommittee for water resources and coastal and marine environments.

Meetings
Chuck Hopkinson was invited to make a presentation at the annual meeting of the American Chemical Society, held in San Diego, California, in March. His talk was on the dynamics of dissolved organic carbon during spring bloom conditions on Georges Bank.

Bruce Peterson and Donna DeAngelo of the University of Georgia organized a session titled "Models of Lotic Systems" for the North American Benthological Society meeting, held May 24 to 27 in Orlando, Florida. Bruce gave a talk on modeling nitrogen cycles in rivers.

The Ecosystems Center was well represented at the Ecological Society of America annual meeting, held in Knoxville, Tennessee, during August. Loretta Johnson presented a poster on the effects of enhanced drainage and elevated temperature on carbon balance in tussock tundra microcosms. Chris Neill gave a paper on changes in soil carbon and nitrogen stocks following conversion of forest to pasture in the Brazilian Amazon. Bob McKane made a presentation on the effects of changes in climate and CO2 on carbon storage in arctic tundra. Dave McGuire spoke on parameterizing equilibrium responses of soil carbon to climate change. Yude Pan made a presentation on the climatic sensitivity of net primary production estimates with the MBL TEM model. Knute Nadelhoffer gave a paper on the effects of warming and nutrient additions on ecosystem respiration and methane fluxes along a tundra moisture gradient.

Also in August, Anne Giblin gave a paper on the stable isotopic composition of sulfur in lake sediments at the American Chemical Society meeting in Washington, D.C.

At the annual meeting of the Soil Science Society of America, held during November in Seattle, Loretta Johnson and Bob McKane made presentations on the partitioning of nitrogen uptake in an arctic tussock tundra ecosystem. Mathew Williams gave a talk on multi-dimensional sensitivity analysis in modeling nutrient uptake. Kathy Newkirk and Chris Catricala presented a poster on the use of time domain reflectometry in the Harvard Forest soil-warming experiment. Kathy also moderated the concurrent annual meeting of the Association of Women Soil Scientists.

Lectures and Seminars
Early in January, Ed Rastetter visited the U.S. Forest Service's Rocky Mountain Experimental Station in Fort Collins, Colorado, where he gave a seminar on the role of terrestrial nitrogen cycles in constraining ecosystem responses to changes in CO2 and climate.

Knute Nadelhoffer was invited to the University of Connecticut in April to give a seminar on using stable isotopes as tracers at ecosystem scales to identify nitrogen sinks in New England forests. He also spoke on using 15N tracers to characterize nitrogen retention mechanisms in forest ecosystems at the University of New Hampshire in
October and at the Institute for Ecosystems Studies in Millbrook, New York, in November.

In June, Chris Neill gave a talk at the Chesapeake Biological Laboratory on carbon and nitrogen cycling after change in land use in the Brazilian Amazon. Chuck Hopkinson spoke on land-use changes and the estuary at “Oceans at Risk,” an environmental conference for journalists held in Woods Hole.

In November, Ed Rastetter lectured to graduate students in the Tufts University Department of Urban Planning on the responses of terrestrial ecosystems to changes in CO2 and climate and their role in the global carbon budget.

During a visit to Sweden in late November to participate as “opponent” in the examination of a doctoral candidate in Uppsala, Knute Nadelhoffer gave seminars at departments of the Swedish University of Agricultural Science. He spoke on the use of stable isotopes in forest ecosystem studies at the Department of Ecology and Environmental Studies in Uppsala and on what determines fine root biomass and turnover in forest ecosystems at the Department of Forest Ecology in Umeå.

Committee memberships

Staff members at The Ecosystems Center serve on a wide variety of local, national and international boards, committees and panels. Jerry Melillo serves as vice-chairman of the IGBP Scientific Committee and as a member of the steering committee for GCETE, a core project of IGBP. He was recently appointed to the Department of Energy’s Health and Environmental Research Advisory Committee for a three-year term.

Jerry is a member of the advisory committee for the Atmospheric Chemistry Division of the National Center for Atmospheric Research and the scientific steering committee for the NIGEC Northeast Regional Center. He also serves on the National Research Council (NRC) Committee on Research and Peer Review in the Environmental Protection Agency (EPA) and as a member of the public affairs committee of the Ecological Society of America (ESA).

John Hobbie is a member of the Arctic Global Change Working Group of the International Arctic Science Committee. He is secretary of the Arctic Research Consortium of the United States (ARCUS) and a director of the Lloyd Foundation for Environmental Studies in South Dartmouth, Massachusetts.

