CREDITS

Editor in Chief: John E. Hobbie
Managing Editor: Deborah G. Scanlon
Consulting Editor: Margaret C. Bowles
Published by: Promotional Planning Service, Inc.
Printed by: American Printing, Inc.
Graphics by: Members of The Ecosystems Center staff
Cover Design by: Terri J. Svarczkopf

Cover Photography: Top: Pete Raymond wades through tidal salt marshes of the Parker River in northeastern Massachusetts, part of the Plum Island Sound LTER site. Photo by Chuck Hopkinson.
Center: Stephanie Parker, Lynn Stankiewicz, Bruce Peterson, Karen Buzby and Max Holmes under the Alaska oil pipeline en route to field work at the Toolik Lake LTER site. Photo by MaryKay Fox.
Bottom: Chris Neill conducts a nutrient addition experiment in a stream in Rondônia, Brazil. Photo by Linda Deegan.

Printed on recycled paper.
## CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction to The Ecosystems Center</td>
<td>2</td>
</tr>
<tr>
<td>Ecosystems Research, Environmental Policy and Vulnerability Assessments</td>
<td>4</td>
</tr>
<tr>
<td>A Look at the Big Picture: Estimating Plant Production Across an Arctic Watershed</td>
<td>6</td>
</tr>
<tr>
<td>Why is the River so Low in the Summer? Constructing a Water Budget for the Ipswich River Basin</td>
<td>9</td>
</tr>
<tr>
<td>How Does Deforestation Affect the Chemistry of Tropical Streams?</td>
<td>12</td>
</tr>
<tr>
<td>How Old is the Organic Matter that Moves from Land to Ocean?</td>
<td>14</td>
</tr>
<tr>
<td>The Interplay of Modeling and Field Research: Feedbacks between Simulation and Experimental Studies</td>
<td>16</td>
</tr>
<tr>
<td>Semester in Environmental Science: Third Year Brings Largest Class to Date</td>
<td>19</td>
</tr>
<tr>
<td>Education at The Ecosystems Center</td>
<td>21</td>
</tr>
<tr>
<td>Ecosystems Center Events and Activities</td>
<td>24</td>
</tr>
<tr>
<td>Seminars at The Ecosystems Center During 1999</td>
<td>32</td>
</tr>
<tr>
<td>Staff at The Ecosystems Center During 1999</td>
<td>33</td>
</tr>
<tr>
<td>Publications During 1999</td>
<td>35</td>
</tr>
<tr>
<td>Grants for Research and Education in Effect During 1999</td>
<td>39</td>
</tr>
<tr>
<td>Sources of Support for Research and Education</td>
<td>43</td>
</tr>
</tbody>
</table>

Top: Michele Bahr using ice auger on Toolik Lake. Photo by Jim Laundre. Bottom: Annika Nordin labeling Arctic tundra with $^{15}$N tracer. Photo by Inger Kappel-Schmidt.
The Ecosystems Center, founded in 1975, is the largest year-round research program of the Marine Biological Laboratory (MBL). Its mission is to investigate the structure and functioning of ecological systems and their response to changing environmental conditions, to apply the resulting knowledge to the preservation and management of natural resources, and to educate both future scientists and concerned citizens.

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

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

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

The Ecosystems Center staff currently includes 13 principal investigators and 48 research and administrative staff members. The annual operating budget for 1999 was $8.3 million. Although research programs are funded primarily by grants from federal and state agencies, additional support for research and education comes from private foundations, corporations and individual donors.

In 1999, The Ecosystems Center continued its educational venture, the Semester in Environmental Science. The program, launched in the fall of 1997, brings undergraduates from a consortium of small liberal arts colleges and universities to the MBL campus for an intensive introduction to environmental sciences from the perspective of ecosystem ecology. In 1999, the number of participating colleges rose to 37. The semester program is supported by the Andrew W. Mellon Foundation and several other private foundations and donors.

What Is An Ecosystem?

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

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

Studying the Effects of Change on Ecosystems

Our knowledge of the complex relationships among organisms, processes and controls in ecosystems provides insight into questions about the effects of human activities on the functioning of ecosystems. How do changes in farming practices and residential patterns affect the flow of nutrients and organic matter into New England estuaries and alter the food web in coastal waters? What happens to the production of commercially valuable fish as a result? How will the change in location of Boston's sewage outfall affect organisms in the sediment of Boston Harbor?

Research conducted at The Ecosystems Center addresses such questions in ecosystems around the globe. How will
the clearing of tropical forests change the amount of carbon dioxide released into the atmosphere? What will the effect be on global climate? How will change in temperature and atmospheric gas levels affect the productivity of forests? What effects do introduced species or increased use of fertilizers for agriculture have on the ecosystems of tropical lakes and streams?

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

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

Research at The Ecosystems Center

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

Center scientists work at a wide range of field sites. Coastal studies are carried out at the Essex County Greenbelt Association’s station on Plum Island Sound. Studies of temperate forests are conducted at Harvard Forest in central Massachusetts and at the Bear Brook Watersheds in eastern Maine. On Martha’s Vineyard, researchers are working with the Nature Conservancy to recreate a former fire-controlled grass and shrubland ecosystem. Work on coniferous forests of the Pacific Northwest is carried out with colleagues at Oregon State University. Researchers studying tropical systems work with Brazilian colleagues from the Centro de Energia Nuclear na Agricultura of the University of São Paulo at field sites in the western Amazon and at field sites in the central Amazon with researchers from the Instituto Nacional de Pesquisas Espaciais. 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.

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

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

Support for Research and Education

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

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

Applying Ecological Knowledge to Policy and Management

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

Over the 25 years since The Ecosystems Center was founded, a principal focus of our research has been on the effects of human activities on the natural cycling of carbon, nutrients such as nitrogen and phosphorus, and water, all essential to sustaining life. Our approaches include detailed studies of biogeochemical processes such as photosynthesis and decomposition, the construction of whole-ecosystem budgets of the flows of energy and material, the use of remote-sensing data and geographic information systems to help us extrapolate from the results of small-scale studies to larger regions, and simulations with models to help us synthesize our findings and predict ecosystem responses to changing environmental conditions.

The reports that follow show how we use these approaches. Three of the studies described focus on ecosystem processes. Knute Nadelhoffer explains how he and his colleagues are combining field studies with modeling simulations to advance our understanding of the degree to which disruptions of the nitrogen cycle are affecting the process of carbon storage in plants and soil. Linda Deegan and Suzanne Thomas show how studies of nutrient levels in small streams and pastures in the Brazilian Amazon are adding to our knowledge of the environmental consequences of tropical deforestation. And postdoctoral scientist Peter Raymond, working with John Hobbie and Charles Hopkinson, describes the use of carbon-14 dating techniques to study the origins, age and transformations of dissolved and particulate organic carbon in several East Coast rivers.

Charles Hopkinson reports on the construction of a water budget for the Ipswich River watershed that is intended to help explain why river flow is so low during the summer months. He and his colleagues are using a mass-balance approach to determine how both natural processes such as evapotranspiration and the diversion of water for human use affect the water cycle in the Ipswich River Basin.

Matthew Williams and his colleagues draw on small-scale field experiments, modeling simulations, remote-sensing data and geographic information technology to estimate photosynthesis and thus plant production across the Kuparuk River Basin in Alaska. Their approach allows them to account for the effects of diversity in the landscape in making a basin-wide extrapolation of a fundamental ecosystem process.

In addition to conducting basic ecosystems research, Ecosystems Center scientists use their knowledge to provide policymakers and resource managers with a sound scientific foundation for making decisions on environmental issues. We have provided expert advice on local issues such as the preservation of salt marshes, the effects of nitrogen enrichment on the structure and functioning of estuarine ecosystems, the capacity of forest vegetation to take up nitrogen from sprayed effluent at the Falmouth Sewage Treatment Facility, and the restoration and management of the Massachusetts Military Reservation to encourage biodiversity and minimize the impact of training activities on the surrounding environment.

At the regional level, we have assisted policymakers and other stakeholders with information on the potential environmental consequences for both Boston Harbor and Cape Cod Bay of relocating the Boston sewage outfall. We have also contributed to the growth of public knowledge about the effects on estuaries of changing land-use patterns in the coastal watersheds of New England.

For more than a decade, scientists around the world have influenced policymaking through the scientific assessment of links between human activities and environmental changes. The first major assessment, which linked chlorofluorocarbon use in aerosols to stratospheric ozone depletion, led to an apparently successful international effort to protect the ozone layer. The global assessment process for climate-change issues was formalized with the establishment of the Intergovernmental Panel on Climate Change (IPCC) under United Nations charter in the late 1980s. Ecosystems Center scientists have served as lead authors on chapters in the periodic summaries that the IPCC publishes and have taken part in peer reviews of IPCC reports. Their research contributes to the findings cited in these reports.

IPCC assessments have focused primarily on the natural and anthropogenic, or manmade, causes of climate change as well as on the magnitude of changes and the rates at which they occur. They have paid less attention to the effects of climate change. This focus is beginning to change with the growing public interest in the vulnerability of ecological and social systems to alterations in the Earth's climate. Managers and policymakers are now demanding the results of vulnerability assessments.

Vulnerability assessments are relatively new to ecologists. The vulnerability of a system, community or individual species depends upon the number and magnitude of potential stresses and upon the possibility of mitigation or adaptation to these stresses. The vulnerability of agricultural ecosystems to climate change is useful as an example to illustrate how the parts of the vulnerability concept fit together.

Crop models that integrate plant and soil processes, including photosynthesis, carbon allocation between roots and shoots and soil moisture, project low yields for soybeans in the southeast United States if the climate of the region becomes hot and dry enough to subject plants to stress from drought. Our understanding of the climate system suggests that mitigation actions that reduce carbon dioxide emissions into the atmosphere could lead to less frequent and less severe drought in the Southeast. Possible adaptive measures include changing planting times to avoid the hottest and driest months, planting drought-resistant varieties and increasing soil organic matter through crop-residue management to increase soil water-holding capacity. These actions could reduce crop sensitivity to climate change.

Assessments such as the ongoing National Assessment of Climate Change Impacts on the United States have shown that vulnerability depends inherently on scale. The range of beneficial and harmful effects grows wider as the focus shifts from the nation as a whole to regions or specific loca-
tions. This shift occurs in part because climate change is not expected to occur uniformly throughout the world. We can use another agricultural example to illustrate this point. For the set of hotter and drier climate scenarios examined in the National Assessment, wheat yields are likely to increase at the national level for much of the 21st century. However wheat yields in western Kansas, a key breadbasket region, are projected to decrease because of soil moisture stress.

What does this scale-dependent perspective on vulnerability imply for the design of assessments to help society deal with the effects of climate change? It suggests that assessments will have to go beyond the global and continental-scale analyses undertaken by the IPCC. Regional and subregional analyses are required if we are to achieve a comprehensive understanding of the vulnerability of ecological and social systems to climate change.

Should vulnerability assessments be guided by scenarios that tie human activities such as fossil-fuel burning or deforestation to vulnerabilities? We think the answer is yes. Climate-change scenarios should be developed that link these activities to projected rates and magnitudes of climate change that, in turn, can serve as "inputs" to vulnerability assessments. Possible emissions scenarios combined with climate-simulation models known as General Circulation Models (GCMs) produce a set of plausible climate-change scenarios that can be used in vulnerability analyses.

Two features of this approach are attractive. First, the set of "driving" scenarios will be well defined. And second, because of the structure of the GCMs, the resulting climate scenarios are consistent with what we know about the physics of the Earth. Thus we would not have to deal with physically impossible combinations of earth-system features such as a significantly warmer planet with a slowed hydrological (water) cycle.

Each step in the scenario-building process has uncertainty associated with it. First, there is uncertainty in the greenhouse-gas emission scenarios. We do not know for sure how much carbon dioxide will be released from the burning of fossil fuels in 2010, 2050 or 2100. Second, we are not sure how various parts of the global climate system, such as ocean waters, sea ice, precipitation or clouds, will respond to the accumulation of greenhouse gases in the atmosphere. And third, uncertainties exist in the estimates of the vulnerability of ecological and social systems.

Because of this cascade of uncertainty, some would argue that we can say little about the vulnerability of ecological and social systems to climate change. But this line of reasoning obscures what we know about the relationships between climate, ecosystems and society. Given a defined set of climate conditions, we can say a great deal about the structure and functioning of ecosystems, threshold responses, the role of disturbances such as fire and so on. For example, we know that fish in rivers have defined tolerances to temperature and that their habitat will be destroyed if water temperature exceeds a critical threshold.

Estuaries offer another example. If change in climate reduces the amount of fresh water that flows into an estuary by increasing evaporation and transpiration losses on land, then the salinity of estuarine waters will change, altering the quality of the estuary as a habitat for organisms.

We need a way to present uncertainty in climate-change studies honestly without masking the fact that our knowledge of ecosystem vulnerabilities to climate change is extensive. One way of doing so might be to treat the various components of these studies - emissions, climate projections, and ecosystem vulnerabilities - as separate units, each with its own set of uncertainties. With this approach, which is being proposed for the IPCC's third assessment report, the uncertainties associated with all three parts of climate-change studies would be addressed without obscuring what we know about ecosystem vulnerabilities.

