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INTRODUCTION TO THE ECOSYSTEMS CENTER

The Center was founded in 1975 as a year-round program of the Marine Biological Laboratory, a private research institution located in Woods Hole, Massachusetts. The goals of the Center are to investigate the interactions of organisms with their environment and to apply the resulting knowledge for wise management of natural resources. The Center is organized as an association of ecologists under a director, John E. Hobbie; most decisions are made collegially. Funding for the Center comes mostly from competitive government grants but vital support for salaries, administration and research also comes from a reserve fund created by awards from private foundations.

We believe the research goal can best be met by studies organized around an ecosystem. An ecosystem, which can range in size from a square meter of a coastal sediment to an entire forest, is the smallest ecological unit that contains all of the processes, organisms, and interactions necessary to reflect the complexity of nature. Ecologists who study ecosystems may make measurements of a large-scale process which integrates a number of reactions, such as the release of carbon dioxide from a forest floor, or may measure a single process (such as nitrogen fixation) or population (such as the numbers of a single type of planktonic algae). Ecosystem ecologists make decisions about what to study according to whether or not an important ecosystem population, species, or flux of elements or energy are affected or controlled. This criterion for judgement, that is, based upon the importance to ecosystem structure or function, distinguishes ecosystem ecologists from species, population, or community ecologists who may often make some of the same types of measurements.

It is difficult for one person to have all of the skills necessary to study ecosystems. Accordingly, the skills of the Center’s ten scientists include terrestrial and aquatic ecology, microbiology, chemistry, remote sensing, botany, zoology, physiology and modeling. Each has his own project but also works with the others on various grants and in various combinations. One of the strengths of the Center is the ability of those scientists to interact closely over the years; the constant challenge and stimulation is invaluable.

The offices of the Ecosystems Center staff are located in the Homestead Building; the adjoining Environmental Sciences Building contains the aquatic, terrestrial and chemical laboratories. The aquatic and terrestrial labs are shared by all the projects and are used for sample preparation, radiometric experiments, and microscopy. The chemistry lab, shared by all, contains such instruments as an Auto-Analyzer, gas chromatographs, an ion chromatograph, an emission spectrometer for 15N, and other spectrometers. In 1985, the Center also began construction on a mass spectrometer facility for analysis of the ratios of isotopes of carbon, hydrogen, oxygen, nitrogen and sulfur.

The research projects at the Center are mostly funded by the National Science Foundation; there are also grants from the Department of Energy and NASA. Almost all of the grants are cooperative ones. That is, there are at least two scientists from the Center on every grant or a Center scientist and a scientist from outside the MBL. One grant, the NSF carbon project, includes four scientists from the Center and one from the University of New Hampshire. Finally, the realities of the granting process dictate that each of the Center staff is on three or more grants at any given time. While this arrangement means the staff is continually involved in writing proposals and reports, there are great benefits to the investigators through learning about many aspects of ecosystem ecology.

The second goal of the Ecosystems Center, that of application of knowledge to the management of natural resources, is approached in a number of ways. Some of the Center’s research, such as that on acid rain and groundwater quality, will provide answers immediately useful to managers and governments. Some of the time of Center scientists is spent in consulting with government agencies, such as EPA, or with environmental groups and in serving on committees of the National Research Council.
View of the Homestead Building and Environmental Science Building from the MBL quadrangle.
GLOBAL ECOLOGY

The study of the fluxes of energy and matter between ecosystems and the atmosphere is an aspect of ecology appropriately studied at the global level because the atmosphere is a well-mixed reservoir and thus budgets of heat, energy, and gases can be tractably quantified. One advantage of working at the global level derives from the conservation of mass and energy. Individual measurements at specific ecosystems over the earth’s surface must sum to a global total that is measured or measurable independently. Once an initial global budget has been constructed, the relative importance of different processes or different geographic regions becomes obvious and allows research priorities to be set.

One question that must be studied at the global level is the causes of increases in the concentrations of CO₂ and other trace gases in the atmosphere. The sources of these greenhouse gases to the atmosphere are largely biotic although their rates of release are influenced by human activity. Management can occur only when scientists identify the sources and sinks of these gases and document the factors controlling their rates of exchange with the atmosphere.

Trace amounts of carbon, nitrogen and sulfur gases play a significant role in the control of the chemistry and heat budget of the atmosphere. Buildup of such gases as organic sulfur gases, carbonyl sulfide (COS) and carbon disulfide (CS₂), may have as much of an influence on future climate as the buildup of carbon dioxide. While we know a great deal about the loading of the atmosphere with carbon dioxide and we are gaining a better understanding of the sources of some of the trace gases such as methane (CH₄), nitrous oxide (N₂O) and the Freons, relatively little is known about the sources of the important sulfur gases such as COS and CS₂. Based on a field study of gaseous sulfur fluxes from salt marsh sediments (Steudler and Peterson), our review of literature, and some preliminary field measurements from forest soils, we have reached two conclusions: 1) biotic sources and not industrial sources dominate the global COS and CS₂ emissions to the atmosphere (Figure 1), and 2) upland soils may be the major biotic source of these two compounds.

A large fraction of the upland soils of the world are covered by forests. In the northern hemisphere, many of these forests receive high inputs of sulfur and nitrogen associated with acid rain. We have hypothesized that the higher the sulfur and nitrogen inputs in acid rain, the higher the COS and CS₂ emissions. The temperate and boreal forests that are under the influence of acid rain may account for as much as 45% of the COS and CS₂ entering the atmosphere. The acid rain contains increased amounts of sulfur and nitrogen from the combustion of fossil fuel. Thus, while industrial activity is directly responsible for a small fraction of the COS and CS₂ emissions to the atmosphere, industrial activity may be indirectly responsible for a major fraction of these releases.

We are measuring COS and CS₂ emissions from forest ecosystems along two acid-rain gradients in the northern hemisphere; one in eastern North America and the other in western Europe. Results to date from the forest site (Figure 2) we are studying most intensely, the Harvard Forest in Petersham, Massachusetts, support our contention that temperate and boreal forests are net sources of COS and CS₂ to the atmosphere.

We are also measuring these sulfur gas fluxes from forest sites receiving different levels of nitrogen fertilization to test the hypothesis that nitrogen availability at a site (and thus nitrogen input in acid rain) is directly related to COS and CS₂ fluxes from the soil.
Figure 1.
Global COS and CS₂ budget.

Figure 2.
Net fluxes of COS and CS₂ over a 24-hour sampling period from soils in a mixed hardwood stand at Harvard Forest, 18 October 1985. Also, measurements of the following environmental variables: air temperature, soil temperature and illumination.
REMOTE SENSING IN THE TROPICS
Thomas A. Stone

Ecologists are accustomed to collecting data on the basis of a square meter or even a hectare. It is difficult, however, to use this type of data to calculate a global rate. At the very least, there is the problem of geographic variation and many ecologists believe other scaling problems exist. For some ecological processes, it is possible to take a direct approach and to use remote sensing to construct global rates.

We are using satellite data from the tropics both to analyze rates of deforestation and to improve the quality and timeliness of data from ground surveys. Improved data on the rates of clearing will not only improve our knowledge of the global carbon cycle but may also aid in preservation and better management as the high rate of clearing becomes better known.