John also serves on the NAS/NRC committee responsible for reviewing the EPA Environmental Mapping and Assessment Program (EMAP) and is a member of the LTER executive committee. He heads two NSF committees, serving as chairman of the LMER coordinating committee and chairman of the scientific steering committee for the Land-Atmosphere-Ice Interactions section of the Arctic Systems Science program.

Gus Shaver is a member of the ESA editorial board. He serves on a review committee for the Electric Power Research Institute and on the NSF Ecosystem Studies panel. He is a member of the Arctic Research Consortium (ARCUS) council.

Chuck Hopkinson is a member of the LMER coordinating committee and serves on an NSF-sponsored committee that is addressing the problem of measuring dissolved organic matter in the ocean. He is also a member of the Waquoit Bay Fellowship Selection Committee of the Boston University Marine Program. He served on the program

Visiting Scientists

On sabbatical leave from the Department of Environmental Sciences at the University of Virginia, Jim Galloway spent 10 months as a visiting scientist at The Ecosystems Center. During the course of his visit, he gave several lectures on the impact of human activities on the global nitrogen cycle.

Göran Agren of the Swedish University of Agricultural Sciences in Uppsala spent two months at the center working with Ed Rastetter on modeling carbon-nitrogen interactions in vegetation and soils.

Joe Landsberg of the Commonwealth Scientific and Industrial Research Organization in Australia spent a month as an MBL library reader working on a book on tree canopy processes.

Brazilian scientists Marisa de Cássia Piccolo and Carlos Cerri, director of the Centro de Energia Nuclear na Agricultura (CENA), University of São Paulo at Piracicaba, visited for two weeks during the summer to work with Chris Neill, Paul Steudler and Jerry Melillo on data from joint research projects in the western Amazon Basin.

Supported by an MBL Associates fellowship, Italian scientist Christina Zago from the Instituto Per Lo Studio Della Dinamica Delle Grande Masse in Venice returned to Anne Giblin’s laboratory for a second summer to work on modeling the effects of pollutants from Boston Harbor. A short report on Christina’s 1993 research on predicting the toxicity of Boston Harbor sediments was published in the Biological Bulletin.

Christina Zago
committee for the 1994 Ocean Sciences AGU/ASLO meeting, held in February.

Anne Giblin serves on the panel that reviews the National Oceanic and Atmospheric Agency's Coastal Ocean Program. She is chairman of the section on environmental quality. She has also joined the council of delegates for the American Association for the Advancement of Science section on biological sciences.

Linda Deegan serves on the executive committee of the Estuarine Research Federation. She is also a member of the Plum Island Sound Minibays Project Technical Advisory Committee of the Massachusetts Audubon Society and of the National Strategy Planning Committee of the American Fisheries Society.

Kathy Newkirk is the current editor of the newsletter of the Association of Women Soil Scientists. She is also a member of the association's executive committee.

Joe Vallino serves as an external advisor for a NATO project on developing ecosystem models for management of the Black Sea.

Yude Pan is the acting secretary and secretary-elect of the Asian Study Section of ESA.

MBL boards and committees

Ecosystems Center staff members serve on a number of MBL boards and committees. In August, Knute Nadelhoffer was chosen to serve for two years as the center’s member of the MBL Science Council, a committee of scientists that represent the laboratory’s corporation of members to the trustees and administration. He replaces John Hobbie, who completed his term on the council last summer. John is also chairman of the laboratory safety committee and a member of the committee for the MBL/WHOI Joint Library.

Jerry Melillo serves as a member of the MBL’s research space committee. Knute has recently completed a term as the center’s representative to the Council of Year-Round Scientists. Chuck Hopkinson is chairman of the laboratory’s radiation safety committee. Linda Deegan is a member of the marine resources committee. Ed Rastetter chairs the computer users committee. Paul Steudler serves on the research services committee and the safety committee. John Helfrich serves on the staff council of the MBL.

Anne Giblin is chairman of the MBL’s diving control board, and Jane Tucker is a member. Anne also serves on the MBL’s fellowship committee and the Lakian Fellowship committee. Jane is also a member of the Hay Committee, an employee group that decides on job classifications at MBL. Anne took on a new task this year as well, serving as co-chairman of the program committee for the MBL general scientific meetings in August.