The involvement of ecologists in climate-change assessments that focus on the vulnerability of ecological and social systems will increase in coming years. The mandate will broaden to require consideration of multiple stresses because climate change is occurring concurrently with other ecological and social changes. Partnerships between ecologists and social scientists are essential. In some of The Ecosystems Center's research projects, such as the one being conducted with the Massachusetts Institute of Technology Joint Program on Global Change and the Long-Term Ecological Research project in Plum Island Sound, partnerships between natural and social scientists already exist and will continue to grow. The Ecosystems Center is well positioned to be a strong voice in the national debate on the science and policies of climate change and the larger issues related to a sustainable future for the Earth.
It is not possible to measure photosynthesis remotely at present. Instruments that measure changes in CO₂ concentration associated with photosynthesis must either be attached to individual leaves or positioned to sample the atmosphere above the vegetation. Thus only a very small portion of the landscape can be sampled directly. How can these small-scale measurements be used to guide estimates of photosynthetic activity over a whole river basin?

One way to extrapolate information from small-scale experiments to larger-scale areas is to develop a mathematical model that relates the rate of photosynthesis to the physical and biological characteristics of the landscape. We have used our understanding of the metabolic and physical processes in the foliage of plants to generate a computer simulation model of photosynthesis as it takes place in a collection of leaves representing a plant canopy. We initially applied this model to temperate forest ecosystems. Because the underlying principles of photosynthesis remain the same for all of the higher plants, however, the model should be valid in the Arctic as well.

To see whether our soil-plant-atmosphere model would work in the Arctic, we tested it against independent CO₂ exchange data collected in a variety of tundra ecosystems. Terry Chapin and his colleagues from the University of California at Berkeley had measured whole-ecosystem exchange of CO₂ between plants and soils and the atmosphere in wetland, tussock, heath and shrub tundras. In 1997 Mat Williams and Ed Rastetter visited these sites to collect vegetation samples for analysis to determine leaf
area and foliar nitrogen content. Leaf area determines the amount of light, which provides the energy for photosynthesis, that is absorbed by the foliage. Nitrogen is strongly correlated with the concentration in leaves of rubisco, the most abundant enzyme on earth and the catalyst for the critical reaction in the conversion of CO₂ to sugar.

Our research showed that leaf area and foliar nitrogen values differed by up to 10 times among the vegetation types we sampled, demonstrating the wide variability of the Kuparuk ecosystems. We also found that the amount of leaf area and the amount of foliar nitrogen were strongly correlated in all types of vegetation. Although plant communities vary tremendously across the landscape, this correlation shows us that they are structured in the same way. Their capacities for absorbing light and transforming carbon through photosynthesis are maintained at a relatively constant ratio. Thus the amount of carbon taken up per unit of light absorbed is constant. Such discernible linkages simplify the task of extrapolation for us, because a correlation between two key controls on photosynthesis reduces the amount of independent data we require in order to make regional estimates.

We used our measurements of leaf area and foliar nitrogen, along with local climate data, to predict hourly rates of photosynthesis and thus CO₂ exchange at each site at which Chapin’s group had measured gas exchange. We found that we were able to explain most of the hourly variation in CO₂ exchange, and that we could explain differences among sites in the rates of CO₂ uptake by differences in leaf area and foliar nitrogen (Figure 1). We also found that we could explain differences in CO₂ fluxes among sites on the basis of vascular plants alone. Vascular plants, which have conducting tissue, include grasses, shrubs and trees. Non-vascular plants, such as mosses and lichens, are important components of arctic ecosystems, and their abundance varied enormously among the sites we sampled. But our results suggest that, during the measurement period at least, they were relatively inactive photosynthetically.

After corroborating the model, our next step was to assemble the physical and biological data needed for regional predictions. Tests with the model showed that the most important physical data to collect were daily sunlight measurements and daily maximum and minimum temperatures. The most important biological data were leaf area and foliar nitrogen measurements. There are two approaches to creating the necessary fields or “maps” that describe the variation in time and space of physical and biological characteristics in the Kuparuk Basin. For the physical features, we took data collected at weather stations throughout the basin and estimated values between stations using a computer program. We then tested the accuracy of our estimates by comparing predictions with data from locations not used in generating the estimates. We found that we were able to make accurate, unbiased estimates of temperature and sunlight throughout the basin.

In order to determine the distribution of essential biological features, we used images from an instrument mounted on a National Oceanic and Atmospheric Administration satellite. The instrument, an advanced very high resolution radiometer (AVHRR), records the spectrum of the light reflected from the surface of the earth. Because the chlorophyll in vegetation absorbs light preferentially in the red compared to the near infra-red part of the spectrum, comparing reflectances provides a useful index.

Figure 2: Estimates of peak leaf area index (LAI), a measure of plant cover, and total annual gross primary production (GPP), the summation of all photosynthetic activity by vascular plants, over the Kuparuk River Basin for 1995. The LAI scale shows square meters of leaf area per square meter of ground area; data are derived from remote-sensing measurements of vegetation reflectance and field surveys. The GPP data are derived from the LAI estimations, a relationship between LAI and total foliar nitrogen, and patterns of temperature and sunlight across the basin for May through September 1995. Both maps have a resolution of one square kilometer.
known as the normalized difference vegetation index or NDVI, of the degree of vegetation cover. We found that NDVI measurements from the peak growing season were strongly correlated with estimates of leaf area derived from our field surveys and detailed land-cover maps prepared by Donald Walker and his colleagues at the University of Colorado. We used this correlation to predict leaf area, and foliar nitrogen via the observed relationship between the two, across the landscape with satellite data collected throughout the growing season (Figure 2).

Our final task was to estimate photosynthesis for each day of the growing season and for each location in the landscape. Because the complexity of our model makes it run slowly, we created a much simpler, faster version. We assembled the various data needed to run the model within a geographic information system (GIS), a computer program designed to display and manipulate spatial data. With all the pieces of the puzzle now assembled, we estimated photosynthesis for each day and each location within the GIS (Figure 2). Our results show how much rates of photosynthesis and thus gross primary production vary from one area to another within the Kuparuk Basin. They underscore the need to account for heterogeneity carefully in generating regional estimates.

How can these regional estimates be corroborated? Checking results against independent data is a crucial step in any modeling exercise. In this case, no suitable regional data set exists. Therefore we plan to carry out a corroborative exercise with data on evapotranspiration, another ecosystem process, rather than on photosynthesis.

Evapotranspiration, the loss of water through evaporation from the land surface and transpiration through leaves, is closely linked to photosynthesis. As vascular plants take up CO₂ from the atmosphere, they release water from the humid interior of foliage into the dryer atmosphere. These linked processes are simulated within our model. But we also know that non-vascular plants play a major role in the flow of water from land surface to atmosphere in the Arctic; mosses release water like a giant evaporator. Once we are able to incorporate the dynamics of evaporation from mosses into the model, we can use our scaling approach to estimate evapotranspiration throughout the basin.

If we can link these estimates to precipitation data and combine them in a model of water flow across the landscape, we should then be able to simulate the discharge of water from the mouth of the Kuparuk River, which drains the watershed. Long-term records exist for the Kuparuk River discharge. These data can provide an independent test of our ability to extrapolate rates of evapotranspiration from local measurements to the whole landscape. Because evapotranspiration and photosynthesis are so tightly linked in terrestrial ecosystems, corroboration of our evapotranspiration model will enhance confidence in our model of photosynthesis in the Kuparuk Basin.
Why is the River So Low in the Summer? Constructing a Water Budget for the Ipswich River Basin

Articles and photos featuring sun-dried fish lying on the cracked mud of dry stream bottoms have appeared regularly in local newspapers over the last several years. Scenes from the arid southwest? Evidence of changing climate from around the globe? These stories come instead from our own back yard. They describe the low-water conditions that occur on a seasonal basis in the Ipswich River in northeastern Massachusetts.

Why does river flow fall so low in the summer? Are the causes natural or the result of human activity? Local, state and federal agencies are investigating the phenomenon, searching for causes and remedies. Ecosystems Center researchers Luc Claessens, Charles Hopkinson, Edward Rastetter and Joseph Vallino, Bates College student Susannah Canfield, and Clark University scientist Gil Pontius have joined in the effort by examining the effects of change in land use, municipal water use and climate on the water cycle in the Ipswich River watershed.

Examination of United States Geological Survey (USGS) records of Ipswich River discharge since 1931 indicate that strong seasonal variation in river flow is the norm. River flow typically varies by more than a hundredfold during the year, ranging from more than 50 cubic meters per second in the spring to less than 0.5 cubic meters per second in the summer. Why is the seasonal variation in river flow so large? Has the pattern become more extreme in recent years? If so, what factors might be responsible?

In our search for answers to these questions, we have taken a watershed approach to analyzing the water (or hydrologic) budget of the region. A watershed is an area of land that collects and drains water into a stream, river or estuary. As functional units of the landscape, watersheds do not necessarily coincide with the political boundaries that set jurisdictional limits for environmental management. Working at the watershed level presents numerous challenges because resource-allocation decisions that affect the hydrologic cycle, such as levels of water use, are generally made within the confines of town, county or state boundaries. The Ipswich River watershed covers parts of Middlesex and Essex counties and contains all or part of 22 cities or towns.

We have constructed water budgets for the Ipswich River watershed for every month from 1931 to the present. In these budgets, precipitation is equal to the sum of evapotranspiration, river discharge, net diversion for human use across watershed boundaries and the change in soil water storage (Figure 1). All components of the watershed budget are reported as depth per unit time, in the same way that precipitation is commonly reported. Thus a millimeter of water per year is equivalent to 400,000 cubic meters per year spread over the entire basin.

Our precipitation data come from the National Weather Service. Evapotranspiration, which includes both evaporation from land and water surfaces and transpiration from vegetation, was calculated using a mathematical model. USGS provided the river flow data. We tabulated diversions of water for human use into and out of the watershed by collecting data from town water departments, the Massachusetts Department of Environmental Protection and the Massachusetts Water Resources Authority. We calculated change in soil water storage as the difference between precipitation and the sum of all the other variables. Because patterns of precipitation runoff, soil water recharge and evapotranspiration are closely related to land use, we also analyzed the long-term record of land-use change in the watershed.

The three largest components of the Ipswich River water budget are precipitation, evapotranspiration and river discharge (Figure 1). Approximately equal portions of precipitation leave the watershed as evapotranspiration (an average of 487 millimeters per year) and river discharge (an average of 536 millimeters per year). Although smaller vol-

---

Figure 1: Average annual water budget for the Ipswich River watershed for the period 1979 to 1988. All measurements are given in millimeters of water per year.
umes are associated with municipal water usage, they are significant. There is a net export of water from the Ipswich watershed for municipal use; nine millimeters of water are imported per year on average, and 82 millimeters per year are exported. Much of the population of watershed towns located outside watershed boundaries, and most of its water is pumped from the ground or drawn from surface water within the watershed. An additional 43 millimeters of water per year, on average, is pumped from the watershed to sewage treatment facilities in adjacent towns and cities, including Boston.

Our monthly water budgets show that the strong seasonal variation in river flow is due primarily to seasonal changes in evapotranspiration rather than to changes in precipitation or in diversions. Evapotranspiration is controlled by seasonal variation in solar radiation, temperature and foliage. During summer when all these variables are at their highest annual levels, evaporation usually exceeds precipitation and groundwater reserves are consumed. Little or no water from precipitation flows into streams during the summer, and river flow decreases. Even though diversions do not change much over the year, they also reduce river flow in the summer. During July, August and September, the volume of water diverted from the watershed is equivalent to that discharged from the river. In upstream portions of the watershed, ground water continues to be pumped in the summer, even when the river dries up.

We examined the long-term record of diversions from the watershed to determine whether their effects on river flow have changed over the years (Figure 3). Amounts of water withdrawn from both surface sources and ground water have increased greatly since 1930, as have the amounts of water exported from and imported into the watershed. Although water for municipal use exported from the watershed represents the largest component of diversion, the amount has not changed substantially over time. The increase in the export of water during the 1960s and 1970s was reversed during the next two decades. Export of waste-

Figure 2: Average monthly figures for major components of the water budget of the Ipswich River watershed for the period 1979 to 1988. As evapotranspiration rises over the first six months of the year, the amount of water stored in the ground is reduced. All measurements are given in millimeters of water per month.

Figure 3: Diversions of water for human use into and out of the Ipswich River watershed from 1931 to 1998.
32%. Agriculture occupies only 7% of the land, and water bodies and wetlands cover 8%.

The present distribution of forms of land use differs substantially from that at the turn of the century (Figure 4). Records indicate that 55% of the land was used for agriculture in 1908 and that most of the remainder was covered in forest. Urban development occupied less than 1% of the total. From 1910 until the 1950s, some 50% of the agricultural land was abandoned and reverted to forest. Urban and residential development increased steadily, especially after 1950. Although the growth of towns and cities was initially at the expense of agriculture, more recently development has taken over forested land. Impervious surfaces increase as urbanization proceeds, with the result that a greater percentage of rainfall runs off directly into streams rather than augmenting the ground water.

Although precipitation, evapotranspiration and river flow in the Ipswich River watershed vary greatly from year to year over the long term, diversions vary relatively little (Figure 5). Both precipitation and diversions have increased somewhat over time, however. Diversions currently represent 15% to 20% of annual stream flow. We would expect that an increase in diversions would be linked to a comparable decrease in stream flow. But the percentage of rainfall that leaves the basin as river discharge has remained constant over time. It is possible that changes in land cover have counteracted the effects of diversion.

The switch from forested lands to residential development could be expected to decrease evapotranspiration, which is linked closely to the total area of evaporative surfaces. These decrease as trees are replaced by paved surfaces and buildings. The switch in land use could also be expected to increase river runoff directly. As impermeable surfaces increase with development, surface-water runoff generally increases.