For example, we are developing a technique to combine higher resolution Landsat satellite data (40 to 80 m resolution) and NOAA AVHRR data (1.1 km of resolution) to define the deforestation rate of the Texas-sized state of Mato Grosso in the Brazilian Amazon Basin. With co-workers at NASA’s Goddard Space Flight Center, we first stratified Mato Grosso into regions of low and high rates of forest clearing activity using several months of composited AVHRR data from a near-infrared sensor band (0.5 to 3.9 microns). In this region, all of the clearing is by burning and this band shows the location of fires. We examined data from the entire dry season, the period of maximum clearing by burning. Using this information, we purchased Landsat data for specific regions within Mato Grosso. After determining clearing rates within each Landsat scene (185 × 185 km), we can scale up this higher resolution data with the lower resolution AVHRR data and develop clearing rates for the entire state. Scaling up is done by calibration of total forest clearing determined with higher resolution Landsat data with forest clearing determined with lower resolution AVHRR data in a small area. We then examine a larger area with AVHRR data to determine the amount of forest cleared and adjust or calibrate that value based on the high resolution Landsat subsample. If successful, and a preliminary study in the smaller Brazilian state of Rondonia suggests that it will be (Figure 1), this same approach can be applied to the tropical forests of the world to provide timely and unbiased statistics on forest clearing rates (Figure 2).

All clearing is by burning. This 45 day old burn area will most likely be planted directly into pasture. Little timber is extracted before burning.
Figure 1.
Total deforestation in the Brazilian Amazon Basin state of Rondonia by several estimates including our own based on Landsat-calibrated AVHRR satellite data.

Figure 2.
Carbon \(10^{12}\) grams lost to the atmosphere over time from deforestation in the area of one Landsat scene (32,000 km\(^2\)) calculated from estimates of deforestation based on satellite data. We used two different estimates from the literature of the stock of carbon in the soils and biota of Rondonia, Brazil.
The changes in the global carbon budget can be summarized in four terms: increase in the atmosphere, uptake by oceans, release from fossil fuels, and uptake or release from terrestrial ecosystems. After more than 15 years of research on the topic, scientists cannot make the terms balance. The calculated annual releases of carbon to the atmosphere from fossil fuels and terrestrial ecosystems are greater than the sum of the calculated uptake by the oceans and the observed accumulation in the atmosphere. Explanations for the imbalance include possible errors (in the terrestrial and oceanic terms), poor documentation of atmospheric CO₂ concentrations prior to 1957, and the possibility that the calculated net flux of carbon from terrestrial ecosystems has estimated only a part of the total net flux. Most of the ecological research on this topic carried out at the Center and elsewhere has addressed the net flux of carbon to or from terrestrial ecosystems as a result of changes in land use. Deforestation causes a release of carbon to the atmosphere; the regrowth of forests following abandonment of agriculture stores carbon on land. In addition to the net flux of carbon caused by these changes, there is also a possibility that changes in the environment have caused a net storage of carbon on land. Subtle changes in global climate or changes in the availability of nutrients are examples of environmental changes that might affect the net storage of carbon on land.

The discrepancies in the global carbon budget might be resolved, or at least more precisely defined, if the estimates of the global fluxes of CO₂ between the atmosphere and fossil fuels, oceans, and terrestrial ecosystems could be disaggregated and distributed among geographic regions. Together with models of atmospheric circulation and measurements of CO₂ concentrations at various locations over the earth, these estimates of terrestrial storage and release might identify the specific locations of the budget errors.

The regional estimates of the net flux of carbon, those due only to changes in land use, have been calculated at The Ecosystems Center (Figure 1). Estimates of a net flux were distributed among tropical countries on the basis of deforestation rates reported by a recent FAO/UNEP survey of tropical forests. The rates of deforestation were weighted by the volumes of wood per unit area in those forests (again the FAO/UNEP survey provided the estimates of wood volume). The white, grey, and black shades represent the intensity (black is highest) of the net release of carbon from different regions of the earth’s surface. It is immediately clear from the world map that almost all of the release was from the tropics in 1980. Net releases from North America, Europe, and the U.S.S.R. were so small as to be insignificant in the global total.

Research on the effects of changes in the environment on carbon storage in terrestrial ecosystems is in its initial stages at the Center. The approach is to construct a generic model of the important ecosystem processes that determine the cycling of carbon and nutrients: primary production, decomposition, and mineralization. The model will be applied to various areas of the globe in half degree by half degree sections using a University of New Hampshire computer. How are these processes affected by warming temperatures and wetter or drier climates? The answers to these questions appear to be known for specific processes controlled in the laboratory, but they are not known for natural ecosystems. As evidence of a climatic change becomes stronger, the need for predictions of its direction and magnitude will become more urgent.
WHOLE ECOSYSTEMS
EXPERIMENTS AND
OBSERVATIONS

Experiments at the ecosystem level are critical in order to test and constrain predictions based on knowledge of individual ecological processes. Without controlled experiments it is difficult to isolate and compare the components of response to a complex environmental change. It is especially difficult to determine the importance of interactions between processes without ecosystem-level experiments.

Whole ecosystems are not very tractable experimental units. Most natural ecosystems are highly complex, extremely diverse, and have boundaries that are poorly defined. The size, spacing, and diversity of the organisms in them often means that experimental units must be so large that experimentation is very expensive and difficult to justify. The logistical difficulties and expense of sampling such large and diverse areas mean that replication is often impractical and sampling must be stratified or aggregated, with a consequent loss of information.

EXPERIMENTAL
STUDIES AT THE
ECOSYSTEM LEVEL:
WHY WORK IN ALASKA?

Gaius R. Shaver
Bruce J. Peterson

One solution to this problem of experimental ecology is to create microcosms in the laboratory that are simple and can be enclosed in a reasonable volume, yet include a representative level of the diversity of natural ecosystems. The microcosm approach is extremely useful and we have used it successfully in many of the research projects done at The Ecosystems Center. Microcosms help greatly to understand interactions between processes and between organisms, but they cannot substitute completely for field experiments.

Another solution is to find natural ecosystems that are relatively simple, that can be sampled intensively and with reasonable replication, and that can be manipulated with a minimum of expense and logistical difficulties. These systems are abundant in northern Alaska, where the staff of The Ecosystems Center has been experimenting with both terrestrial and aquatic ecosystems for the past ten years. These arctic ecosystems offer the further advantages of a nearly pristine environment and the possibility of long-term research without unwanted disturbances.

In terrestrial ecology, Gus Shaver has been working for several years near Toolik Lake, Alaska, trying to understand the controls on the distribution of plant growth forms in tundra ecosystems. The question is important because many ecologists believe that functional differences in nutrient use between growth forms may have considerable influence on overall ecosystem nutrient cycles. More recently, Shaver, Anne Giblin and Knute Nadelhoffer have begun research on the importance of nutrient movement between ecosystem types, across the tundra landscape. Both of these projects depend upon ecosystem-level experiments.

The experiments on the abundance of various plant growth forms have included the building of small greenhouses over the tundra to raise air temperature, reduce light intensity, and fertilize (Figure 1). These treatments have been applied both singly and in combination with each other, with dramatic effects on the vegetation (Figure 2). The experiments show clearly that the growth form composition of tundra vegetation is strongly responsive to light, temperature, and nutrient availability.