Promotions

Ed Rastetter and Linda Deegan received word early in the year of their promotions to the rank of associate scientist. Ed joined the center as a postdoctoral research associate in 1986. He received his undergraduate degree in mathematics and zoology from the University of Hawaii and his doctorate in environmental sciences from the University of Virginia in 1986.

Linda came to the center in 1989 from the University of Massachusetts at Amherst, where she was an assistant professor in the Department of Forestry and Wildlife Management. She received her undergraduate degree in biology from Northeastern University in 1976, her masters degree in zoology from the University of New Hampshire in 1979 and her doctorate in marine sciences from Louisiana State University in 1985.

Paul Steudler was made a senior research specialist at the same time. He received his undergraduate degree in chemistry from Ohio University in 1965 and his masters degree in organic chemistry from the University of Oklahoma in 1973. Paul joined the center as a research associate in 1975.

Longest Field Trip of the Year

John Hobbie, a regular summer visitor to the Arctic, returned to Antarctica in February for the first time in many years as a member of an NSF team charged with reviewing the Palmer Station LTER site. After a U.S. Air Reserve flight from Punta Arenas, Chile, to King George Island, the team traveled aboard R/V Polar Duke to Palmer Station on the Antarctic Peninsula for the three-day site visit. Highlight of the trip was a visit to a penguin rookery, where the reviewers helped to round up juvenile penguins for weighing.

Michele Bahr

John Hobbie and friend

30
Seminars at The Ecosystems Center during 1994

January

11 Candace Oviatt, University of Rhode Island, “Biological considerations in marine enclosure experiments: Challenges and revelations.”

February

1 Gaius Shaver, Marine Biological Laboratory, “Plant diversity and the regulation of primary production in Alaskan arctic tundras.”
15 David Caron, Woods Hole Oceanographic Institution, “Fitting mixotrophy/symbiosis into the microbial food loop paradigm.”

March

1 Dean Moosavi, University of New Hampshire, “CH$_4$ oxidation as a control on CH$_4$ flux from Alaskan wetlands: A comparison between North Slope communities and taiga communities.”
8 Jeffrey Cornwell, University of Maryland Center for environmental and Estuarine Studies, “Biogeochemical controls on the benthic-pelagic exchange of phosphorus in Chesapeake Bay sediments.”
15 Brad Seely, Boston University, “Retention and cycling of atmospherically deposited N in a forested, coastal watershed on Cape Cod.”
22 Gary King, University of Maine, “Regulation of methane consumption by soils.”
29 Peter Groffman, Institute of Ecosystem Studies, “Nitrogen dynamics in riparian forests.”

April

12 Charles Canham, Institute of Ecosystem Studies, “Spatially explicit dynamics in forests: Linkages between population biology and biogeochemistry.”
26 Gordon Bonan, National Center for Atmospheric Research, “Coupled energy, water and CO$_2$ exchange for climate system models.”

May

3 Raymond Bevort, University of Wales at Cardiff, “Fish population biology and fisheries research.”
10 Hal Caswell, Woods Hole Oceanographic Institution, “Second derivatives of growth rate: How can you calculate them and why would you care?”
17 Michael Goulden, Harvard University, “Ecosystem net exchange of carbon at Harvard Forest: Response to climate change on interannual time scales.”

September


October

4 Edward Rastetter, Marine Biological Laboratory, “Validating ecosystem models of long-term responses to global change and other forms of self-delusion.”
11 Jana Compton, Harvard University, “Phosphorus cycling in N$_2$-fixing red alder stands.”
18 Rick Murray, Boston University, “Fe limitation of biogenic production in the equatorial Pacific? A paleochemical view of the last six glacial periods.”

November

1 Ruth Yanai, State University of New York at Syracuse, “Nutrient cycling in northern hardwoods: Focus on the forest floor.”
8 Timothy Ford, Harvard University, “Coastal pollution and public health: Current concerns and future directions.”
15 Stuart Findlay, Institute of Ecosystem Studies, “Influence of subsurface exchange on stream ecosystems: Variability within and among systems.”
22 Mark Dornblaser, Marine Biological Laboratory, “Antarctica: A multi-media magical mystery tour.”
29 Slava Epstein, Northeastern University, “Bacterial production versus bacterial consumption in marine sediments: Major disbalance and its causes.”