Our analysis of the water budget for the Ipswich River watershed continues. We are currently trying to determine the combined and interactive effects of land-use change and change in climate variability on evapotranspiration. Because changes in land use can have opposing effects on the water budget, we must replace our direct budgeting approach with more sophisticated modeling simulations. Before we do so, however, we must acquire better data on solar radiation, vegetation canopy height and leaf area, which have a major effect on rates of evapotranspiration and volume of water lost to the atmosphere.

As development and the demand for water increase in the Ipswich River watershed, the seasonal drop in river flow is likely to grow. The Commonwealth of Massachusetts has recently adopted a watershed approach to addressing hydrologic and coastal issues; this decision should help with the management of municipal water usage in the Ipswich basin. We are working closely with the Ipswich River Watershed Association and with the Massachusetts Executive Office of Environmental Affairs to transfer information that we gain about the watershed hydrologic cycle to town planners and decisionmakers. Better knowledge of the linkages between components of the water budget will improve planning for water use, sewage disposal and changes in land use.
HOW DOES DEFORESTATION AFFECT THE CHEMISTRY OF TROPICAL STREAMS?

One of the most prevalent forms of change in both temperate and tropical landscapes is the clearing of forested land for farming or pasture. Nowhere in the world is this change occurring faster than in the Amazon Basin of Brazil, where the states of Mato Grosso, Pará and Rondônia are experiencing some of the highest rates of deforestation in the world. The clearing and change in vegetation from forest to crops or pasture affects the exchange of carbon dioxide between the land and the atmosphere; it also alters the chemistry and biology of ecosystems, including those of the streams that flow through the deforested areas.

Alterations in the chemistry of small streams can lead to similar changes in the large rivers downstream and eventually to nutrient enrichment or depletion and changes in the biology of coastal and oceanic waters. We need to study the chemical and biological processes of small headwater streams, larger streams and rivers if we are to be able to predict all of the consequences of deforestation.

A lesson learned from temperate forests and streams is that nitrogen is tightly bound in forest soils, with the result that the growth of organisms in forest streams is usually limited by lack of nitrogen. Another lesson from temperate forests is that nitrogen is often released from forest soils at higher rates after trees are cleared. Are these lessons valid for tropical ecosystems with different flora and deeply weathered soils?

Ecosystems Center researchers Linda Deegan, Christopher Neill and Suzanne Thomas, along with Brazilian colleagues Reynaldo Victoria, Alex Krusche and Carlos Cerri at the University of São Paulo, are examining the connections between land-use changes and stream ecology by studying streams that drain forests and pastures in the Brazilian state of Rondônia. This state, located in the southwestern part of the Amazon Basin, has experienced an explosive growth in the conversion of forested land into cattle pasture since the early 1980s. By 1997, satellite data showed that 21% of the forested land in Rondônia had been cleared for other uses, primarily cattle pasture.

In our investigation of the ecological effects of this conversion, we study small streams and rivers located on a 50,000-acre cattle ranch named Fazenda Nova Vida. It contains lightly logged forests as well as pasture areas. We are interested in how forest clearing alters the amounts of particulate and dissolved materials that flow into small streams, the concentration of these materials in streams, and the changes that occur as streams increase in size.

In the process of addressing these questions, we made dry-season measurements of dissolved nutrients in small watersheds that were either completely forested or covered in pasture as well as along transects in the small streams that drain them and the larger stream, the Rio Aldeia, that is formed from their confluence (Figure 1). During the dry season, the forest stream (Reach 1) discharges about 20 liters of water per second. It originates in the forest and flows through pasture for about two kilometers before joining the pasture stream. The stream that originates in the pasture (Reach II) is a similar size. After the confluence of the two, the Rio Aldeia (Reach III) flows through a kilometer of forest and then pastureland until it joins the Rio Valha me Deus. Inputs of groundwater increase its size until it has a discharge of about 80 liters per second.

Groundwater samples taken in forests had high concentrations of nitrate, an essential nutrient for plant production, while those from pastures had very low levels of nitrate. These contrasts were mirrored in samples from the streams in the forest and pasture (Figure 2). Tropical forests typically release nitrogen in the form of nitrate into streams, unlike typical temperate forests, which hold tightly to nitro-
gen, as we observed above. Ammonium is also high in both of these Amazon streams, at least compared with those of temperate regions.

A second element, phosphorus, is also necessary for biological activity. We found low concentrations of phosphate in the small stream draining the forest watershed (Figure 2). As Figure 2 also shows, the ratio of dissolved inorganic nitrogen (DIN) to dissolved inorganic phosphorus (DIP) was high in the forest stream. When this ratio is above 16, phosphorus availability limits the rate of certain biological processes, while a ratio below 16 indicates that nitrogen is the limiting nutrient.

As the stream from the forest passes through the pasture, its inorganic nitrogen content drops, indicating that both nitrogen and phosphorus levels are high enough for biological processes such as photosynthesis to take place. We observed the highest phosphate concentrations of the whole study in the small stream that originates in this pasture. It is possible that high amounts of phosphate also enter the forest stream as it passes through the pasture, but that the biological processes remove this nutrient as fast as it enters.

At 4,000 meters downstream, the Rio Aldeia enters a short stretch of forest. We observed a decrease in ammonium and an increase in nitrate in this stretch, evidence of nitrification, the biological process by which ammonium is transformed into nitrate. Nitrate concentrations continue to rise as the stream passes through pasture again, beginning at approximately 4,500 meters. Both nitrate and ammonium concentrations show relatively little change throughout the rest of the study transect to 10,000 meters downstream. Figure 2 also shows data from sampling sites on two larger rivers downstream, the Rio Valha me Deus and the Rio Quatro Cachoeiras, that suggest the possibility of nitrogen limitation, at least in the latter.

One unusual result of this study is the indication of a shift in the limiting nutrient as the stream originating in the pasture joins the stream that starts in the forest. The high amounts of phosphate in our samples from the pasture stream indicate that nitrogen is limiting biological activity in Reach II. But phosphate levels drop downstream, and the more usual phosphorus limitation takes over. Figure 2 shows the increase in the ratio of DIN to DIP from less than 16 to more than 30 in samples taken just a few hundred meters apart.

Our research sets the stage for a detailed study of the ways in which land use and stream processes interact to determine the chemistry of Amazonian streams. Predicting the consequences of land-use change on the larger watersheds of the Amazon Basin will require additional measurements of both in-stream processes throughout the landscape and the mechanisms and rates of flow of dissolved and particulate inorganic nutrients into streams. Understanding these kinds of processes will be important for predicting how the cumulative changes in small watersheds will affect larger rivers and ultimately the Amazon River itself.

Figure 2: Dissolved nutrients measured in forest and pasture streams and in the main channel of the Rio Aldeia downstream. Each point represents the mean of multiple dry-season measurements over four years. The figure also includes measurements at sites on two larger rivers, the Rio Valha me Deus and the Rio Quatro Cachoeiras, shown on Figure 1. Micromolar concentrations of ammonium (NH₄⁺) are given in the top panel, nitrate (NO₃⁻) concentrations in the next, phosphate (PO₄³⁻) concentrations in the next, and the ratio of dissolved inorganic nitrogen (DIN) to dissolved inorganic phosphorus (DIP) in the bottom panel.

Suzanne Thomas
HOW OLD IS THE ORGANIC MATTER THAT MOVES FROM LAND TO OCEAN?

Rivers and estuaries transport huge amounts of organic matter from the continents into the ocean. Some of this organic matter is derived from terrestrial ecosystem processes and some from natural erosion of soils and rocks. But human activities in coastal watersheds have altered these natural patterns, changing the character and amounts of dissolved and particulate materials that flow into coastal waters. It is difficult to obtain a clear picture of how land-use changes have altered the natural flow of materials from the continents to the ocean because we have no baseline data from before human settlement. One way to study the biogeochemical linkages between the continents and the ocean is to determine the age and source of organic matter currently flowing into rivers and estuaries and to investigate the alterations that this organic matter undergoes as it is transported into coastal waters.

Peter Raymond, now a postdoctoral scientist at The Ecosystems Center, conducted a study of the flux of organic matter in three rivers on the East Coast of the United States in collaboration with Ecosystems Center scientists John Hobbie and Charles Hopkinson as part of his doctoral research under James Bauer at the Virginia Institute of Marine Science. These rivers vary greatly in freshwater discharge and in size of the watersheds that they drain. The Hudson River in New York discharges 375 cubic meters of freshwater per second from a watershed that is 21,000 square kilometers in size. The York River in Virginia, with a watershed of 4,350 square kilometers, discharges 70 cubic meters per second. The Parker River in Massachusetts, with a watershed of 609 square kilometers, discharges 11 cubic meters per second. Our studies focus on two pools of material in these rivers and their estuaries: particulate organic matter or POC, which can be caught on a 0.7 micron filter, and dissolved organic matter or DOC, which passes through such a filter.

The organic matter transported from the land into the ocean via rivers and estuaries ranges in age from ancient marine sediments to modern plant material. We age organic matter through the process of "carbon dating," which uses carbon-14 (14C), a radioisotope of carbon created naturally in the upper atmosphere by cosmic ray bombardment. All radioactive isotopes disintegrate over time. The half-life of 14C, the time it takes for half of a given amount of the isotope to decay, is 5,730 years. The 14C content of terrestrial plants reflects that of the atmosphere while they are alive because the plants take up carbon dioxide (CO2) from the atmosphere during photosynthesis. The 14C in living phytoplankton cells in the ocean reflects that of the CO2 dissolved in the water.

Historically the CO2 in the atmosphere has always had the same 14C content. Live plant material is in equilibrium with the atmosphere; therefore living plant material has had the same 14C content. As soon as a plant dies, however, it no longer takes up atmospheric CO2, and the "14C clock" is started. Using the carbon dating method, we compare the amount of 14C we find in a sample of organic material with the amount expected from historic atmospheric levels to determine its age. Radiocarbon data are reported as the per mil (‰) difference (Δ) from a fixed standard, which is the ratio of 14C to total carbon in 19th century wood.

Scientists who use this method to determine the age of organic materials must observe one major caveat. The 14C in atmospheric CO2 was in steady state until the early 1950s, when the nuclear powers released large concentrations of this radioisotope into the atmosphere during the testing of atomic weapons (Figure 1). Samples that contain high concentrations of "bomb" carbon have positive Δ14C values and cannot be dated by this method. Scientists

---

**Figure 1:** Concentrations of 14C in atmospheric carbon dioxide (CO2), taken from a 1997 article by Ingeborg Levin and Bernd Kromer in Radiocarbon. Before the 1950s, 14C levels in atmospheric CO2 were at a steady state created by the production and radioactive decay of atoms in the upper atmosphere. In the 1950s, large amounts of 14C were released into the atmosphere during the testing of nuclear weapons. After the testing ended, levels of 14C gradually diminished as the affected CO2 was taken up by the terrestrial biosphere and the ocean, and more CO2 low in 14C was released with the rise in fossil fuel emissions.
interested in the global carbon cycle, however, are able to use the \(^{14}\text{C}\) released by the bomb tests to trace the movement of carbon on land and in the ocean.

Our study of the three East Coast rivers revealed a striking pattern. The concentrations of \(^{14}\text{C}\) in the POC exported from these rivers are considerably lower than the pre-bomb concentration of \(^{14}\text{C}\) in atmospheric \(\text{CO}_2\) (Figure 2). Our measurements show that the average age of the POC from these rivers is 4,609 years for the Hudson River, 690 years for the York River and 1,210 years for the Parker River. Potential sources of the material with the low \(^{14}\text{C}\) levels include ancient marine deposits, terrestrial soils, pollution from petroleum residues and organic matter residing in clays. We were interested to find, when we were able to make comparisons, that the POC we sampled had significantly lower \(^{14}\text{C}\) values than the DOC (Figure 2). Samples of DOC from the Hudson River showed that carbon in this pool was low in \(^{14}\text{C}\) and could be dated at more than 1,300 years. The DOC samples from the York and Parker rivers, on the other hand, had positive \(^{14}\text{C}\) values. They clearly contained "bomb" \(^{14}\text{C}\), which indicates that most of the carbon in the dissolved organic matter transported by these rivers is less than 50 years old.

We believe that the disparity between the ages of the carbon in the POC and DOC pools is partly a result of the different ways in which carbon in DOC and POC is transported. Terrestrial DOC enters streams and rivers after it leaches into groundwater from soils and decaying leaves. This process occurs with each rain; thus freshly produced dissolved organic matter flows fairly steadily into streams and rivers.

In contrast, POC enters rivers primarily through the physical erosion of soils. Physical erosion tends to occur episodically with larger and more intense storms. When it occurs, however, it can carry deep, old soils containing POC into rivers and streams. Furthermore, once POC enters a river, it can sink to the bottom and remain there until turbulence from a strong storm or flooding carries it farther downstream.

Part of our research is aimed at understanding how organic matter changes in rivers and estuaries. In any ecosystem, some organic matter is broken down by natural populations of bacteria, which consume both POC and DOC. Certain components of newly produced terrestrial organic matter are not decomposed on land. Once this terrestrial organic matter is transported into a river or estuary, however, its environment is drastically altered. It encounters different communities of bacteria and different levels of nutrients, oxygen and light, which may favor the breakdown of organic matter that was not decomposed on land. We conducted incubation experiments with water from the York River to see how bacterial decomposition altered the \(^{14}\text{C}\) values of riverine DOC (Figure 3). We sampled during times of the year when the flow of terrestrial DOC into the river was expected to be high.

During all our incubations, the \(^{14}\text{C}\) values of the DOC pool went down, indicating that bacteria consumed the younger "bomb" carbon preferentially (Figure 3). During our June 1997 incubation, the DOC that remained after the bacteria consumed the rest had a \(^{14}\text{C}\) value of -65 o/oo, which indicates that the carbon in it was more than 500 years old.