The results of the experiments were in general predicted by earlier work on individual species, but there were a number of surprises that could not have been anticipated from species- and process-level studies alone. For example, we expected deciduous shrubs to be much more responsive to fertilizer than we actually observed. Although many species-level studies suggested that all species should respond strongly to fertilizer, the graminoid response predominated. The fertilizer-greenhouse interaction for deciduous shrubs was much stronger than we expected, as was the relative lack of response of graminoids to fertilizer plus greenhouse.
Our results indicate that species and growth form interactions must be considered in extrapolating from process-level studies to the whole ecosystem, and illustrate the importance of ecosystem-level experimentation in a field situation. This kind of experiment could not have been done in most temperate ecosystems, such as a deciduous forest. Yet, we believe that the fundamental characteristics of ecosystems should be the same everywhere, and thus arctic ecosystems are important experimental tools for expanding our general knowledge of how ecosystems work.

Also working near Toolik Lake, a team of aquatic ecologists is manipulating tundra lakes and rivers to answer practical questions about the responses of these aquatic ecosystems to stress. The principal investigators include John Hobbs and Bruce Peterson from The Ecosystems Center, Mike Miller and Robie Vestal from the University of Cincinnati, John O'Brien from the University of Kansas, Anne Hershey from the University of Minnesota, Maurice Lock from the University College of North Wales, United Kingdom, and George Kipphut from the University of Alaska.

The experiments on lakes are designed to assess the responsiveness of the biota to disturbances (stress) applied at either the bottom of the food web or at the top. Nutrients added to the water stimulated phytoplankton growth (the bottom of the food web); this increased organic carbon production caused subsequent changes in bacterial biomass and activity in zooplankton, in benthic animals and in sediment chemistry. This type of experiment is being repeated at different levels of nutrient addition and in different size ecosystems ranging from limnocorals to whole lakes. A parallel set of experiments involves modification of the aquatic food web structure by changing the abundance of fish such as grayling. Grayling feed efficiently on large predaceous zooplankton which selectively remove certain species of herbivorous zooplankton. Consequently, the presence or absence of grayling has been shown to markedly affect the structure of the planktonic food web at lower trophic levels.

The river studies are examining the limitation of productivity by phosphorus and nitrogen. By adding phosphorus to the Kuparuk River, it has been possible to show that primary production in the river is often limited by phosphorus alone. When phosphorus is added there is usually a rapid increase in the biomass of algae on the river bottom rocks. Bacterial activity in the slime on the rocks is greatly stimulated as a consequence of the increases in algal activity. Insects which graze on the rocks and which filter particles from the water experience increased growth. On the other hand, decomposition of terrestrial-derived detritus is not greatly affected by the added nutrient.

We have repeated this experiment three times (Figure 3). In 1983 and again in 1984 we found a large and rapid response to phosphorus addition. In 1985 we found

Figure 1.
A field study site near Toolik Lake, Alaska, showing portable greenhouse built over the tundra to raise air temperature. These greenhouses may also be placed over fertilized areas, or shaded to reduce light intensity.
**Figure 2.**
Effects of fertilizer, greenhouse, greenhouse plus fertilizer, and shading on annual productivity of tussock tundra vegetation. The left-hand panel shows the effects of these treatments on total amounts of new biomass produced, and the smaller panels on the right show the percentage of the total amount in each treatment that is due to each of the four major plant growth forms in tussock tundra.

**BELLOW:** The use of limnocorals in Toolik Lake allows the scientists to test the responses of aquatic ecosystems to stress.
only a slow and small response to added phosphorus. We think the relatively poor response in 1985 was caused by the lack of sufficient nitrate to allow rapid growth. We know from previous studies that nitrate concentrations are inversely related to discharge and that riverine nitrate concentration increases as the season advances. In 1985 we had a late thaw and high flows early in the experiment and consequently nitrate concentrations were unusually low. In bioassay experiments either ammonium or nitrate added to phosphorus-enriched river water stimulated rapid algal growth. To further examine the effects of nitrate, we plan to enrich the whole river with both phosphorus and nitrogen in 1986.

This case of dual nitrogen and phosphorus limitation is a good example of the variable interaction between two element cycles which creates important year-to-year differences in productivity that affect the entire ecosystem. It is also an excellent example of the way in which biological activity in the river ecosystem is directly dependent on terrestrial soil processes. The nitrate required to produce algal biomass is derived from the nitrification process which occurs most vigorously in the mineral soils of the tundra. The supply of nitrate to the river can be limited by a low rate of nitrification, by a loss of fixed nitrogen by denitrification, by the uptake of nitrate by terrestrial vegetation, or by lack of soil water flow to transport the nitrate. Thus, understanding the factors regulating river and lake ecosystem production will ultimately require close cooperation between terrestrial scientists interested in nitrogen budgets of tundra and aquatic ecologists studying the metabolism of rivers and lakes.

Insight gained from the river and lake experiments has important practical application in predicting and controlling the environmental changes that accompany human activity. We can use the experimental results to predict what will happen to lakes and rivers when sewage effluent rich in nitrogen and phosphorus is discharged. And we can predict the ecosystem-level consequences of overfishing of the long-lived top predator fishes in arctic lakes and streams. These are two of the most common and widespread impacts of man on tundra ecosystems. While we can not eliminate human impacts, we can use the knowledge gained through ecological research to either minimize adverse effects or to take advantage of opportunities to increase rather than deplete the productivity of arctic ecosystems.

Figure 3.
Effect of phosphorus addition on chlorophyll concentration (an indicator of productivity) in the Kuparuk River, near Toolik Lake. Phosphorus was added as phosphoric acid from a constant-flow dripper; the horizontal axis indicates distance downstream.
ELEMENT INTERACTIONS IN FOREST ECOSYSTEMS
Jerry M. Melillo
Knute Nadelhoffer

During the past two decades there has been impressive progress in the study of whole ecosystems. Research at the ecosystem level has had three main themes: development of carbon and nutrient budgets for "reference" ecosystems; experimental manipulation of ecosystems to determine the effects of disturbance (e.g., clearcutting, fire, eutrophication) on nutrient cycling patterns; and detailed process studies designed to elucidate factors that control carbon and nutrient dynamics within and among ecosystems. As ecosystem research proceeds, we are beginning to recognize that an understanding of the mechanisms that control the flux rates of an element within or among ecosystems requires consideration of element interactions.

In our studies of forest ecosystems of the temperate zone, we have focused on carbon-nitrogen interactions because nitrogen is thought to be an important growth limiting factor in these systems. Working in collaboration with John Aber and his colleagues at the University of Wisconsin, we have studied the relationship between inorganic nitrogen availability in soils and the net primary production (net carbon fixation by plants) in 18 coniferous and deciduous forests in Wisconsin and Massachusetts. A strong correlation between measured nitrogen availability (annual nitrogen mineralization) and aboveground production suggests an important role for nitrogen in controlling net primary production (Figure 1).

Our studies of carbon-nitrogen interactions in forests have also led us to develop hypotheses about how the form of inorganic nitrogen (ammonium versus nitrate) available to plants influences the mass of fine roots and their turnover rate. Based on the study of fine roots in 13 stands in Wisconsin and Massachusetts, we suggest the following: 1) mean total fine root mass declines as nitrate becomes the dominant form of inorganic nitrogen available to plants; 2) fine root turnover increases with increasing nitrogen availability and it may be affected by the form of nitrogen available, with the highest rates of turnover being in forest stands with nitrate economies.