December

6 Jonathan Cole, Institute of Ecosystem Studies, “Carbon dioxide supersaturation in the surface waters of lakes.”
13 Timothy Fahey, Cornell University, “Response of early successional northern hardwood forest to changes in soil resource availability.”
Staff at The Ecosystems Center during 1994

Administrative Staff

John E. Hobbie
Co-Director
Ph.D., Indiana University

Jerry M. Melillo
Co-Director
Ph.D., Yale University

John V.K. Helfrich III
Research Administrator
B.S., St. Mary's College of Maryland

Suzanne J. Donovan
Executive Assistant
Massachusetts College of Art

Jean A. Monahan
Administrative Assistant
A.B., Coker College

Susan M. Pennington
Administrative Assistant
M.A., University of Wisconsin

Mary Ann Seifert
Administrative Assistant
B.A., Alfred University

Deborah G. Scanlon
Executive Assistant, LMER
Coordination Office
B.A., Syracuse University

Scientific Staff

John E. Hobbie, Senior Scientist
Ph.D., Indiana 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

Brian D. Fry, Associate Scientist
Ph.D., University of Texas

Anne E. Giblin, Associate Scientist
Ph.D., Boston University Marine Program

Charles S. Hopkinson, Associate Scientist
Ph.D., Louisiana State University

Knute J. Nadelhoffer, Associate Scientist
Ph.D., University of Wisconsin

Linda A. Deegan, Associate Scientist
Ph.D., Louisiana State University

Edward B. Rastetter, Associate Scientist
Ph.D., University of Virginia

Paul A. Steudler, Senior Research Specialist
M.S., University of Oklahoma

Mark S. Castro, Research Associate
Ph.D., University of Virginia

A. David McGuire, Research Associate
Ph.D., University of Alaska-Fairbanks

Robert B. McKane, Research Associate
Ph.D., University of Minnesota

Christopher Neill, Research Associate
Ph.D., University of Massachusetts at Amherst

Educational Staff Appointments

David N. Fernandes, Postdoctoral Research Associate
Ph.D., Stanford University

Loretta C. Johnson, Postdoctoral Research Associate
Ph.D., University of Connecticut-Storrs

Yude Pan, Postdoctoral Research Associate
Ph.D., State University of New York, Syracuse

Matthew Williams, Postdoctoral Research Associate
Ph.D., University of East Anglia

Joseph J. Vallino, Postdoctoral Research Associate
Ph.D., Massachusetts Institute of Technology

Xiangming Xiao, Postdoctoral Research Associate
Ph.D., Colorado State University

Technical Staff

Michele P. Bahr, Research Assistant
M.S., University of Hawaii

Jean Monahan, Sue Donovan and Mary Ann Seifert

John Helfrich
Consultants
Francis P. Bowles, Research Systems Consultant
Principal, Research Designs
Ph.D., Harvard University
Margaret C. Bowles, Administrative Consultant
B.A., Bryn Mawr College
Elisabeth C. Schwarzman, Administrative Consultant
M.S., Stanford University
Lee Thomson, GIS Consultant
Principal, Corvis Consulting
M.S., University of Massachusetts at Amherst

Visiting Scientists and Students
Göran Ågren
Swedish University of Agricultural Sciences, Uppsala
James N. Galloway
University of Virginia
Joseph J. Landsberg
Commonwealth Scientific and Industrial Research Organization, Australia
Marisa de Cássia Piccolo
Centro de Energia Nuclear na Agricultura, University of São Paulo, Brazil
Camille Lecat
Université de Technologie de Compiègne, France
Visiting Student

Debbie Scanlon and Mardi Bowles

Andy Ricca


**IN PRESS**


Fry, B. Adding 15N to ecosystem experiments. In: E. Wada and B. Fry (eds.), *Stable Isotopes in Biological Systems*.


Brian Fry
Research Grants in Effect during 1994

I. National Science Foundation

NSF-DEB-8811764
"Harvard Forest: Long Term Ecological Research" (subcontract from Harvard University)
October 1988 - March 1994
Investigators: Melillo, Nadelhoffer, Steudler
$496,583

NSF-DEB-9108329
"Long-Term Intersite Experiments of Leaf and Fine Root Decomposition" (subcontract from Oregon State University)
July 1991 - May 1996
Investigator: Rastetter
$53,492

NSF-DEB-9019055
"Global Change and the Carbon Balance of Arctic Ecosystems: The Importance of Carbon-Nutrient Interactions"
November 1991 - October 1995
Investigators: Shaver, Giblin, Nadelhoffer, Rastetter
$1,246,358