These findings show that riverine DOC has two components. The larger one is made up of biologically available (labile) material with high \(^{14}\text{C}\) values, which indicates that the carbon in this material is relatively young. The smaller component of riverine DOC is made up of biologically refractory material with low \(^{14}\text{C}\) values, indicating that the carbon in it is old. As the labile DOC is consumed, we can predict that the remaining DOC will be much older than the average age of the original material. This DOC is more likely to be exported to the ocean.

The age of the carbon in DOC and POC pools in East Coast estuaries varies widely. Our experiments provide preliminary evidence that positive \(^{14}\text{C}\) values associated with young organic matter containing bomb \(^{14}\text{C}\) may conceal pools of much older carbon. Understanding the origins and transformations of organic material as it moves from the land to the ocean is an important step in the development of accurate regional and global carbon budgets.

![Figure 3: Results from three dissolved organic carbon (DOC) utilization experiments performed on filtered fresh water from the York River in 1996 and 1997. Incubations were carried out in the dark. Concentrations of DOC were measured and \(^{14}\text{C}\) values calculated at the beginning and end of each incubation. Values in parentheses indicate the amounts of DOC consumed by bacteria during each incubation. The September and March incubations were each carried out for one month; the June incubation lasted for a year. Bacteria took up 15% of the DOC in the first of these incubations, 8% in the second and 63% in the third.](image-url)
Ecologists tend to divide their methods of conducting research into two broad categories, with field observations and experiments in one category and the construction and use of models in the other. Both approaches have contributed substantially to advances in our understanding of the way ecological systems work. Much of what we know is based upon our observations of ecosystem responses to large-scale disturbances, such as fire, drought, hurricanes or air pollution, or upon experimental manipulations in plots or small watersheds. Such manipulations might include adding fertilizer, increasing acidity, warming soils and vegetation or increasing levels of greenhouse gases such as carbon dioxide (CO$_2$). The use of models to simulate ecosystem responses to changing conditions helps us gain insight into the results of ecological processes that occur over decades or longer time periods and across large regions such as major drainage basins, continents or Earth itself. Modeling simulations also allow us to predict responses of ecosystem processes to a range of perturbations that we cannot reproduce in a field study.

Ecosystems Center researchers and their colleagues are increasingly combining modeling and field experiments in order to obtain new insights into ecosystem dynamics. The broad range of research skills and interdisciplinary perspectives of center investigators and their collaborators facilitates this approach. The goal of one such project at the center is to determine how increasing rates of nitrogen deposition are affecting the amount of CO$_2$ that plant and soil processes remove from the atmosphere. In this project, center researchers Knute Nadelhoffer, Martha Downs, Patricia Micks and Benjamin Colman have been using a stable isotope to follow the movement of nitrogen added to New England forest plots in the early 1990s.

Nitrogen-15 ($^{15}\text{N}$), a stable isotope of nitrogen that is rare in nature compared to $^{14}\text{N}$, is taken up by plants and soils in the same way as the more abundant isotope. When $^{15}\text{N}$ is added to an experimental plot in a forest, its movement through the ecosystem can be traced by measuring the $^{15}\text{N}$ in plant and soil samples with a mass spectrometer. Thus $^{15}\text{N}$ is a useful tracer with which to investigate the pathways nitrogen follows as it moves through ecosystems.

We are using $^{15}\text{N}$ as a tracer to test the hypothesis that forests are being inadvertently fertilized by elevated levels of nitrogen deposition from the atmosphere. The compounds involved include nitrogen oxides produced by the burning of fossil fuel and ammonium produced by the use of fertilizers. We want to know about the fertilizing effect of nitrogen deposition on forests in temperate regions for a number of reasons. One of the most important is that this process has the potential to stimulate tree growth and therefore the uptake of as much as a fourth of the CO$_2$ released into the atmosphere through fuel burning and deforestation. This level of uptake would require, however, that most of the nitrogen deposited on forests end up in the woody biomass of trees. If most of the nitrogen deposited on forests enters slowly cycling organic-matter pools in the soil or is leached from the forest as nitrate, the elevated levels of deposition would not increase tree growth and carbon removal from the atmosphere.

Ecosystems Center researchers have been investigating the effects of adding nitrogen to forest plots in Massachusetts and Maine for more than a decade. At the

![Figure 1: Modeled and measured recoveries of $^{15}\text{N}$ tracers in foliage on regularly fertilized plots in oak and red pine forests at the Harvard Forest Long-Term Ecological Research site in Petersham, Massachusetts. Tracers were added in 1991 and 1992 in the form of ammonium ($\text{NH}_4^+$) or nitrate ($\text{NO}_3^-$) ions. Model results from TRACE (version 2.2) are shown as a solid line. Measurements are shown as symbols.](image-url)
Harvard Forest Long-Term Ecological Research (LTER) site, we have been collaborating with John Aber, Alison Magill and others from the University of New Hampshire; at the Bear Brook Watershed site in Maine, we have been working with Ivan Fernandez, Steve Kahl, Steve Norton and Lindsey Rustad of the University of Maine. Our studies have shown that nitrogen deposition is unlikely to be increasing tree growth in New England forests. Evidence that nitrogen deposition is not increasing tree growth appreciably has come both from direct comparisons of tree growth on fertilized and control plots and from observations that only small fractions of the $^{15}$N tracers added to both fertilized and control plots are taken up into tree biomass.

In 1999, Nadelhoffer and a group of European colleagues reported results from $^{15}$N tracer studies at Harvard Forest, Bear Brook Watershed and five European forest sites in a paper in *Nature*. Averaging over all these sites, investigators found that roughly 5% of nitrogen deposited from the atmosphere was taken up into woody biomass. Most of the rest was taken up by soils and stored below ground for at least one to three years, the time scale of the experiments.

How robust are these results? Combining modeling with our experimental work allows us to extend our results to address important questions at longer time scales and larger spatial scales than is possible with field studies alone. For example, although our results show that much more of the nitrogen deposited on temperate forests moves into soils than into tree biomass initially, we do not know whether nitrogen inputs will remain in soils over time scales of decades or longer. It is possible that sustained nitrogen inputs from the atmosphere, replicated in our long-term fertilization of experimental plots, will eventually result in more nitrogen being taken up by trees than by soils.

Other scenarios are possible as well. Forests that are subjected to sustained nitrogen deposition could eventually export large quantities of nitrate into groundwater and streams. This exported nitrate would acidify soils, which would, in turn, decrease tree growth. Predictions of longer-term responses of forests to perturbations such as nitrogen deposition depend on our ability to incorporate field data into models.

In collaboration with former Ecosystems Center post-doctoral researcher William Currie, now at the University of Maryland’s Appalachian Laboratory, and John Aber of the University of New Hampshire, we have developed a model known as TRACE, for Tracer Redistribution Among Components in Ecosystems. TRACE is useful for extending results from field experiments to make larger-scale estimates of how nitrogen inputs will influence forest nutrient cycling and carbon balances. The model simulates carbon and nitrogen interactions in forests based on our current understanding of element cycling processes. A key feature of this model is that it can simulate movements of $^{15}$N tracers within forests for years after they are added. Comparing modeling estimates of $^{15}$N tracer redistributions on experimental plots through time against measured $^{15}$N redistributions allows us to test our fundamental understanding of ecosystem processes.

We used TRACE to interpret and estimate the movements of $^{15}$N tracers added to oak and pine forest plots at the Harvard Forest LTER site, some unfertilized and some fertilized regularly from 1988 on. During 1991 and 1992, tracers were added to these plots, enriching the ammonium nitrate fertilizer with more $^{15}$N than was naturally present. On some plots the ammonium ion ($\text{NH}_4^+$) was enriched with $^{15}$N, and on others the nitrate ion ($\text{NO}_3^-$) was enriched. Comparing the estimated movements of these labeled nitrogen ions in our modeling simulation against measured

![Figure 2: Modeled (lines) and measured (symbols) recoveries of $^{15}$N tracers added as $^{15}$NO$_3^-$ ions in foliage and tree wood in a red pine forest. Model results are from TRACE (version 2.2). The symbols, green for foliage and black for wood, represent values based on field measurements in 1992 and 1998. Tracers were added in 1991 and 1992.](image)

Ben Colman sampling red pine wood for nitrogen isotope measurements.
15N redistributions on the plots provided valuable tests of our knowledge of forest nitrogen cycling processes. Many ecosystem models, including an early version of TRACE, represent the dynamics of both ammonium and nitrate inputs in the same way. As a result, the TRACE simulation predicted that these two forms of nitrogen would behave similarly in the years following tracer additions in fertilized oak and pine plots (Figure 1). However, measurements of 15N redistributions on these plots showed that the form of the nitrogen added strongly influenced the fate of the nitrogen inputs. The model accurately estimated rates at which nitrate additions moved into and out of foliage in both oak and pine forests. In contrast, it overestimated the rates at which ammonium additions moved into and out of foliage. Thus we learned that TRACE and other models require modifications that simulate ammonium and nitrate dynamics according to different rules.

We can also use models such as TRACE to predict the future behavior of ecosystems. For example, we used TRACE to predict the redistribution of nitrogen added to forests during the decade following the addition of 15N tracers. The model predicted that the distribution of the tracers among tree foliage, wood and roots as well as forest-floor and mineral-soil organic matter would vary according to the form of nitrogen introduced and the rates at which it was added. Sampling is now being conducted at our research plots to test model predictions on decadal time scales.

Preliminary sampling conducted in 1998 suggested that the model is indeed useful for making predictions at time scales longer than the typical three-year experiment. For example, TRACE simulations showed that in the foliage of fertilized forests, 15N tracers peaked the year after the additions were discontinued. In subsequent years, foliar 15N contents declined as some nitrogen moved from leaves into wood and some was transferred to the forest floor as leaf litter. TRACE simulations also showed a gradual increase in the 15N contents of wood as a result of the movement of tracer nitrogen from foliage into accumulating woody biomass and, at a slower rate, from soils to trees. Measurements of 15N distributions on the plots in 1992 and 1998 were consistent with the simulated trends (Figure 2).

More complete sets of measurements are now being made on the forest plots in New England and Europe that previously received additions of 15N. Comparing measured and modeled redistributions of the tracers will allow more comprehensive testing and improvements of the model. In turn, TRACE will become more useful for improving our understanding of how nitrogen cycles through forest ecosystems and how atmospheric deposition might be influencing tree growth and carbon uptake by forests across large regions in the coming decades.
SEMESTER IN ENVIRONMENTAL SCIENCE: THIRD YEAR BRINGS LARGEST CLASS TO DATE

Ecosystems Center staff members welcomed 18 students to the MBL campus in early September for the third year of the Semester in Environmental Science (SES). Designed to train students to approach environmental problems from a whole ecosystem perspective, SES is a major commitment by the MBL and the center to educating a generation of environmentally aware citizens and scientists.

The class was the largest yet, bringing the number of undergraduates who have completed the program to 46 and the number of colleges and universities represented to 22. More than a quarter of the students who have completed the SES course have been hired by the center. Ten have been employed as summer field assistants, as interns in the National Science Foundation’s Research Experience for Undergraduates, or as teaching assistants in the course. Three SES alumni, Sam Kelsey, Toby Ahrens, and Greg Peterson, have been hired by the center as full-time research assistants after their graduation from college.

During 1999, five more educational institutions joined the Environmental Sciences Consortium led by the MBL, bringing the total membership to 37. New members are Beloit College and Lawrence University in Wisconsin, Earlham College in Indiana, and Southwestern University and Trinity University in Texas. More than a dozen other colleges and universities are currently reviewing the program. Participating institutions agree to grant a semester’s worth of credits to students who complete the program successfully.

The SES curriculum takes advantage of the strengths of The Ecosystems Center’s research program, emphasizing biogeochemical topics and methods and a focus on environmental change. SES students learn by doing, spending nearly 20 hours a week in the laboratory and field working in teams of four. They study a variety of ecological systems on Cape Cod, including an experimental forest tract at Falmouth’s municipal sewage treatment plant that is sprayed with treated effluent; West Falmouth Harbor, which is expected to receive the plume from the wastewater treatment plant, and the nearby Waquoit Bay estuary. They also investigate several brackish and freshwater kettle ponds.

The spectrum of ecosystems available to SES students facilitates comparisons of relatively pristine and heavily impacted environments, both terrestrial and aquatic.

During the 10-week introduction to ecosystems science, students measure the abundance and distribution of plants and animals and rates of processes such as primary production, decomposition and nutrient cycling. They synthesize the data they collect to construct simple budgets of nitrogen and phosphorus fluxes between land and sea with the aim of understanding larger-scale interactions among ecosystems.

Field and lab work stimulates new questions and leads students to original research topics. During the last five weeks of the program, students collaborate on independent research projects designed to answer these questions. Although faculty mentors provide guidance, students are encouraged to work on their own. They present their findings at a public symposium held at the end of the semester. For most students, this project represents both their first attempt at independent scientific inquiry and the highlight of their semester at the MBL.

This year, the MBL Associates sponsored a $100 prize for the best presentation at the symposium. Adena Greenbaum of Wellesley College received the prize for her work on heavy-metal inventories in sediments of experimental plots at Great Sippewissett Marsh. These plots have been treated with fertilizer in the form of sewage sludge since the mid-1970s. By comparing her results to those obtained by SES faculty member Anne Giblin during her doctoral research
at this site more than 20 years ago, Adena was able to assess long-term changes in the distribution of metals within the marsh.