To test these hypotheses, we are performing "whole ecosystem" manipulations in which we are attempting to increase nitrogen availability and to switch the form of nitrogen available from ammonium to nitrate. Through the heavy application of lime over the past two years to large areas in a red pine plantation in Massachusetts, we have altered decomposition processes in the soil and increased by 57% the amount of nitrogen available to the plants each year in manipulated (limed) plots relative to control (unlimed) plots (Table 1). We are also beginning to see more nitrate being produced in the limed plots than in the controls, although ammonium is still the dominant form of inorganic nitrogen available to the plants in the limed plots. In a preliminary survey of the root systems in the limed and control plots that we conducted in conjunction with A. E. Linkins and Robert Antibus of Clarkson University, we found that fine root mass and the extent of micorrhizal infection of fine roots appeared to have been reduced in the limed plots relative to the controls, but we need to collect more data on the responses to liming to confirm the results of the preliminary survey.
Table 1.
Nitrogen mineralization rates (kg/ha/yr) in control and limed plots in a red pine plantation at the Harvard Forest in central Massachusetts. The rates are for the top 10 cm of soil.

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<th>HORIZON</th>
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<td>Forest Floor</td>
<td>14.7</td>
<td>20.2</td>
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<tr>
<td>Mineral Soil</td>
<td>15.3</td>
<td>26.9</td>
</tr>
<tr>
<td>Total</td>
<td>30.0</td>
<td>47.1</td>
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Figure 1.
The annual net nitrogen mineralization (kg/ha/yr) from in situ incubations vs. aboveground primary production (T/ha/yr).
RESOURCE INTERACTIONS AND PROCESS CONTROLS

From the beginning of the study of ecosystems, the measurement of nutrient budgets and nutrient cycling has been an important approach. In the 1960s and 1970s, complete and complicated cycles for carbon, nitrogen, and phosphorus were made for a number of ecosystems. These constructs of the cycling of a single element are now the basis for our ideas of some of the ways organisms in an ecosystem are linked with each other and with physical and chemical factors of their environment. In some systems, tracking a single element may give all the information necessary about the controls of the various transfers and processes. In most systems, however, it is now known that the cycles of one element are usually controlled by the interactions with another element or elements. For example, it is impossible to understand the regulation of algal photosynthesis in the ocean from measurements of biomass, carbon dioxide, and light; the rate of supply of nitrogen and phosphorus are equally important controls.

ELEMENT INTERACTIONS IN SEDIMENTS

John E. Hobbie

Decomposition of organic matter in estuaries and coastal oceans mostly occurs in the sediments by anaerobic processes linked to sulfate reduction. The main parts of the carbon and sulfur cycles are shown in Figure 1. Each interaction of these two element cycles is indicated by a Roman numeral.

The small organic molecules produced by fermentation bacteria are used for energy by sulfate reducing bacteria (interaction I). In sediments from waters near Woods Hole, there is a direct relationship between the rate of breakdown of acetate, an important small molecule, and the rate of sulfate reduction (Figure 2). The environments range from the oligotrophic Buzzards Bay to the rich sediments in a fertilized experimental mesocosm in Narragansett Bay.

Another interaction is the inhibition of the fermentation process by the buildup of H₂S (II). This inhibition occurs only under very special conditions; our experiments indicate that the fermenting bacteria have an amazing tolerance and are not inhibited by 3 mM H₂S, the maximum we have measured.

When sulfate is abundant and sulfate reduction occurs, then methane production is inhibited (interaction III). If methane formation did occur, then bubbles of methane would move from below the sediment surface to the water and atmosphere. More of the oxidation would occur in the water column than it does now and some energy would even be lost from the sediment systems.

In sediments, the H₂S forms sulfides, usually of iron. When the sediment is disturbed by animals or storms, this sulfide pool is oxidized by any oxygen that is transported down into the sediments. The sulfide pool acts as a buffer (interaction IV) to keep the sediments anaerobic and the fermentors happy.

This interaction of carbon and sulfur cycles illustrates various types of interactions, from those fueling sulfate reduction to those buffering the anaerobic conditions.
Figure 1.
Pathways of carbon and sulfur in anaerobic decomposition in coastal sediments. The Roman numerals refer to interactions described in the text.

ACETATE OXIDATION AND SULFATE REDUCTION

Figure 2.
Daily summer rates of sediment acetate oxidation and sulfate reduction in Buzzards Bay (MA), Eel grass bed (Vineyard Sound, MA), and fertilized experimental chambers at Marine Experimental Research Laboratory (MERL, RI).
Nitrogen (N) metabolism in cells and tissues of forest trees affects both carbon allocation within individual plants and carbon and nitrogen cycling in forest ecosystems because considerable amounts of plant carbon reserves (or photosynthetic) are expended assimilating mineral N into organic compounds. Consequently, carbon allocation to plant organs, such as leaves and roots, is strongly related to rates of N assimilation within the tissues of these organs.

Although the metabolic costs to plants of assimilating either form of mineral N are high, the energy required for assimilating nitrate (NO$_3^-$) into organic compounds is considerably greater than that required for assimilating ammonium (NH$_4^+$). This is because the N in both ammonium and plant amino acids is very reduced (oxidation state = -3), whereas nitrate-N (oxidation state = 5+) is highly oxidized. Thus, when nitrate is the dominant form of mineral N available for uptake from soils, plants must provide more energy for N assimilation.

Many herbaceous plants and some forest tree species are capable of minimizing the potentially high carbon costs of nitrate assimilation by translocating nitrate from roots to leaves. In the leaf, nitrate-N can be reduced in chloroplasts using photosynthetically generated reductants (such as NADPH and ferredoxin) rather than the carbohydrate reserves used in the roots. Because photosynthesis in leaves exposed to direct sunlight is typically limited by CO$_2$ availability, not by supplies of reductant, the excess ferredoxin and NADPH in exposed leaves can be used to chemically reduce and assimilate nitrate into organic compounds. Carbohydrates consumed by nitrate reduction in non-photosynthetic organs such as roots may tax a plant’s carbon reserves considerably and may ultimately restrict overall growth.

The differences between leaf and roots in the carbohydrate requirements for nitrate reduction have led us to ask whether certain tree species might be better adapted to soils with nitrate economies than others. We hypothesized that species well adapted to sites with high soil nitrate availability are likely to reduce more nitrate in leaves than in roots. As a test, we conducted in vivo Nitrate Reductase Assays (NRAs) on fresh leaf and root tissues from four sugar maple stands where soil nitrification rates had been previously measured by our collaborators at the University of Wisconsin, John Aber and Mark Lennon.

Our June 1985 nitrate reductase assays at these sites showed that sugar maple leaves generally had about ten times greater potential for reducing nitrate than did fine roots collected at the same site (compare Figure 1a and 1b). In addition, the potential for reducing nitrate in these forest grown sugar maples differs among sites and appears to increase with soil nitrate availability (Figure 1a). These observations strongly suggest that sugar maple is a species well adapted to sites where soil nitrification is an important process.

Our assays also show that although sugar maple roots apparently reduce only a small percentage of nitrate taken up from soil, nitrate reductase potentials of roots do increase with soil nitrate availability (Figure 1b). This suggests that fine roots of sugar maple on more nitrate rich sites are more metabolically active than on nitrate poor sites and is consistent with our hypothesis that fine roots turn over (or grow and die) more rapidly at nitrate rich sites than at either nitrate poor sites or sites where only ammonium-N is available for plant uptake (see Melillo and Nadelhoffer in this issue).