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

NSF-DEB-9205137
"Workshop: CO2 and Climate Change Effects on Plants and Soils"
October 1992 - March 1994
Investigator: Melillo
$62,000

NSF-DEB-9209696
"Ecosystems Nitrogen Status and Trace Gas Fluxes"
March 1993 - August 1994
Investigator: Melillo
$125,000

NSF-DEB-9307888
"Recovery of Terrestrial Ecosystems from Major Disturbance: Contrasts Due to Carbon/Nutrient Interactions"
August 1993 - July 1996
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 1996
Investigator: Giblin
$35,561

NSF-DEB-9408794
"Predicting Forest N Dynamics Using Ecosystem-Scale 15N Tracers"
July 1994 - June 1997
Investigator: Nadelhoffer
$400,000

NSF-DEB-9407829
"An Isotopic Tracer Experiment at the Ecosystem Scale"
October 1994 - September 1997
Investigator: Peterson
$899,358

NSF-DEB-9416807
"Investigating Controls on the Benthic Flux of Nitrogen and Phosphorus from Lake Sediments: A Comparative Ecosystems Approach"
November 1994 - October 1997
Investigator: Giblin
$200,000

NSF-OCE-9218220
"LMER Coordination"
August 1992 - January 1995
Investigator: Hobbie
$222,589

NSF-OCE-9214461
"Plum Island Sound Comparative Ecosystems Study (PISCES): Effects of Land Use and Organic Matter-Nutrient Interactions on Estuarine Trophic Dynamics"
September 1992 - February 1996
Investigators: Hopkinson, Hobbie, Giblin, Deegan
$1,600,000

NSF-OCE-9216897
"Sources of DOC in the Equatorial Pacific Ocean"
October 1992 - March 1994
Investigator: Fry
$35,000

NSF-OCE-9416294
"Coordination for Land Margin Ecosystems Research (LMER)"
September 1994-August 1995
Investigator: Hobbie
$171,947

NSF-OCE-9419078
"SCOPE Workshop on Estuarine Synthesis"
September 1994 - August 1995
Investigator: Hobbie
$55,000

Georgia Murray, Jim Laundre and summer student Mark Waldrop
NSF-OPP-9024188
“Freshwater Systems”
August 1991 - September 1995
Investigators: Hobbie, Peterson, Deegan, Rastetter
$2,547,508

NSF-OPP-9318529
“Attaining Ecological Understanding at the Regional Level: The Kuparuk River as a Model Arctic System”
June 1994 - May 1997
Investigator: Hobbie
$474,791

NSF-OPP-9400722
“Controls of Structure and Function of Aquatic Ecosystems in the Arctic”
June 1994 - May 1997
Investigators: Hobbie, Peterson, Deegan, Rastetter
$2,726,000

II. U.S. Department of Energy

DEFG02-92ER61438
June 1992 - May 1995
Investigator: Hopkinson, Fry
$756,908

Northeast Regional Center of the National Institute for Global Environmental Change (NIGEC)
“Atmosphere-Biosphere Feedback Mechanisms in Forest Ecosystems”
October 1990 - June 1995
Investigators: Melillo, Steudler
$734,120

Northeast Regional Center of the National Institute for Global Environmental Change (NIGEC)
“Biological Controls on Soil Organic Matter Quality and Quantity” (subcontract from Harvard University)
July 1993 - October 1995
Investigator: Nadelhoffer
$19,908

III. National Aeronautics and Space Administration

NASA-NAGW-3752
“Land Use Change, Soil Processes and Trace Gas Fluxes in the Brazilian Amazon Basin”
June 1993 - May 1996
Investigators: Melillo, Steudler
$702,000

IV. National Oceanic and Atmospheric Administration

NOAA Sea Grant R/P-56
“Benthic Processing of Sewage Additions: Controls of Denitrification in High Energy Environments”
August 1992 - July 1996
Investigators: Giblin, Hopkinson
$149,000

V. U.S. Environmental Protection Agency

CR-818633-02-0
Current and Future Global Terrestrial Carbon Pool”
September 1992 - September 1995
Investigators: Melillo, Shaver, Hopkinson, Rastetter
$788,873

CR-823606-01-0
“Testing the Estuarine Biotic Integrity Index Across Biogeographic Regions”
October 1994 - September 1997
Investigator: Deegan
$406,557