An important goal of the SES is to foster communication about major environmental issues. The program includes a science-writing seminar that gives students a chance to talk with writers who cover science and the environment for public audiences. Journalists and authors who participated in the 1999 seminar included Chris Bright, author of Life Out of Bounds, Bioinvasion in a Borderless World, Diane Dumanoski, author of Our Stolen Future, and Bill McKibben, author of The End of Nature. Students also write essays of their own as part of the seminar. An article about efforts to restore grasslands on Martha’s Vineyard by Greg Peterson of Wesleyan University was selected for publication in MBL Lab Notes in spring 2000.

Linked with the science-writing seminar is a distinguished scientists seminar series at which prominent researchers present talks on key topics relevant to the curriculum (see box). Each student was expected to interview and write a profile about one of these speakers.

The SES offers a fellowship each fall to a professor from a participating college or university. In 1999, two faculty exchange fellows joined the SES staff for the semester. Marianne Moore came to Woods Hole from Wellesley College, where she is a professor of biology. An aquatic ecologist, she is interested in understanding how the differences in light and temperature in urban lakes affect fish foraging and zooplankton migration and population dynamics. Thomas L. Millette came from Mount Holyoke College, where he is a professor of geography. During his fellowship, he worked with Ecosystems Center researchers on exploring ways of applying remote sensing observations to mapping marsh topography.

Finally, The Ecosystems Center produced an informative video about SES during 1999. Narrated by Bill Kurtis, producer of the educational program "The New Explorers," the 16-minute film provides viewers a chance to hear from faculty members as well as from students who have completed the program and to see SES activities in the laboratory and at field sites. Copies of this video may be requested by electronic mail at SES@mbl.edu.

**Distinguished Scientist Seminar Series**

**September**

10  Heinrich D. Holland, Harvard University, "The evolution of atmospheric oxygen."

24  James R. Ehleringer, University of Utah, "Atmospheric CO2, photosynthesis, and mammalian evolution."

**October**

8  Christopher S. Martens, University of North Carolina, "Sources, decomposition, and burial of organic matter in coastal sediments."

15  Sybil Seitzinger, Rutgers University, "Global distribution of nitrogen transport by rivers to coastal ecosystems: 1990 and predictions for the year 2050."

29  Richard S. Ostfeld, Institute for Ecosystems Studies, "Ecological dynamics of Lyme Disease risk."

**November**

12  JoAnn M. Burkholder, North Carolina State University, "Impact of the toxic Pfiesteria complex on fish in human health."

19  James T. Carlton, Williams College, "Global marine biological invasions."

**December**

6  Jerry Melillo, Marine Biological Laboratory, "Scientific basis for policy decisions."

*Jill Sohn of Harvey Mudd College prepares samples for analysis during her independent project research.*

*Julie Horowitz of Hampshire College pipets samples while Ryan Kirkby of Harvey Mudd looks on.*

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

Science Education on the Local Scene

Neil Bettez, Hap Garritt, Knute Nadelhoffer, Kama Thieler and Jane Tucker judged science fair projects at Falmouth Academy, while Pat Micks and Jane judged the Falmouth Public Schools' science and technology fair. Pat, Jane, Michele Bahr, Sam Kelsey, Pete Raymond and Max Holmes advised junior high school students on developing ideas for their science fair projects. Chris Neill continued to write his weekly column on natural history for the Falmouth Enterprise.

Science Writers

Once again, The Ecosystems Center staff participated in the MBL's Science Writing Fellowship program. Nine writers spent five days with investigators, visiting Long-Term Ecological Research (LTER) field sites at Plum Island Sound and Harvard Forest. They also attended lectures and discussions led by members of the center staff, including Jerry Melillo, Ed Rastetter, Anne Giblin, Chuck Hopkins, Ken Foreman, Jane Tucker, Hap Garritt, Marty Downs and Kris Tholke. Science writers who participated were Todd Bates from the Asbury Park (NJ) Press; Mindy Pennybacker from the Green Guide; Perry Beeman of the Des Moines Register; Michael Burns of the Baltimore Sun; Nancy Cohen, a freelance reporter; Cheryl Hogue from the Bureau of National Affairs; Carolyn Lesser, a children's book author; Dan Grossman, producer for the "Living Earth" radio program, and Gretel Schueller of Audubon magazine. Michael, Cheryl and Gretel spent an additional two weeks at the Toolik LTER research site in Alaska, while Nancy went to Plum Island and Harvard Forest.

Perry and Barbara Moran, a freelance producer who participated in the MBL's biomedical science writing course, traveled to the Amazon for three weeks with Chris Neill. Their first stop was the center's field site at Fazenda Nova Vida to conduct nutrient tracer experiments in forest and pasture streams. They then went on to the Biological Dynamics of Forest Fragments project in Manaus, run jointly by the Brazilian National Institute for Amazon Research and the Smithsonian Institution. There they visited patches of forest that have been isolated for 20 years in order to study extinction and changes in the composition and biomass of plant and animal species. Their trip also included visits to a rain tower forest where Brazilian scientists measure carbon exchange, to Santarem, main field site for the joint U.S.-Brazil large scale biosphere atmosphere experiment in Amazonia, and to the Brazilian space agency to look at images that help that government measure deforestation.

Semester in Environmental Science

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

**Student Research Opportunities**

A number of students participated in the National Science Foundation's Research Experience for Undergraduates (REU) program. Erica Gwynn, from the University of Michigan, conducted research on plankton algae at the Toolik Lake, Alaska, LTER site, while Jeremy Sinaikin, Brown University, worked with Gus Shaver to complete his senior honors thesis on soil chemistry research. Ammie Genung of Central Michigan University studied the response of mosses to fertilization in the Kuparuk River, also at Toolik field station. Lynn Stankiewicz, Clark University, worked with Karen Buzby to measure juvenile grayling growth. Trent Petersen, Appalachian State University, also worked at Toolik on prey selection by littoral invertebrate predators. Suzannah Canfield, Bates College, worked with Chuck Hopkinson, Luc Claessens, Ed Rastetter and Joe Vallino on long-term effects of municipal water use on the water budget of the Ipswich River Basin; their work was published in the *Biological Bulletin.*

**Postdoctoral Scientists**

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

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

Inger Kappel Schmidt finished her doctorate in 1997 at University of Copenhagen, Denmark, where she worked with Sven Jonasson in the Department of Plant Ecology. Her dissertation research focused on soil-plant-microbe interactions in arctic tundra ecosystems subjected to long-term perturbation of environmental factors (temperature, light and nutrients). Inger came to The Ecosystems Center in 1999 where she is working with Gus Shaver and Knute Nadelhoffer. She has investigated the impact of environmental changes on plant and soil microbial communities as part of an inter-site comparison between long-term warming experiments in Toolik, Alaska, and Abisko, Sweden. Together with Annika Nordin, she has also investigated the uptake of various nitrogen forms, inorganic as well as organic, by plants and soil microbes in the arctic tundra at Toolik Lake, Alaska.

Matthew Cieri joined The Ecosystems Center in 1999 to work with Linda Deegan, Bruce Peterson and Joe Vallino to...
study nitrogen flow and trophic interaction of an estuarine food web. Matt completed his doctorate in oceanography in 1999 at the University of Maine. While there, he researched the early life history and migrations of the American eel under the guidance of James M. McClave. Currently, Matt is working with Linda, Bruce, and Joe to examine estuarine food webs using a stable nitrogen isotope tracer.

Peter Raymond came to The Ecosystems Center in October after completing his doctorate in chemical oceanography at the Virginia Institute of Marine Science of the College of William and Mary, where he studied with James Bauer. His dissertation focused on the age and dynamics of carbon in estuaries. Pete’s work utilizes natural isotopes of carbon (\(^{13}\)C and \(^{14}\)C) to study dissolved organic and inorganic carbon pools. He is working with John Hobbie, Chuck Hopkinson and Joe Vallino on the Plum Island Ecosystem LTER studying organic matter cycling in the Parker River estuary and associated watershed.

Byron Crump also came to The Ecosystems Center in October after completing his doctorate in biological oceanography at the University of Washington, where he studied with John A. Baross. His dissertation described the microbial ecology of the Columbia River estuary, focusing on the abundance, activity and community structure of particle-attached and free-living bacteria, and on the relationships between bacterial activity and the physical and chemical conditions of estuarine turbidity maxima. He is working with John Hobbie at the Plum Island Ecosystem LTER and at the Arctic LTER, studying short- and long-term changes in microbial activity and community composition.

Annika Nordin completed her doctorate in 1998 at the Swedish University of Agricultural Sciences in Umeå, where she worked with Torgny Nåsholm in the Department of Forest Genetics and Plant Physiology. For her thesis she studied nitrogen utilization by boreal forest plants. Annika received a stipend from the Swedish Foundation for International Cooperation in Research and Higher Education for a two-year stay at The Ecosystems Center. She is working with Knute Nadelhoffer and Gus Shaver on the exchange of nitrogen between plants and soil in arctic tundra. She and Inger Kappel-Schmidt have investigated plant and soil microbial uptake of different organic and inorganic forms of nitrogen in the tundra of the Alaskan Arctic.

Craig Tobias received his doctorate in 1999 at the Virginia Institute of Marine Science of the College of William and Mary, under the guidance of Iris Anderson and Elizabeth Canue. His dissertation research concentrated on the effects of groundwater discharge on nitrogen cycling in fringing marshes, specifically the use of combined natural gradient-isotope tracer releases to quantify marsh processing of groundwater nitrogen loads. He is currently working with Bruce Peterson, Linda Deegan and Joe Vallino on an estuarial-scale nitrogen tracer experiment that examines the effect of food webs on the cycling and burial of nitrogen in estuaries.
ECOSYSTEMS CENTER EVENTS AND ACTIVITIES

HIGHLIGHTS OF 1999

Progress On New Environmental Sciences Building

Ecosystems Center staff members, currently scattered among four buildings on the MBL campus, will be reunited in a single facility if all goes according to plan over the next couple of years. Over the 25 years since the center was founded, its staff has increased six-fold, creating severe shortages of office, laboratory and teaching space.

Plans were completed in 1999 for a 32,000-square-foot environmental sciences building that will ease the crowding and promote the interaction among staff members that is essential to the work of the center. It includes offices, laboratories, staging areas for field samples and equipment and classrooms for the Semester in Environmental Science and other MBL courses. The design of the new building reflects the laboratory’s commitment to an environmentally responsible facility.

The new building received a favorable review from the Cape Cod Commission, a regional regulatory agency, in December. The commission’s approval cleared the way for application for permits from the relevant town agencies. Groundbreaking is scheduled to take place, if all goes well, in June 2000.

The cost of the new building, including an endowed fund for maintenance, is expected to be roughly $8.5 million. The MBL plans to raise at least $4.8 million of the total in gifts and grants and to finance the rest.

In early December, The Kresge Foundation awarded the MBL a challenge grant of $500,000. Some $2.2 million had been raised before this award; the Kresge grant is contingent upon the MBL’s success in raising the additional $2.1 million needed to meet its goal.

Other support for the new building has come from The Starr Foundation, The Clayes Fund, The Bay Foundation, The Harken Foundation, the Environmental Data Research Institute and an anonymous foundation. In addition, the building project has received generous gifts from a number of individual donors.

Promotions and Elections

Knute Nadelhoffer received a promotion from associate scientist to senior scientist in November 1999. He joined the staff of The Ecosystems Center as a postdoctoral fellow in 1983 after receiving his doctorate in forestry from the University of Wisconsin at Madison. He became an assistant scientist at the center in 1985 and an associate scientist in 1991.

Postdoctoral scientists Darrell Herbert and Jeffrey Hughes were promoted to the position of staff scientist I. Darrell came to The Ecosystems Center in 1996 after completing his doctorate at the University of Hawaii. Jeff also joined the center staff in 1996 after completing his doctorate at the University of Rhode Island and postdoctoral work at Rutgers University.

After a two-year term as president-elect, Anne Giblin became president of the Estuarine Research Federation in October.

Events at the MBL

Several scientists from the Massachusetts chapter of The Nature Conservancy visited The Ecosystems Center in March to talk with staff members about their work and to discuss possibilities for collaboration. With these scientists, Chris Neill subsequently organized a meeting at the MBL on islands ecological research. Some 32 researchers who study land-use change and the ecology and biodiversity of Martha’s Vineyard and Nantucket got together in November to review results of recent research projects and to discuss future collaborative investigations. Among them were representatives of various conservation organizations as well as scientists from area universities, the MBL and the Massachusetts Department of Environmental Management.

Arctic Research Commission (ARC) Activities

With his fellow commissioners, John Hobbie traveled...
to Colorado in May to tour the National Center for Atmospheric Research in Boulder and the National Ice Storage Facility in Denver. In December the ARC held an open meeting in Anchorage, Alaska, to evaluate the state of planning by federal and state agencies for fisheries research in the Bering Sea. Commission members also visited Kodiak to talk with fishermen and researchers.

Long-Term Ecological Research (LTER) Events

Debbie Scanlon and John Hobbie organized the annual planning meeting for the Arctic LTER project at Toolik Lake, Alaska, held in Woods Hole in early March. Other participants from The Ecosystems Center were Michele Bahr, Neil Bettez, Karen Buzby, Linda Deegan, Marty Downs, Anne Giblin, Max Holmes, Inger Kappel-Schmidt, Sam Kelsey, Bonnie Kwiatkowski, Jim Laundre, Knute Nadelhoffer, Bruce Peterson, Ed Rastetter, Gus Shaver, Karie Slavik, Kama Thieler and Mat Williams.

At the annual symposium of the Harvard Forest LTER project, held in Petersham, Massachusetts, on March 29, Knute Nadelhoffer gave a talk on the long-term responses of forest carbon and nitrogen cycles to nitrogen deposition at stand and regional scales. Pat Micks also attended.