We are planning further tests of nitrate reduction potentials of other important tree species both in natural stands and in systems where soil nitrate availability is experimentally altered in ecosystem level experiments (see Melillo and Nadelhoffer in this issue). We believe this planned work will allow for developing a better understanding of the implications of ammonium vs. nitrate economies for ecosystem properties such as net primary production, species composition, and nutrient retention.
Figure 1.
Nitrate reductase activity in sugar maple leaves and fine roots from four well-drained Wisconsin sites in relation to field measures of soil nitrate availability. Assays were done using fresh tissue samples incubated in a buffered medium containing 40 mmol nitrate. Units are nitrite produced per unit dry weight of tissue per hour. Vertical lines are ±1 standard error of means. Soil nitrification rates were estimated by Mark Lennon and John Aber using field incubations of soils.
ACID RAIN IN NEW ENGLAND

Anne E. Giblin
Bruce J. Peterson
Brian Fry

Bruce Peterson, Anne Giblin and Brian Fry

Water quality in New England has been reduced by deposition of sulfuric and nitric acids in rainfall (acid rain), in snowfall, and in particles that settle in dry weather. The effect of acid deposition on ecosystem processes and water quality is largely determined by the ability of natural systems to neutralize this acid. We are studying neutralization by ecosystem processes to understand and predict the long term effect of acid precipitation on lakes and drinking water quality.

Bruce Peterson has investigated the relative importance of processes which can neutralize acidity through compiling data on the chemistry of water as it moves from precipitation, to surface water, to groundwater (Figure 1). As water flows through the aquifer there is a decrease in hydrogen ion concentration (acidity) and an increase in the bicarbonate concentration (alkalinity or acid neutralizing capacity). As water moves into the groundwater, clay minerals break down and produce alkalinity. This weathering causes an increase in calcium, magnesium and potassium concentrations. The biological assimilation of nitrogen compounds by plants also changes the alkalinity of water as it passes through the aquifer. The assimilation of ammonium (NH₄⁺) consumes alkalinity while the assimilation of nitrate (NO₃⁻) adds acidity. Overall, nearly all the nitrogen entering with precipitation is consumed and two times more alkalinity is produced than is consumed during nitrogen removal.

The removal of sulfate by biological or abiotic reactions may also affect acidity. In soils, the abiotic adsorption of sulfate by iron and aluminum hydrous oxides results in the displacement of hydroxyl (OH⁻) ions which neutralize some of the acid in precipitation. Preliminary data indicate that the ratio of chloride to sulfate is unchanged in rain and groundwater so this mechanism may not be important in the Cape Cod aquifer (Figure 1).

In the anaerobic zones of lakes, the biological reduction of sulfate to sulfide may also be an important mechanism producing alkalinity. This process occurs in the bottom waters and sediments. The importance of this mechanism to the long term ability of the lake to neutralize acid from precipitation depends upon the fate of the hydrogen sulfide produced by this process. If the hydrogen sulfide reacts with iron or organic material in the sediment and is stored, a net production of alkalinity occurs in the lake. However, if the hydrogen sulfide escapes to surface waters where it can react with oxygen, acid will be regenerated when the sulfide oxidizes back to the sulfate.

Sediment data from lakes in the eastern United States indicate that sulfate reduction may be important in generating alkalinity in some lakes. For example, the amount of sulfur in sediments from two mountain lakes shows an increase near the surface (Figure 2) which may reflect a recent increase in sulfur storage as a
result of increased sulfur inputs from acid precipitation. However, it does not tell us whether or not sulfur is being stored in reduced forms, which would mean that alkalinity was generated, or as oxidized forms, which would not affect the acid budget of the lake. We can use the abundance of two naturally occurring stable isotopes of sulfur to see if sulfur has been reduced. Anaerobic microorganisms which reduce sulfur preferentially use the lighter isotope ($^{32}$S) more than the heavier ($^{34}$S) isotope. Brian Fry has examined the stable isotope ratios from several lakes in the Adirondacks (Figure 2) and found that the lighter form of sulfur is more abundant in the sediments than in the overlying water. This indicates that sulfate reduction is an important process in these lakes.

What controls the form and quantity of reduced sulfur in lake sediments? Anne Giblin and collaborators Bob Howarth at Cornell and Gene Likens of the Institute of Ecosystems Studies have found that substantial quantities of sulfur are stored in some lakes in inorganic reduced forms. A small quantity is present as elemental sulfur but the majority is present as iron minerals, primarily pyrite (FeS$_2$). The amount of inorganic reduced sulfur in the sediments varies considerably between lakes (Figure 3) and may be a function of the availability of iron as well as the chemical, biological and physical characteristics of the lake. The current research concerns the interaction of sulfate loading, iron availability and lake productivity in controlling the accumulation of reduced sulfur in a wide variety of lakes.
BIOLOGICAL PROCESSES
OF NITROGEN REMOVAL
FROM WASTEWATER BY
FORESTS AND TURF:
EFFECTS ON
GROUNDWATER
QUALITY

Marilyn J. Jordan

Contamination of groundwater supplies and depletion of groundwater reserves are becoming serious national problems. Pollution associated with a rapidly growing regional population threatens groundwater quality in many areas including Cape Cod (Barnstable County, MA)—the fastest growing of the 75 New England counties. It is essential on Cape Cod that only high quality water be returned to the underlying groundwater, which is a sole source aquifer. Effluent from domestic septic systems is contaminating the groundwater in the most densely populated areas on the Cape, for only 12% of the Cape’s population is served by sewers. Wastewater collected by municipal sewer systems must receive tertiary treatment if the receiving aquifer is to remain potable.

Land application, an effective means of tertiary wastewater treatment and groundwater recharge, will be employed at the wastewater treatment facility now being constructed by the Cape Cod town of Falmouth. Beginning in the spring of 1987, 400,000 gal/day of secondary treated wastewater will be spray irrigated over 52 acres. About 35% of the irrigated area is a fertile oak-pine forest—80 years of age; an additional 35% is an impoverished 24-year-old pitch pine woodland. The remaining 30% will be perennial grasses seeded along the swaths cleared for the irrigation pipes (Figure 1). Thus, there are three distinct types of vegetation which can be compared under similar conditions of soil, climate, and wastewater irrigation. Adjoining the irrigated area is a control area containing both forest types.

Organic matter and solids are removed by physical filtering and adsorption as applied wastewater percolates through the soil, while chemical reactions and plant uptake remove a significant fraction of many of the major ionic constituents. Nitrate can be particularly difficult to remove since it is soluble in soil water, is not adsorbed to soil particles, and readily leaches to the groundwater. Nitrate can cause human health problems at nitrate-nitrogen concentrations above 10 mg/L (EPA drinking water standard).

The most important role of vegetation in land-based wastewater treatment is in taking up nitrogen. Storage of nitrogen in biomass can be a major short-term mechanism of nitrogen removal from wastewater. In some cases gaseous losses of nitrogen may be considerable (Figure 2). Although considerable physical and chemical information is available for design of land-based wastewater treatment systems, biological information, particularly for forests, is relatively limited. Most research on land treatment has been carried out on crop and grasslands.

Our overall basic research objective is the improvement of our understanding of nitrogen cycling in terrestrial ecosystems, particularly factors regulating microbially mediated denitrification losses and mycorrhizal-nutrient relationships. In the course of carrying out this basic research, we will address the following applied objectives: (1) to determine the effectiveness of N uptake by vegetation, N storage in soil and organic matter, and gaseous losses in removing N from municipal wastewater; (2) provide data needed to improve the accuracy of EPA models used to predict allowable nitrogen loading rates; (3) provide data useful for the design and operation of slow rate land-based wastewater treatment facilities; (4) provide data that could facilitate vegetation management for maximum sustained wastewater renovation; and (5) begin a long-term study of ecosystem efficiency in wastewater renovation in relation to site aging, vegetation type, and possible management and possible management techniques.