VI. U.S. Department of Agriculture

USDA-28C2659
“Potential of North American Forests to Function as Carbon Sinks”
September 1992-February 1995
Investigator: Melillo
$53,695

VII. Electric Power Research Institute

EPRI-RP3316-04
“Vegetation/Ecosystem Modeling and Analysis Project”
September 1993 - December 1995
Investigator: Melillo
$289,432

EPRI-94-033
“Carbon Cycle Linkage Project”
(subcontract from the University of New Hampshire)
August 1993 - December 1995
Investigator: Melillo
$53,050

Chris Tholke
Bonnie Kwiatkowski
Leslie Redmond and Amy Nolin
VIII. Miscellaneous

Exxon Corporation
“Education and Research for Latin American/Caribbean Scientists on Trace Gas Fluxes”
December 1988 - December 1994
Investigator: Steudler
$145,000

Exxon Corporation
“Global Change Research”
April 1994 - April 1995
Investigator: Melillo
$50,000

Texaco Foundation
“Texaco Fellowships In Environmental Research”
September 1990 - December 1995
Investigators: Melillo, Steudler
$300,000

Wingwalker Initiatives
“Measurement of Primary Productivity in Buzzards Bay”
May 1991 - December 1994
Investigators: Hobbie, Giblin
$37,843

Massachusetts Water Resources Research Center/SAIC
“Seasonal Determination of Sediment Oxygen Demand and Nutrient Flux in Boston Harbor and Massachusetts Bay”
July 1992 - July 1994
Investigator: Giblin
$84,287

Massachusetts Water Resources Authority G2360-178D/S138
“Harbor and Outfall Monitoring” (subcontract from Battelle Memorial Institute, Columbus Division)
February 1993 - May 1995
Investigators: Giblin, Hopkinson
$260,192

Sweet Water Trust
“Operation of a Field Station”
January 1993 - December 1995
Investigator: Hopkinson
$23,250

Conservation, Food and Health Foundation, Inc.
“Ecological Research Internships in Brazil”
June 1993 - July 1994
Investigator: Melillo
$7,800

Andrew W. Mellon Foundation
“The Microbial Ecology of Biogeochemical Cycles”
“River Basin Modeling”
October 1993 - September 1996
Investigators: Staff
$600,000

Andrew W. Mellon Foundation
“Semester in Environmental Studies in Woods Hole”
November 1994 - October 1996
Investigator: Melillo
$265,000

Massachusetts Institute of Technology CES-462041
“Coupling the MBL Model with the MIT Framework”
March 1994 - February 1995
Investigator: Melillo
$50,000

The Cox Foundation
“Managing Coastal Ecosystems: Understanding the Link Between Upland Management and Fisheries Declines”
April 1994 - March 1996
Investigator: Deegan
$50,000

Sweden: Nature Protection Agency 116-94-Ff
“Ecological Responses to Increases in Carbon Dioxide Concentration and Temperature: A Global Change Study at Abisko, Sweden”
July 1994 - June 1997
Investigator: Melillo
$155,904

Dave Jones

Wilfred Woilheim
The annual operating budget of The Ecosystems Center for 1994 was $5,310,000, almost the same as the previous year. Roughly 75% of the income of the center comes from grants for basic research from government agencies. The other 25%, about $1,327,500, comes from gifts and grants from private foundations, corporations and individuals as well as institutional support for administration and income from the center's reserve and endowment funds.

These non-governmental funds provide flexibility for the development of new research projects, public policy activities and educational programs. More information about sources of support appears in the “Introduction to the Ecosystems Center” and in “Research Grants in Effect in 1994.”

The combined total value of the center's reserve fund and endowment at the end of 1994 was $4,600,000, a decrease of roughly 6% from the 1993 year-end value of $4,900,000. This decrease reflects the general decline in the equity and bond markets during 1994. 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
Robert Sterling Clark Foundation, Inc.
The Clowes Fund, Inc.
Conservation, Food & Health Foundation, Inc.
The Cox Foundation
Charles E. Culpepper Foundation, Inc.
Arthur Vining Davis Foundations
Henry L. and Grace Doherty Charitable Foundation, Inc.
Electric Power Research Institute
Exxon Corporation
Max C. Fleischmann Foundation
The Ford Foundation
General Electric Foundation
Grace Foundation, Inc.
The Grass 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.
Surdna Foundation, Inc.
Sweet Water Trust
Texaco Foundation
Wingwalker Initiatives