Knute Nadelhoffer traveled to Budapest, Hungary, in June to give a talk on controls on forest soil organic matter development and dynamics at the Eastern European Regional International LTER Workshop. Later in the year he spoke at the same topic at the East Asia LTER workshop in Seoul, Korea.

At the fall meeting of the LTER coordinating committee, held at Hubbard Brook in New Hampshire, Gus Shaver spoke at a symposium on primary production at the LTER sites. Hap Garrett attended an LTER technology committee meeting in San Diego, California, in March and a data managers committee meeting in Spokane, Washington, in August.

Arctic Systems Science (ARCSS) Workshops

John Hobbie, Bonnie Kwiatkowski, Knute Nadelhoffer and Ed Rastetter participated in an ARCSS Land-Atmosphere Ice Interactions (LAII) planning workshop in Seattle in mid March. Knute presented several posters, including one by Kama Thieler on the effect of nutrient enrichment on plant carbon allocation in wet tundra ecosystems. Ed made a presentation on extrapolating from results of small-scale field experiments to a whole river basin. Bonnie presented a poster on responses of tussock tundra to changes in carbon dioxide (CO₂) and climate at various time scales.

Bruce Peterson attended an ARCSS Committee meeting as well as a workshop on the Arctic Shelf-Basin Program in October in Virginia Beach.

Global Change and Terrestrial Ecosystems (GCTE) Conferences

A number of Ecosystems Center scientists traveled to the Abisko Naturvetenskapliga Station in northern Sweden in mid June for a GCTE conference titled "How Do Nutrient Cycles Constrain Carbon Balances in Boreal Forests and Arctic Tundra?" Knute Nadelhoffer was among the organizers of the conference. Chris Neill presented a paper on nutrient control of responses to climate warming in research plots at Abisko. Gus Shaver gave a talk on interactions between carbon and nutrients in tundra ecosystems. In his talk, Mat Williams discussed controls on productivity in tundra ecosystems and the problem of scaling in space and time. Inger Kappel-Schmidt presented a poster on mineralization and allocation of nutrients by plants and microbes in heath tundra and their responses to warming. The topic of Annika Nordin’s poster was the correlation of plant nitrogen preferences with soil nitrogen forms and availability.

In October, Knute attended a GCTE symposium titled "Root Dynamics and Global Change: An Ecosystem Perspective" in Tennessee, where he gave a talk on the potential effects of nitrogen desposition on fine root production in forests.
Calendar of Other Conferences and Workshops

Linda Deegan joined other marine experts at a workshop in January, sponsored by The Nature Conservancy and held at the New England Aquarium Conference Center in Boston. Gus Shaver attended an International Tundra Experiment (ITEX) workshop that month in East Lansing, Michigan, where he presented talks on research in the Alaskan Arctic and on the GCPE network of ecosystems warming studies.

Jerry Melillo and Dave Kicklighter attended Massachusetts Institute of Technology (MIT) Global Change Forums in Boston in January and November. Jerry made a presentation on the potential for carbon sequestration in terrestrial ecosystems at the January session and another on the U.S. National Assessment in November.

A number of Ecosystems Center investigators participated in a workshop titled "A Cross-Biome Synthesis of Ecosystem Response to Global Warming" at the National Center for Ecological Analysis and Synthesis (NCEAS) in Santa Barbara, California, in early February. Gus Shaver was a member of the organizing committee. Chris Neil presented a paper on soil and air warming experiments at Abisko in the Swedish Arctic, and Jerry Melillo spoke on results from eight years of experimentation at Harvard Forest. Other participants from the center were Anne Hartley and Knute Nadelhoffer.

Max Holmes, Bruce Peterson and Kris Tholke attended a workshop of the Lotic Intersite Nitrogen Experiment (LIX) during March at the University of Illinois.

In early April, Jerry Melillo went to Sweden to give a talk on global climate change at the dedication of the new meeting facility at the Abisko Naturvetenskapliga Station. Later in the month Chris Neil traveled to Belem, Brazil, to attend a workshop on the Large-Scale Biosphere-Atmosphere Experiment in Amazonia.

Also in April, Ed Rastetter made a presentation on Ipswich River water quality and land use at the annual meeting of the multiagency Partnership for Environmental Research Water and Watersheds Program in Washington, D.C. Mat Williams gave a talk on carbon and hydraulic limitations at a workshop on the Ponderosa Pine ecosystem and environmental stress, held at Oregon State University. Dave Kicklighter participated in a workshop at NCEAS to help organize an Ecological Model/Data Intercomparison workshop to be held later in the year at the University of New Hampshire.

In early May, Knute Nadelhoffer participated in a workshop at NCEAS on regional and global analyses of nitrogen transport and transformations that was sponsored by the Scientific Committee on Problems in the Environment (SCOPE). Shortly thereafter he joined Jerry Melillo, Ed Rastetter, Joe Vallino and Mat Williams on a visit to Biosphere II in Oracle, Arizona, as members of a committee that reviewed the potential of the facility for ecosystems research. Jerry served as chairman of this review committee.

In mid May John Hobbie took part in a meeting of the Council of Visitors for the NSF Division of Environmental Biology. Byron Crump presented a poster on Archaea in the Columbia River estuary and adjacent coastal ocean at the annual NSF Hyperthermophile Symposium, held in Athens, Georgia. Anne Giblin and Jane Tucker attended a workshop on dissolved gas analysis as a method for denitrification at Horn Point Environmental Laboratories in Maryland.

Also during May, Dave Kicklighter served as co-chairman of a session at the annual scientists' meeting of the NASA Land Cover/Land Use Change (LCLUC) program at Airlie Center in Virginia. Max Holmes and Bruce Peterson traveled to Moscow and Rostov-on-Don to work with Russian colleagues Stava Gordeev and Alexander Zhulidov on the analysis of nutrient data for Russian rivers within the Arctic Ocean drainage basin.

Anne Giblin and Ed Rastetter participated in a Gordon Conference on forested catchments in Andover, New Hampshire, during July. Anne gave a talk titled "Are our scales of measurements ecologically relevant?" Ed's talk was titled "Scaling across space and time: What is the role of mechanism?" At a symposium on ecohydraulics, held in Salt Lake City later in the month, Joe Vallino made a presentation on an inverse technique for estimating estuarine ecosystem metabolism from oxygen measurements.

Hanqing Tian gave a talk on agricultural ecosystem modeling at a model intercomparison workshop on this topic at Colorado State University in Fort Collins in August.

Bruce Peterson made a presentation on river discharge to the Arctic Ocean at a workshop on the paleohydrology of the Arctic Ocean, held in Monterey, California, in the beginning of October. The important attributes of seagrass sys-
tems as essential habitat for marine fish were the subject of a talk given by Linda Deegan at the NOAA Marine Ecosystem Classification Workshop, held during October at Long Key Marine Station in Florida.

In early November, Linda Deegan and John Hobbie attended the 1999 Florida Bay Science Conference in Key Largo, convened to address a comprehensive set of research questions concerning Florida Bay. Anne Giblin attended the "President’s Summit" of the American Institute of Biological Sciences, held at Airlie Center in Virginia.

Following a Carbon Cycle Modeling Linkage Project (CCMLP) writing workshop in Jena, Germany, during October, Dave Kicklighter participated in a CCMLP Phase II organizational workshop in Basel, Switzerland, in late November. Jerry Melillo also attended the workshop in Basel and a subsequent SCOPE meeting.

In December Linda Deegan attended the Dahlem Workshop on Science and Integrated Coastal Management at the Free University of Berlin, Germany, where she spoke on the use of models in integrated resource management in the coastal zone.

Meetings
Several Ecosystems Center investigators made presentations at the American Society of Limnology and Oceanography (ASLO) annual meeting in Santa Fe, New Mexico, in early February. Joe Vallino spoke on the use of data assimilation and mesocosm experiments to improve marine ecosystem models. Chuck Hopkinson gave a talk on nutrient sources, transformations and budgets on the watershed scale. John Hobbie presented a paper on impact of global change on biogeochemistry and ecosystems of arctic freshwaters. Fluorometric measurement of ammonium in marine and fresh water was the topic of a presentation by Max Holmes. Craig Tobias gave a paper on the fate and transport of groundwater nitrogen in marshes. Anne Giblin, Neil Bettez and Jane Tucker attended.

John Hobbie and Bruce Peterson took part in the annual meeting of the Arctic Research Consortium of the U.S. (ARCUS) in Washington, D.C., in March.

Research projects in Amazonian and North American streams were featured in Ecosystems Center papers at the North American Benthological Society annual meeting, held in Duluth, Minnesota, in late May. Chris Neill spoke about links between deforestation, soil nutrient cycling and water chemistry; Linda Deegan discussed nutrient uptake experiments, and Susanne Thomas gave a talk on changes to water chemistry across the forest-to-pasture transition in Amazonian streams. Karie Slavik spoke on biological responses to long-term fertilization of the Kuparuk River, Alaska, and Karen Bubzy discussed interannual site fidelity in arctic grayling. Bruce Peterson gave a talk on nitrogen dynamics in the streams of North America, and Max Holmes made a presentation on contrasting biogeochemical cycles of riparian forests in temperate, wet tropical and arid regions.

Byron Crump presented a poster on the bacterially active particle fraction in the Columbia River estuary at the annual meeting of the American Society for Microbiology, held in Chicago in early June.

Mat Williams discussed controls on net ecosystem productivity along an arctic transect, comparing modeling results with flux measurements, at the June meeting of the American Geophysical Union in Boston. Luc Claessens gave a talk on land-use transformations and their effects on water and nutrient dynamics. Jerry Melillo presented a review of progress on the U.S. National Assessment.

Later in June, Jerry participated in the World Science Conference in Budapest, Hungary, where he organized and chaired a session on the disruption of global biogeochemical cycles.

A number of Ecosystems Center scientists made presentations at the Ecological Society of America meeting, held in mid August in Spokane, Washington. Chris Neill spoke on links between deforestation, soil nutrient cycling and water chemistry in small Amazonian streams. Diana Garcia-Montiel made a presentation on soil phosphorus transformations following forest clearing for pastures in the Brazilian Amazon. Darrell Herbert presented a poster on plant-attribute diversity and stability of ecosystem function. Gus Shaver gave a talk on the effects of changes in species composition over 15 years in fertilized arctic tundra plots. Heidi Lux was co-author of a poster on mycorrhizal contributions to aluminum tolerance in tulip poplar.

Bruce Peterson

Byron Crump

Darrell Herbert
Also in August, Diana Garcia-Montiel made a presentation on potential effect of soil fertility on forest recovery in the Brazilian Amazon at the XVI International Botanical Congress in St. Louis.

The Ecosystems Center was well represented at the 15th Biennial International Conference of the Estuarine Research Federation (ERF), held in September in New Orleans. Anne Giblin, currently president of ERF, made a presentation on the effects of salinity on the fate of inorganic nitrogen in the sediments of the Plum Island Sound estuary. Linda Deegan gave a paper on changing land use and estuaries: modeling the links between land use and fish production. Chuck Hopkinson spoke on watershed nitrogen budgets. Bruce Peterson's talk was on nitrogen flow in oligohaline food webs. Joe Vallino made a presentation on using a $^{15}$N enrichment experiment for the development and calibration of an estuarine biogeochemistry model. MaryKay Fox and Craig Tobias also attended.

Paul Steudler presented a paper on microbial regulation of soil methane consumption at the Soil Science Society of America annual meeting, held in November in Salt Lake City.

At the December meeting of the American Geophysical Union in San Francisco, Paul Steudler gave a talk on trace gas responses to nitrogen and phosphorus fertilization of forest and pasture soils in the Brazilian Amazon. Diana Garcia-Montiel made a presentation on patterns of trace gas emissions from Brazilian forests and pastures after a simulated rainfall. Max Holmes discussed the delivery of nutrients from the pan-Arctic watershed to the Arctic Ocean and the establishment of a baseline against which to measure changes. Hanqin Tian and Shufen Pan presented a poster on the U.S. carbon budget at multiple time scales and the quantifying mechanisms responsible for the terrestrial carbon sink.

**Lectures and Seminars**

Ed Rastetter visited the La Selva Biological Reserve in Costa Rica in January to discuss the use of Ecosystems Center models in a long-term biogeochemical project at the reserve and the possibility of future collaborations.

Knute Nadelhoffer spoke to students about the relationship between nitrogen deposition and the uptake of CO$_2$ in forests, first at Harvey Mudd College in California in February, and then at Colorado State University in April. Jerry Melillo presented a talk on the causes and consequences of climate change at a campus-wide symposium at Dickinson College in Pennsylvania. Craig Tobias made a presentation on the role of salt marshes as buffer zones for marine ecosystems at the University of Virginia.

During March, Chris Neill presented a seminar on the links between deforestation and changes in the chemistry of Amazonian streams at Macalester College in Minnesota. He also gave a lecture for fellows in the Southern Connecticut State University Institute for Science Instruction and Study during their three-day visit to the MBL.

Chuck Hopkinson was invited to speak on classifying estuaries in terms of susceptibility to eutrophication in Washington, D.C., in March at a meeting of the National Research Council's Committee on Causes and Management of Coastal Eutrophication.

Anne Giblin made presentations at the Massachusetts Water Resources Authority (MWRA) science review meeting in April and the MWRA Outfall Monitoring Science Advisory Panel meeting in September.
Mat Williams traveled to São Jose dos Campos, Brazil, in April to give a lecture at the National Institute for Space Research (INPE) on terrestrial ecosystems and the global carbon cycle. Chuck Hopkinson gave a talk on the stoichiometry of ocean dissolved organic matter at the Dauphin Island Marine Laboratory in Alabama in May.