We will determine: concentrations of N and P in wastewater, precipitation, soil water and groundwater; storage of N and P in plant biomass, litter, and soil; N and P losses through leaching, and N losses through volatilization of applied NH3. Gaseous losses of N through denitrification will be estimated by the difference between “inputs” and “outputs + storage” (Figure 2). The effectiveness of the above processes in removing N from the applied wastewater will be determined for each vegetation type. We will relate differences in N sequestering capacities to plant species composition, biomass, growth rates, soil fertility and denitrification. Yearly soil fertility testing will also be carried out for K, Ca, Mg and Na. Baseline samples of soil and vegetation will be collected and stored for possible future analysis for heavy metals.
INPUTS = OUTPUTS + STORAGE

Figure 2.
Nitrogen cycling and transport in land treatment of wastewater.

N = nitrogen
NH₃ = ammonia
NH₄⁺ = ammonium
N₂ = nitrogen gas
NO₃ = nitrate
NOₓ = oxides of nitrogen
Research is at the heart of the Center's activities but the research results become valuable only when they are communicated to students, scientists, and policy makers. This communication takes place through courses, presentations at scientific meetings, visiting students and scientists, publications, and expert testimony and advice. At the present time, we give no formal courses but do lecture extensively at various universities and in the MBL Marine Ecology Course. The goal of these lectures is to present our understanding of how ecosystems function and how to approach the study of ecosystems.

It is equally important to the scientists at the Center to have information flowing in as well as out. Short courses and workshops help but even more stimulation and excitement comes from visiting students and scientists. To foster this interaction, the Center supports two postdoctoral fellows, each in residence for two years, and encourages the visits of other scientists. For example, during the summer George Luther, an expert in sulfur chemistry from Kean College, visited the lab for research with Anne Giblin. Also, Paul Novelli from Stony Brook measured hydrogen formation and oxidation in collaboration with the anaerobic sediment project.

Because the MBL does not award degrees, graduate students at the Center are enrolled at a variety of universities. Over the past decade, students from Yale, Harvard, Boston University, and North Carolina State University have carried out research at the Center. During 1985, the graduate students were Colleen Cavanaugh from Harvard, Gary Banta from Boston University, and David White from Boston University. We would like to have more students at the Center but the main barrier continues to be the problems of funding their first two years of school when they must be full-time at their home institution.

Post-doctoral fellows work at the Center in association with at least one staff member, but most have taken full advantage of the diversity of staff and opportunities available at the Center.

Knute Nadelhoffer came to the Center from the University of Wisconsin in September 1983. He has collaborated with Jerry Melillo on carbon and nitrogen interactions in forests, and has worked on various aspects of the Ecosystems Center's global carbon cycling project. Knute has also worked with Gus Shaver and Anne Giblin on the nutrient cycling in landscapes in Alaska. In June, Knute was appointed an assistant scientist. Some of his work appears in earlier sections of this issue.

David Rudnick joined the Center in October 1984, after completing a dissertation in oceanography at the University of Rhode Island. He has worked with John Hobbie and Jonathan Cole on the effects of eutrophication on bacterial production in the sea. Currently, he is working with Bob Hewarth and John Hobbie on anaerobic decomposition processes in marine sediments. Some of the background on the post-doctoral research is described in this report.
The decomposition of organic matter is essential for the maintenance of the food webs and geochemical cycles of all ecosystems. Within the sea, much of this decomposition occurs on and in the sediments. In the coastal region, between 10% and 60% of the phytoplankton production is oxidized by sedimentary organisms (the benthos). Most of this decomposition occurs soon after particles fall to the bottom (days to weeks), but some organic particles remain in the sediments for months to thousands of years.

What controls the decomposition rate of these particles? Major factors that are usually considered are the "quality" of organic matter, the availability of oxygen, and the accumulation of inhibitory metabolic byproducts (such as sulfides). Measurements of organic carbon accumulation rates indicate that the availability of oxygen is an important factor, since accumulation rates are very high under anoxic waters. However, such high rates may merely be a reflection of high deposition rates from the water column. Furthermore, benthic fauna are absent from these anoxic systems. By their burrowing, fauna mix and irrigate the sediment. This activity increases the penetration of oxygenated water into the sediment and flushes anoxic porewater, which also contains metabolic byproducts, from the sediment.

Given the coincidence of these possible controlling factors in the field, laboratory experiments which can separate factors are needed. With the help of John Hobbie, Anne Giblin, Gary Banta and Bob Howarth, I set up an experiment to find out whether decomposition rates are inhibited by high concentrations of metabolic byproducts or are stimulated by the presence of oxygen.

In the lab, cores of Buzzards Bay sediment were injected with \(^{14}\text{C}\) labelled phytoplankton detritus. For several months, water was slowly pumped through the cores while we measured the rate of \(^{14}\text{CO}_2\) production as a measure of decomposition. The treatments consisted of four different types of water: aerated seawater, anoxic seawater, porewater from Buzzards Bay, and porewater from an anoxic basin (rich in sulfides and ammonium).

Metabolic byproducts in porewaters did not inhibit the decomposition of organic matter in sediments (Figure 1). The \(^{14}\text{C}\)-\(^{14}\text{CO}_2\) production rates in the three anoxic treatments were nearly identical, despite a wide range in the concentration of potential inhibitors (e.g., sulfide concentrations of 3 mM in the anoxic basin porewater, 0.1 mM in the Buzzards Bay porewater, and no sulfide in the deoxygenated seawater).

Figure 1. The cumulative production of radiolabelled dissolved inorganic carbon (DIC) in DPM from the decomposition of labelled algae in Buzzards Bay sediment. The four types of water that were pumped through the sediment were aerated seawater (oxygen), deoxygenated seawater (nitrogen), porewater from Buzzards Bay mud (B. Bay), and porewater from an anoxic basin's mud (Orleans).

Decomposition was faster in the presence of oxygenated seawater, but only after this water had been pumped through the sediment for several weeks. It is probable that this time lag occurred while aerobic microbes colonized the sediment. If microbes in the field respond this slowly to the injection of oxygen into the sediment by faunal irrigation, then this oxygen is probably scavenged by reduced minerals and does not stimulate decomposition.

These simple manipulations of porewater chemistry in the laboratory have illuminated two general properties of the cycling of organic matter in nature. First, the occurrence of high accumulation rates of organic matter in anoxic environments is at least partially caused by anoxia itself. Second, faunal mixing of sediment increases porewater exchange with the water column, but this increase apparently does not stimulate decomposition rates.
# SEMINARS

## JANUARY

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<td>Steve Hamburger, Stanford University</td>
<td>“Ecosystem organic matter and nitrogen pool changes during old-field succession in New Hampshire.”</td>
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<td>15</td>
<td>Peter Doering, University of Rhode Island</td>
<td>“The effect of the clam Mercenaria mercenaria on carbon cycling in shallow estuarine systems: A mesocosm experiment.”</td>
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<td>22</td>
<td>Elaine Matthews, NASA, Goddard Space Flight Center</td>
<td>“Anthropogenic changes in global vegetation from preagricultural time to the present.”</td>
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<td>Dean E. Cycon, Marine Policy and Ocean Management, Woods Hole Oceanographic Institution</td>
<td>“When worlds collide: Effect of development on indigenous people.”</td>
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## FEBRUARY