In June, Mat Williams visited the Institute of Hydrology in Wallingford, United Kingdom, in June to give a lecture on interactions of carbon and water exchange in a tropical rainforest. Craig Tobias gave a talk on nitrogen reduction at the interface between groundwater and salt marshes at the College of William and Mary in Virginia. Jeff Hughes spoke on the health of coastal ecosystems in the Aquavets course at MBL.

Mat Williams spoke on carbon exchange in arctic and tropical terrestrial ecosystems at Lamont-Doherty Earth Observatory in Palisades, New York, in August.

In September, Hanqin Tian gave a seminar on quantifying the terrestrial carbon sink at the University of California at Berkeley and another on modeling agricultural ecosystems at MIT.

Chuck Hopkinson spoke on inferring the stoichiometry of organic matter from field and laboratory experiments at the Institute of Ecosystem Studies in Millbrook, New York, in October.

In November, Jerry Melillo briefed representatives of the International Petroleum Industry Environmental Conservation Association (IPIECA) on the progress of the U.S. National Assessment. Gus Shaver gave a seminar presentation on the effects of changes in species composition in fertilized arctic tundra plots at the University of Rhode Island.

Darrell Herbert traveled to Puerto Rico in December to present a seminar at the University of Puerto Rico's Institute for Tropical Ecosystem Studies on the effect of plant growth characteristics on biogeochemistry and community composition in a changing climate.

Committee Memberships
John Hobbie is chairman and Linda Deegan is a member of the scientific oversight panel for the Interagency Florida Bay Science Program, a study of the entire bay ecosystem supported by both federal and state governments. The panel provides an independent review of the science program and advice to the program management committee and resource managers.

John completed his service as chairman of a National Research Council committee charged with reviewing the effectiveness of the Community Development Quota program of the National Marine Fisheries Service. This program uses a percentage of the Bering Sea fishery quota for economic and social development in 57 native Alaskan coastal communities. The council's final report was published in May.

John also serves on the board of directors and executive committee of ARCUS and on the Arctic Research Commission of the U.S., which met this year with the ARCUS board to find out the concerns of the research community.

Jerry Melillo is president of the Scientific Committee on Problems of the Environment (SCOPE), created 31 years ago by the International Council of Scientific Unions (ICSU) to assess information on anthropogenic environmental changes and disseminate it worldwide. He continues to serve on the design committee for the Report on the State of the Nation's Ecosystems.

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

Anne Giblin is on the advisory committee for Cornell University's program in biogeochemistry and environmental change. She also serves on the science board of the Cape Cod National Seashore and the advisory board of the Cooperative Institute for Coastal and Estuarine Environmental Technology.

Chuck Hopkinson serves as an advisory panelist for the Florida Department of Environmental Protection. The panel's charge is to review and evaluate Everglades nutrient threshold research. Chuck is also a member of the Committee on the Causes and Management of Coastal Eutrophication of the National Research Council and an editor in chief of Mangroves and Salt Marshes, now called Wetlands Ecology and Management.

Ed Rastetter serves as an editor for the journal Ecosystems. Jeff Hughes is an associate editor for Estuaries.
Gus Shaver serves on the executive committee of the U.S. LTER Network, the interdisciplinary advisory board of the Arctic, Antarctic and Alpine Research Committee of the University of Colorado and the advisory committee for the Fritz Went Laboratory at the Desert Research Institute of the University of Nevada at Reno. He is also a panel member for the Canadian National Science and Engineering Research Council’s major facilities access program and an advisor to the Chilean National Fund for Science and Technology.

In addition to her position on the scientific oversight panel for the Interagency Florida Bay Science Program, Linda Deegan is serving a term as president of the New England Estuarine Research Society.

Mat Williams was appointed in May to the graduate faculty of the Department of Forest Science at Oregon State University. Neil Bettez serves as a visiting fellow at Cornell University.

**MBL Boards and Committees**

Chuck Hopkinson is serving a three-year term as a member of the MBL Science Council, a committee of scientists that advises the director and trustees of the laboratory on the scientific aspects of personnel and policy issues. He is also chairman of the radiation safety committee and a member of the program committee for the MBL annual scientific meeting.

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

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

John Hbbie is chairman of the laboratory’s safety committee, and Paul Steudler is a member. John also serves on the joint library advisory committee. Knute Nadelhoffer is a member of the recycling committee.
25th Anniversary Celebration Coming Up

Present and former staff members and their families, friends and colleagues will gather at the MBL in mid October to celebrate the 25th anniversary of the founding of The Ecosystems Center. Kicking off the festivities will be an open house and poster session on Friday, October 13.

A daylong symposium titled "Ecosystem Science for the 21st Century" will take place on Saturday, October 14, in Lillie Auditorium. Former MBL director James Ebert and Ecosystems Center co-director John Hobbie will give the introductory remarks. Other speakers and their topics will be:

- George Woodwell, first director of the center and currently director of the Woods Hole Research Center, "Ecology in a Full World";
- David Schimel, co-director of the Max Planck Institute of Biogeochemistry, Jena, Germany, "The Challenge of Atmospheric Observations to Ecosystem Ecology";
- Chris Neill, The Ecosystems Center, "Deforestation, Ecosystems Science and the Future of the Amazon";
- John Aber, director of the Complex Systems Research Center, University of New Hampshire, "Nitrogen in the Northeast: Are We Saturated Yet?";
- Robert Howarth, Ecology and Systematics Department, Cornell University, "Human Alteration of the Nitrogen Cycle at Regional and Global Scales";
- Anne Giblin, The Ecosystems Center, "Nitrogen Effects in Coastal Ecosystems";
- Jerry Melillo, co-director of The Ecosystems Center, "The Future of Ecosystem Science."

Family activities will go on at the MBL's Marine Resources Center and the Visitors Center throughout the day on Saturday. An alumni picnic will take place on Sunday, October 15, followed by a ballgame, scavenger hunt and awards ceremony.

Members of the organizing committee for the 25th anniversary celebration are Linda Deegan (chair), Dixie Berthel, Sue Donovan, John Hobbie, Hap Garritt and Pam Clapp Hinkle, MBL director for communications. More information is available via the center's web site (http://ecosystems.mbl.edu/25years) or via electronic mail (25years@mbl.edu).
SEMINARS AT THE ECOSYSTEMS CENTER DURING 1999

January

12 Paul Colinvaux, Marine Biological Laboratory, "The ice age Amazon was cooler but remained forested: A paradigm of aridity and refuges overturned."
19 Dan Nepstad, Woods Hole Research Center, "Flames in the Amazon."
27 Erick Boschker, Netherlands Institute of Ecology, Centre for Estuarine and Coastal Ecology, "The contribution of local macrophyte material to microbial biomass in salt-marsh sediments: $^{13}$C analysis of PLFA."

February

9 Annika Nordin, Marine Biological Laboratory, "Nitrogen utilization by boreal forest plants."
16 Deborah Lawrence, Harvard University, "Changes in landscape structure, soil fertility and tree diversity: 200 years of shifting cultivation in a Bornean rainforest."
23 Darrell Herbert, Marine Biological Laboratory, "Plant growth characteristics affect biogeochemistry and community composition in a changing climate."

March

2 William McDowell, University of New Hampshire, "Nitrogen dynamics in a tropical landscape - hurricanes, geomorphology, and human impacts."
16 Nick Brokaw, Manomet Observatory, "Hurricane and Land-use Impacts on a Puerto Rican Forest."
23 David Kicklighter, Marine Biological Laboratory, "How important is CO$_2$ fertilization to the terrestrial carbon sink?"

April

6 Ed Boyle, Massachusetts Institute of Technology, "Spatial and temporal variability of lead and iron in the ocean."
13 Morgan Grove, USDA Forest Service, "The Baltimore Ecosystem Study: Integrating social sciences in a patch dynamics framework."
20 Emery Boose, Harvard University, "Landscape and regional impacts of historical hurricanes in New England."
27 Kevin McGarigal, University of Massachusetts, "Managing spatially and temporally dynamic forest landscapes of the western United States."

May

4 Renate Gebauer, Keene State College, "Plant response patterns to moisture pulses in a cold desert community."
18 Jeff Hughes, Marine Biological Laboratory, "Production and feeding ecology of oligohaline benthivorous fishes."

September

7 Marianne Moore, Wellesley College, "Cities of light: Are they changing the rhythms of the night?"
21 John Hobbs, Marine Biological Laboratory, "A global change research site: The Kuparuk River basin, Alaska."
28 John Harte, University of California, Berkeley, "Self similarity in the abundance and distribution of species."

October

5 Gil Pontius, Clark University, "Land-use change simulation in the Ipswich watershed."
19 Thomas Millette, Mt. Holyoke College, "A multi-scale approach to linking land use dynamics and remotely sensed land cover data in the Middle Mountains of Nepal."

November

2 Michael Weinstein, New Jersey Sea Grant Program, "A retrospective on the salt marsh paradigm."
9 Chris Neill, Marine Biological Laboratory, "Linking deforestation to changes in the characteristics and water chemistry of small Amazonian streams."

December

7 Inger Kappel-Schmidt, Marine Biological Laboratory, "Mineralization and allocation of nutrients by plants and microbes: Results from long-term experiments in Sweden and Alaska."
STAFF AT THE ECOSYSTEMS CENTER DURING 1999

Administrative Staff
John E. Hobbie, Co-Director
   Ph.D., Indiana University
Jerry M. Melillo, Co-Director
   Ph.D., Yale University
Kenneth H. Foreman
   Associate Director of Environmental Studies Program
   Ph.D., Boston University
Dorothy J. Berthel
   Administrative Assistant
Suzanne J. Donovan
   Executive Assistant
Massachusetts College of Art
Priscilla C. Moniz
   Administrative Assistant
   A.S., Becker Jr. College
Guillermo Nuñez
   Research Administrator
   B.S., Texas A & M University
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
Charles S. Hopkinson, Senior Scientist
   Ph.D., Louisiana State University
Jerry M. Melillo, Senior Scientist
   Ph.D., Yale University
Knute J. Nadelhoffer, Senior Scientist
   Ph.D., University of Wisconsin
Bruce J. Peterson, Senior Scientist
   Ph.D., Cornell University
Gaius R. Shaver, Senior Scientist
   Ph.D., Duke University
Linda A. Deegan, Associate Scientist
   Ph.D., Louisiana State University
Anne E. Giblin, Associate Scientist
   Ph.D., Boston University Marine Program
Edward B. Rastetter, Associate Scientist
   Ph.D., University of Virginia
Christopher Neill, Assistant Scientist
   Ph.D., University of Massachusetts at Amherst
Joseph J. Vallino, Assistant Scientist
   Ph.D., Massachusetts Institute of Technology
Mathew Williams, Assistant Scientist
   Ph.D., University of East Anglia
Paul A. Steudler, Senior Research Specialist
   M.S., University of Oklahoma
Darrell A. Herbert, Staff Scientist
   Ph.D., University of Hawaii
Robert M. Holmes, Staff Scientist
   Ph.D., Arizona State University
Jeffrey E. Hughes, Staff Scientist
   Ph.D., University of Rhode Island
Hanqin Tian, Staff Scientist
   Ph.D., State University of New York, Syracuse

Educational Staff Appointments
Brian Bovard, Postdoctoral Scientist
   Ph.D., Duke University
Karen Buzby, Postdoctoral Scientist
   Ph.D., State University of New York, Syracuse
Matthew D. Cieri, Postdoctoral Scientist
   Ph.D., University of Maine
Byron Crump, Postdoctoral Scientist
   Ph.D., University of Washington
Diana C. Garcia-Montiel, Postdoctoral Scientist
   Ph.D., Colorado State University, Fort Collins
Laura Gough, Postdoctoral Scientist
   Ph.D., Louisiana State University
Anne E. Hartley, Postdoctoral Scientist
   Ph.D., Duke University
Inger Kappel-Schmidt, Postdoctoral Scientist
   Ph.D., University of Copenhagen
Annika Nordin, Postdoctoral Scientist
   Ph.D., Swedish University of Agricultural Sciences
Peter Raymond, Postdoctoral Scientist
   Ph.D., Virginia Institute of Marine Science/College of William and Mary
Craig R. Tobias, Postdoctoral Scientist
   Ph.D., Virginia Institute of Marine Science/College of William and Mary

Technical Staff
Toby Ahrens, Research Assistant
   B.A., Connecticut College
Michele P. Bahr, Research Assistant
   M.S., University of Hawaii
Neil D. Bettez, Research Assistant
   M.A., University of North Carolina, Greensboro
James P. Byun, Research Assistant
   B.S., Yale University
Elizabeth Carpino, Research Assistant
   M.E.M., Duke University
Lodevius H. J. M. Claessens, Research Assistant
   M.S., Colorado State University, Fort Collins
Benjamin P. Colman, Research Assistant
   B.A., Carleton College

Mardi Bowles, Debbie Scanlon, John Hobbie
Martha R. Downs, Research Assistant
B.S., Cornell University
Mary Kay Fox, Research Assistant
M.S., University of Minnesota
Robert H. Garritt, Senior Research Assistant
M.S., Cornell University
Keri J. Holland, Research Assistant
B.A., Trinity College
Yarek Hrywna, Research Assistant
M.S., Michigan State University
Sarah A. Jablonski, Research Assistant
B.S., Dickinson College
Tracy A. Jillson, Research Assistant
B.S., University of Massachusetts, Boston
Samuel Kelsey, Research Assistant
B.S., Dickinson College
David W. Kicklighter, Senior Research Assistant
M.S., University of Montana
Andrew Kleinhenz, Research Assistant
B.A., Kent State University
Bonnie L. Kwiatkowski, Research Assistant
M.S., University of New Hampshire
James A. Laundre, Senior Research Assistant
M.S., University of Connecticut
Heidi Lux, Research Assistant
M.S., West Virginia University
Patricia Micks, Research Assistant
M.S., University of New Hampshire
Kathleen M. Newkirk, Research Assistant
M.S., Virginia Polytechnic Institute
Amy L. Nolin, Research Assistant
B.A., Wheaton College
Genevieve Nowicki, Research Assistant
B.S., University of California, Berkeley
Shufen Pan, Research Assistant
M.S., University of Business and Economics at Beijing, Southwest University
Kathleen M. Regan, Research Assistant
Cleveland State University
Andrea Ricca, Research Assistant
B.A., University of Hartford
Carol Schwamb, Laboratory Assistant
University of Connecticut
Karie A. Slavik, Research Assistant
M.S., Bowling Green State University
Kama K. Thieler, Research Assistant
M.S., Duke University

Kristin S. Tholke, Research Assistant
M.S., University of Connecticut
Suzanne M. Thomas, Research Assistant
M.S., University of Pennsylvania
Jane Tucker, Senior Research Assistant
M.S., University of North Carolina
David S. Vasiliou, Research Assistant
B.S., Pennsylvania State University
Nathaniel B. Weston, Research Assistant
B.A., Hampshire College
Wilfred M. Wollheim, Research Assistant
M.S., University of Wyoming
Amos Wright, Research Assistant
B.A., Hampshire College
Jason C. Wyda, Research Assistant
M.S., Florida Institute of Technology

Consultants
Francis P. Bowles, Research Systems Consultant
Principal, Research Designs
Ph.D., Harvard University
Margaret C. Bowles, Administrative Consultant
B.A., Bryn Mawr College
Heidi E. Golden, Research Consultant
M.S., University of Massachusetts
Alexander Igorevich Shiklomanov
The State Scientific Center of the Russian Federation, Arctic and Antarctic Research Institute, (AARI)
St. Petersburg, Russia

Visiting Scientists and Scholars
Gary Banta, Visiting Scientist
Roskilde University, Roskilde, Denmark
Wei Jun Cai, Visiting Scientist
University of Georgia
Thomas Duncan, Visiting Scientist
Nichols College
Dirk Fleischer, Visiting Student
Friedrich-Alexander Universität Erlangen-Nürnberg, Germany
Thomas Mondrup, Visiting Student
Roskilde University, Roskilde, Denmark
Marianne Moore, SES Faculty Fellow
Wellesley College
Thomas Millette, SES Faculty Fellow
Mount Holyoke College


In Press


Crump, B. C., and J. A. Baross. Archaea plankton in the Columbia River, its estuary and the adjacent coastal ocean, USA. *FEMS Microbiology Ecology*


Holmes, R. M., B. J. Peterson, V. V. Gordeev, A. Zhulidov, M. Meyback, R. B. Lammers, and C. J. Vörösmarty. Flux of nutrients from Russian rivers to the Arctic Ocean: Can we establish a baseline against which to judge future changes? *Water Resources Research.*


Tian, H., C. A. S. Hall and Y. Qi. Increased biotic metabolism of the biosphere inferred from observed data and model. Science in China, Series B.


Autumn colors with the Brooks Range in the background, near the Sagavanirktok River, Alaska.
GRANTS FOR RESEARCH AND EDUCATION IN EFFECT DURING 1999

I. National Science Foundation

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

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

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

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

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

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

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

NSF-DEB-9628860
"Nitrogen Uptake, Retention, and Cycling in Stream Ecosystems: An Intersite 15N Tracer Experiment" (subcontract from Virginia Polytechnic Institute and State University)
September 1996 – August 2000
Investigator: Peterson $327,347

NSF-DEB-9615062
"RUI: Using a Paleolimnological Approach to Assess the Interactive Effects of Acidic Deposition and Eutrophication on Softwater Lakes"
September 1997 – May 2000
Investigator: Giblin $15,524

NSF-DEB-9708092
"Physiological and Molecular Diversity of Atmospheric CH4 Oxidizers in Soil"
August 1997 – July 2000
Investigator: Steudler $600,000

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

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

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

NSF-DEB-9815990
"Effects of N Deposition on Forest C Balance: Long-term Responses at Stand and Regional Scales"
March 1999 – February 2002
Investigator: Nadelhoffer $744,506

NSF-DEB-9815598
"Ecosystem Controls on the Biogeochemical Processing of Watershed-Derived Nitrogen in Tidal Rivers"
March 1999 – February 2002
Investigators: Peterson, Deegan, Vallino $813,000

NSF-EAR-9807632
"Predictions of Bioavailability of Riverine Dissolved Organic Matter from Bulk Measures of Geochemical Composition"
October 1998 – September 2000
Investigators: Hopkinson, Vallino $259,483

NSF-MCB-9977897
"Salt Marsh Microbes and Microbial Processes: Sulfur and Nitrogen"
September 1999 – August 2002
Investigator: Hobbie $996,839

NSF - OCE-9416294
"Coordination for Land-Margin Ecosystem Research (LMER)"
September 1994 – February 2000
Investigator: Hobbie $543,936
NSF-OCE-9726921
"LTER: Plum Island Sound Comparative Ecosystem Study (PISCES): Effects of Changing Land Cover, Climate and Sea Level on Estuarine Trophic Dynamics"
January 1998 – December 2004
Investigators: Hopkinson, Deegan, Giblin, Hobbie, Peterson, Vallino
$3,359,981

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

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

NSF - OPP-9400722
"Controls of Structure and Function of Aquatic Ecosystems in the Arctic"
June 1994 – May 1999
Investigators: Hobbie, Deegan, Peterson, Rastetter
$2,731,000

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

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

NSF-OPP-9524740
"Contemporary Water and Constituent Balances for the Pan-Arctic Drainage System: Continent to Coastal Ocean Fluxes"
October 1995 – August 2000
Investigator: Peterson
$959,987

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

NSF-OPP-9615942
"Belowground Carbon Sources and Sinks in Arctic Tundra Ecosystems"
April 1997 – March 2000
Investigator: Nadelhoffer
$478,000

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

NSF-OPP-9615563
"Global Change and the Carbon Balance of Arctic Ecosystems: The Importance of Carbon-Nutrient Interactions in Soils"
April 1997 – March 2001
Investigators: Nadelhoffer, Giblin, Shaver
$742,776

NSF-OPP-9614038
"Modeling Canopy Carbon and Energy Balances in the Pan-Arctic: Scaling from Leaf to Region"
September 1996 – August 2000
Investigators: Rastetter, Shaver, Williams
$285,707

NSF-OPP-9614253
"The Role of High Latitude Ecosystems in the Global Carbon Cycle"
(subcontract from the University of Alaska)
September 1996 – August 2000
Investigator: Melillo
$115,000

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

NSF-OPP-9714327
"LEXEN: Ecology of Microbial Systems in Extreme Environments: The Role of Nanoflagellates in Cold and Nutrient-Poor Arctic Freshwaters"
September 1997 – August 2000
Investigators: Hobbie, Sogin
$300,000

NSF-OPP-9818199
"Water and Constituent Fluxes Across the Eurasian Arctic: Evolving Land-Ocean Connections over the Past 20,000 Years"
April 1999 – March 2002
Investigators: Peterson, Holmes
$978,628

NSF-OPP-9904392
"GCSE Conference: How Nutrient Cycles Constrain Carbon Balances in Boreal Forests and Arctic Tundra"
March 1999 – September 2000
Investigator: Nadelhoffer
$25,090
II. U.S. Department of Energy

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

DOE DEFG02-92ER61438
"Origins and Fates of Dissolved Organic Matter along the New England Continental Margin"
June 1992 – May 1999
Investigator: Hopkinson $1,316,891

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

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

III. National Aeronautics and Space Administration

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

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

NASA NCC-5-338
"Modeling the Biogeochemical System of the Terrestrial Amazon: Issues for Sustainability"
(subcontract from the University of New Hampshire)
Investigator: Melillo $278,895

NASA-NAG5-3859
"Trace Gas Fluxes Associated with Land-Cover and Land-Use Changes in the Brazilian Amazon Basin"
February 1997 – January 2001
Investigators: Melillo, Neill, Steudler $800,000

NASA-NCC-279
"Linking Soil Biogeochemistry to Surface Water Chemistry in Small Drainage Basins of the Amazon"
Investigators: Deegan, Neill $477,191

NASA-NCC-293
"A Modeling Synthesis of the Impacts of Tropical Forest Conversion on Carbon Fluxes and Storage, and on Nutrient Dynamics in Amazonia"
Investigators: Williams, Rastetter $328,673

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

IV. National Oceanic and Atmospheric Administration

NOAA-NA76FD106
"Establishing the Food Web Links Between Estuaries and Nearshore Fisheries in New England"
April 1997 – March 1999
Investigator: Deegan $30,666

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

NOAA-NA770R0357
"A Diagnostic Framework for Characterizing the Status of the Gulf of Maine Watershed and its Contribution of Freshwater and Constituents to the Coastal Zone"
(subcontract from The University of New Hampshire)
April 1999 – July 2001
Investigator: Peterson $21,000

NOAA-NA86RG0075
"Controls on Nitrogen Fluxes from Estuarine Sediments: The Importance of Salinity"
(subcontract from The Woods Hole Oceanographic Institution)
March 1999 – February 2001
Investigators: Giblin, Hopkinson $164,010

V. U.S. Environmental Protection Agency

EPA-CR 823713-01-0
"Interaction of Factors that Control Greenhouse Gas Fluxes: A Transect Study"
June 1995 – June 2000
Investigators: Melillo, Steudler $1,043,936
VI. U.S. Department of Agriculture

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

SRS 33-CA-97-073
"PnET-IIS/TEM Model Comparison and Expansion, Phase II"
April 1997 – April 2000
Investigator: Peterson $83,468

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

VII. Electric Power Research Institute

Electric Power Research Institute-RP3316-04
"Vegetation/Ecosystem Modeling and Analysis Project"
September 1993 – December 2000
Investigator: Melillo $906,703

VIII. Other Research Grants

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

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

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

Sweden Nature Protection Agency-802-116-94-Ff
"Ecological Responses to Increases in Carbon Dioxide Concentration and Temperature: A Global Change Study at Abisko, Sweden"
July 1994 – December 1999
Investigator: Melillo $155,904

Exxon Corporation
(subcontract from the Bermuda Biological Station for Research)
"Investigate the Cycling of Natural and Man-made Nitrogen Compounds Between the Atmosphere, the Land Environment and the Ocean"
January 1997 – December 1999
Investigator: Melillo $55,000

Texaco Foundation
"Environmental Fellowship Program"
September 1990 – December 2000
Investigator: Melillo $485,000

Exxon Corporation
"Global Change Research"
April 1994 – December 2000
Investigator: Melillo $200,000

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

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

Massachusetts Institute of Technology 5700000403
"MBL-MIT Cooperative Research Activity"
July 1997 – December 2001
Investigator: Melillo $313,219

Grants for Support of Semester in Environmental Science and Facilities

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

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

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

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

Charles E. Culpeper Foundation
"Semester in Environmental Science"
April 1997 – April 2000 $150,000
The annual operating budget of The Ecosystems Center for 1999 was $8,315,376, 18.7% higher than the previous year. Roughly 80% of the income of the center comes from grants for basic research from government agencies. The other 20% comes from gifts and grants from private foundations, including support for the Semester in Environmental Science, as well as from institutional support for administration and income from the center's reserve and endowment funds.

These non-governmental funds provide flexibility for the development of new research projects, public policy activities and educational programs. More information about sources of support appears in the Introduction to The Ecosystems Center and in Research Grants in Effect in 1999.

The combined total value of the center’s reserve fund and endowment at the end of 1999 was $7,285,000, an increase of 15.5% from the 1998 year-end value of $6,306,351. Income from the reserve fund and endowment helps defray the costs of operations, writing proposals, consulting for government agencies and the center's seminar program.

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

Atlantic Richfield Foundation
The Burroughs Wellcome Fund
Robert Sterling Clark Foundation, Inc.
The Clowes Fund, Inc.
Conservation, Food & Health Foundation, Inc.
The Jessie B. Cox Charitable Trust
Charles E. Culpeper Foundation, Inc.
Arthur Vining Davis Foundations
Davis Educational Foundation
Henry L. and Grace Doherty Charitable Foundation, Inc.
Electric Power Research Institute
Environmental Resources Management Group
Exxon Corporation
Max C. Fleischmann Foundation
The Ford Foundation
General Electric Foundation
Grace Foundation, Inc.
The Grass Foundation
The Harken Foundation
Charles Hayden Foundation
International Business Machines Foundation
Charles A. Lindbergh Fund
The Andrew W. Mellon Foundation
NL Industries Foundation, Inc.
Jessie Smith Noyes Foundation, Inc.
Rockefeller Brothers Fund
The Rockefeller Foundation
Rowland Foundation, Inc.
Scherman Foundation, Inc.
Phoebe Speck Sunshine Fund
The Starr Foundation
Surdna Foundation, Inc.
Sweet Water Trust
Texaco Foundation
Wingwalker Initiatives
THE ECOSYSTEMS CENTER
MARINE BIOLOGICAL LABORATORY
7 MBL Street, Woods Hole, Massachusetts 02543-1031
(508) 548-3705
Internet: info@mbl.edu
MBL home page: http://www.mbl.edu