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<td>Jostein Goksøy, University of Bergen, Norway</td>
<td>“Estimation of carbon flow in a Calluna heath system.”</td>
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<td>19</td>
<td>Frank Lawrence, Maine Medical Center and Envirolologic Data</td>
<td>“Methods for identification of hazard and risks of toxic materials.”</td>
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<td>26</td>
<td>Brian Fry, Biology and Chemistry Departments, Indiana University</td>
<td>“Perspectives for the future: Stable isotopic studies of pelagic food webs and sulfur biogeochemistry in lakes.”</td>
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## MARCH

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<td>Elizabeth Flint, Duke University</td>
<td>“Carbon release and changing patterns of land use in South Asia: An ecologist’s view.”</td>
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<td>James Lynch, Glasshouse Crops Research Institute, United Kingdom</td>
<td>“Carbon flow and microbial growth in the rhizosphere.”</td>
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<td>Ross Virginia, University of California, Riverside</td>
<td>“Natural variation in the abundance of N-15 as an indicator of the nitrogen economy of desert ecosystems.”</td>
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## APRIL

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<td>2</td>
<td>Kelman Wieder, Villanova University</td>
<td>“Sulfur biogeochemistry in Appalachian peatlands.”</td>
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<td>5</td>
<td>Knute Nadelhoffer, The Ecosystems Center, Woods Hole</td>
<td>“The influence of litter inputs on forest soil C and N dynamics.”</td>
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<td>Percy Donaghay, University of Rhode Island</td>
<td>“The role of nutrient loading and grazing in controlling the dynamics of shallow marine ecosystems.”</td>
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<td>Thomas Boutton, Baylor College of Medicine</td>
<td>“Stable carbon isotope ratios indicate food habits of East African herbivores.”</td>
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<td>23</td>
<td>Carlton Hunt, University of Rhode Island</td>
<td>“Interaction between eutrophication and the estuarine manganese cycle.”</td>
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## MAY

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<td>Ragnar Elmgren, Asko Laboratory, University of Stockholm</td>
<td>“Man’s impact on the Baltic Sea summarized by changes in carbon flow.”</td>
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<td>Thomas Cappenberg, Limnologisch Instituut, Vrije Universiteit, The Netherlands</td>
<td>“Recent developments in cycling of carbon in anaerobic lake sediments.”</td>
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<td>Richard D. Bowden, Yale University</td>
<td>“The nitrogen budget of a moss ecosystem developing in glacial outwash sands in New Hampshire.”</td>
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<td>20</td>
<td>William MacLeish, Charlestown, MA</td>
<td>“George’s Bank: What happens next?”</td>
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## JUNE

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<td>4</td>
<td>Theodore Macdonald, Harvard University</td>
<td>“Native peoples and tropical forests: Issues in national development.”</td>
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<td>George W. Luther, III, Kean College, New Jersey</td>
<td>“Speciation of dissolved sulfur in salt marshes by polarographic methods.”</td>
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<td>16</td>
<td>Anne Giblin, The Ecosystems Center, Woods Hole</td>
<td>“Acid rain or Alaska: An up-to-the-minute report.”</td>
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## SEPTEMBER

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<td>Christopher D’Elia, Chesapeake Biological Laboratory, Solomons, Maryland</td>
<td>“Nutrient enrichment of Chesapeake Bay: The nitrogen vs. phosphorus controversy.”</td>
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<td>17</td>
<td>Bruce Peterson, The Ecosystems Center, Woods Hole</td>
<td>“Transformation of a tundra river from heterotrophy to autotrophy by phosphorus additions.”</td>
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## OCTOBER

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<tr>
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<td>Paul Colinvaux, Ohio State University</td>
<td>“The history of environmental disturbance and diversity of the Amazon ecosystem.”</td>
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<td>Linda Deegan, University of Massachusetts, Amherst</td>
<td>“Ecology and nutrient transport of Gulf Menhaden in a Louisiana estuary.”</td>
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<td>22</td>
<td>Robert Bugg, University of California — Davis and New Alchemy Institute, Falmouth</td>
<td>“The use of polycultures for herbivore control in agroecosystems.”</td>
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## NOVEMBER

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<td>5</td>
<td>Anne Giblin, The Ecosystems Center, Woods Hole</td>
<td>“Nitrogen cycling in a shallow marine cove.”</td>
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<td>12</td>
<td>J. Mark Lennon, G.C.A., Inc./Technology Division, Bedford, MA</td>
<td>“Options for reducing SO2 emissions from electric utility plants.”</td>
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<td>19</td>
<td>Robert Eganhouse, University of Massachusetts, Boston</td>
<td>“Isotopic and molecular methods for tracing anthropogenic wastes in the marine environment.”</td>
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<td>26</td>
<td>Nick Brokaw, Manomet Bird Observatory, Manomet, MA</td>
<td>“Patch dynamics and tree community structure in a tropical forest.”</td>
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## DECEMBER

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<td>3</td>
<td>Ken Kimble, Appalachian Mountain Club, Gorham, NH</td>
<td>“The impacts of air pollutants on high altitude ecosystems.”</td>
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<tr>
<td>10</td>
<td>Richard T. T. Forman, Graduate School of Design, Harvard University</td>
<td>“The emergence of landscape ecology.”</td>
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<tr>
<td>17</td>
<td>Paul Novelli, State University of New York, Stony Brook, NY</td>
<td>“Hydrogen in anoxic sediments.”</td>
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Facilities

The new program in stable isotopes was initiated with an award from the A. W. Mellon Foundation. These funds were used as a partial match for an NSF grant to purchase an isotope ratio mass spectrometer and to hire a scientist, Brian Fry. The instrument arrived in December at about the same time the new laboratory in the Environmental Sciences Building was completed by the MBL.

The purpose of this program is to stimulate the use of the stable isotopes, especially those of carbon, nitrogen, and sulfur in ecological research, both terrestrial and aquatic. Not only will this facility be available for cooperative research at the Center and within the Woods Hole community, but it is also available to ecologists across the country for training. It is expected that a number of graduate students will come to MBL for several weeks at a time to learn how to plan ecological research with stable isotopes, prepare samples for analysis, and operate the mass spectrometer. While mass spectrometers are available at major universities, this instrument is dedicated to ecological use and a visiting scientist can consult with experts in stable isotopes such as Fry and Bruce Peterson.

Appointments

John E. Hobbie was named Director of the Ecosystems Center, effective February 1, 1985, succeeding George M. Woodwell.

Hobbie, who specializes in the role of microbes in ecosystem processes, received his Ph.D. from Indiana University in 1962. He worked as a postdoctoral fellow in the Antarctic and at Uppsala University in Sweden from 1963 to 1965, where he became interested in microbial cycling of organic compounds in lakes. After serving on the faculty at North Carolina State University for ten years, Hobbie joined the staff of the Ecosystems Center as a senior scientist in 1975.

Among Dr. Hobbie's research interests is a project that each summer takes him to the remote foothills of the Brooks Range in Alaska, where he and his colleagues have been conducting research since 1976. Details of his research and that of the other Ecosystems Center investigators may be found in this and previous issues of the Annual Report.

Dr. Hobbie is a member of the Ecological Society of America, the International Association of Limnology, and President of the American Society of Limnology and Oceanography. In June, 1983, Dr. Hobbie was presented with the G. Evelyn Hutchinson Medal in recognition of his outstanding research on the importance of bacteria in natural waters, including the water column and the benthos, from ponds and lakes to estuaries and oceans. In addition, Hobbie is an active member of the Executive Committee of the Board of Trustees at the Marine Biological Laboratory.

Brian Fry joined the Ecosystems Center staff in November 1985 to supervise installation of the new mass spectrometer laboratory. Brian received his Ph.D. from the University of Texas at Austin in 1981, followed by a postdoctoral position as a research scientist in benthic ecology at the Harbor Branch Foundation in Ft. Pierce, Florida. There, his projects focused on estuarine ecology of seagrass meadows including stable isotopic studies of carbon flow in food webs, growth rates of seagrasses, and export of floating leaves as a percentage of primary production. Prior to his arrival at the Center, he was an assistant scientist at Indiana University-Bloomington where his research centered on the role of sulfur-oxidizing bacteria in modern ecological and ancient geological settings, including food web ecology of marine hydrothermal vent fauna, acid rain impacts on bacterial activities in lake sediments and the Precambrian sulfur cycle.

Knute Nadelhoffer was promoted in June to the position of Associate Scientist and Paul Steudler was appointed as Research Specialist.

Awards

In September, 1985, the Exxon Corporation approved a $25,000 award to the Marine Biological Laboratory for partial support of a research program by the Ecosystems Center on trace gas emissions from temperate and boreal forests. This grant will be used to subsidize studies of measurements of sulfur gaseous emissions from European sites along a gradient of acid rain deposition from southern Germany to northern Finland. These sites have been subjected to high rates of deposition for a long time and the results will be an excellent test of the validity and generality of the model of sulfur emission. This research is a part of a larger program funded by NSF and NASA.

Meetings and Workshops

Staff scientists of the Ecosystems Center presented several papers and attended many national and international seminars during 1985.

Skeew Houghton presented a paper at a conference on Carbon Transfer in the Atmosphere-Ocean-and Terrestrial System at Lake Arrowhead, California in May entitled “Biotic controls on the carbon dioxide content of the atmosphere. I. Changes in the area of forests.”
In June, at the 70th Annual Ecological Society of America meeting in Minneapolis, he spoke on terrestrial metabolism and the seasonal pattern of atmospheric CO₂ concentrations. Dr. Houghton acted as a consultant on deforestation at Oxford, England in July and in September attended a conference on Atmospheric Carbon Dioxide: Its Sources, Sinks and Global Distribution in Kandersteg, Switzerland where he spoke on the geographic distribution of the net biotic flux in 1980.

June 18-21, the University of Minnesota in Minneapolis hosted the 48th Annual Meeting of the American Society of Limnology and Oceanography in conjunction with the Ecological Society of America, at which several of the Ecosystems Center scientific staff were in attendance. John Hobbie presented a paper on “The use of experimental ecosystems to study the ecotoxicology of bacteria”, Bob Howarth, Anne Giblin and John Hobbie presented a paper “Regulation of sulfate reduction rates in salt marsh sediments”, Bruce Peterson and John Hobbie presented “Carbon flow in a tundra stream ecosystem” and Anne Giblin, Bob Howarth, Roxanne Marino and Bruce Peterson presented “The regulation of sulfide concentrations in salt marsh porewaters”.

During 1985, Jerry Melillo lectured extensively on the subject of decomposition dynamics, giving talks at the Ecological Society of America’s annual meeting in Minneapolis, the University of Washington in Seattle, and at the Cary Arboretum in Millbrook, New York. Jerry was also a key speaker on global element interactions at the Cary Arboretum open house. In 1985, he continued to serve on the Advisory Committee of the Smithsonian Institute Shore Laboratory and the Ecology Panel at the National Science Foundation.

Tom Stone attended the SIR-B Workshop on Preliminary Science Results at the Jet Propulsion Laboratory in Pasadena, California in May and spoke on “The SIR-B Project: Deforestation in Amazonia”. In June, he delivered a talk on “The Use of Remote Sensing in the Context of Land Use and the CO₂ Problem” at the Eleventh International Symposium, Machine Processing of Remotely Sensed Data, at Purdue University in Indiana. In August, he attended the Tenth Pecora Remote Sensing Symposium at Colorado State University and a Workshop on Biogeochemistry of Tropical Rain Forests in Brazil in October. Also in October, he presented a talk on “Analysis of Deforestation in Amazonia Using Shuttle Imaging Radar” at the International Geoscience and Remote Sensing Symposium in Amherst, Massachusetts.

Gus Shaver gave a seminar on “The regulation of primary production and plant biomass in Alaskan tundra” in February at the University of Rhode Island. He also attended U.S. Department of Energy Arctic Research Program Planning meetings in San Diego in April and in Maryland in November.

At the 1985 Fall AGU meeting, held in San Francisco in December, Paul Steudler, Jerry Melillo and Liz Ferry presented a paper on carbonyl sulfide and carbon disulfide emissions from temperate forest soils.

David Rudnick spoke on “Seasonality in Narragansett Bay: a benthic perspective” in March at an invited seminar held at the Graduate School of Oceanography of the University of Rhode Island. In July, he attended the Eighth Biennial International Estuarine Research Conference in Durham, New Hampshire and presented “Net ecosystem production in Narragansett Bay: seasonal sedimentary storage”.

In March, Knute Nadelhoffer presented a talk at The Institute of Ecosystem Studies in Millbrook, New York on “The influence of litter inputs on forest soil carbon and nitrogen dynamics”. In June, at the Ecological Society of America’s meeting in Minneapolis, Knute gave a poster presentation on “Variations in leaf nitrate reductase activity in north eastern forest tree species”.

Brian Fry and Bob Michener in the new Mass Spectrometer Laboratory.
STAFF OF THE ECOSYSTEMS CENTER 1985

ADMINISTRATIVE STAFF

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

Walter J. Matherly, Administrative Officer
M.A.  Duke University

Suzanne Semino, Secretary

Elisabeth Griffin, Secretary

SCIENTIFIC STAFF

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Ph.D.  Indiana University

Bruce J. Peterson, Associate Scientist
Ph.D.  Cornell University

Jerry M. Melillo, Associate Scientist
Ph.D.  Yale University

Gaius R. Shaver, Associate Scientist
Ph.D.  Duke University

Robert W. Howarth, Associate Scientist
Ph.D.  M.I.T. — W.H.O.I.

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

Richard A. Houghton, Assistant Scientist
Ph.D.  SUNY, Stony Brook

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Ph.D.  University of Wisconsin

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

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

Thomas A. Stone, Research Associate
M.A.  Dartmouth College

VISITING SCIENTISTS

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Ph.D.  Rutgers University

George W. Luther III
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EDUCATIONAL STAFF APPOINTMENTS

David Rudnick,
Post-Doctoral Fellow
Ph.D.  University of Rhode Island

Walter Matherly

Suzanne Semino

TECHNICAL STAFF

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Berit Bergquist, Research Assistant
B.A.  Hampshire College

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Tim Yandow, Research Assistant
B.S.  University of Vermont

Mason DeMay, Laboratory Technician

Travis Bryan, Laboratory Technician

Nancy Plummer, Laboratory Technician
ADVISORY COMMITTEE

The Center’s Advisory Committee consists of eminent scientists appointed jointly by the Director of the Marine Biological Laboratory and the Ecosystems Center. The Committee meets at least once a year to review programs and personnel of the Center, to assist with planning, and to consider any other matters affecting the Center’s capacity to carry on its research. On August 13 and 14, 1985, the following members met in Woods Hole with the Center staff and with the Director of the Marine Biological Laboratory.

Dr. Harold Mooney

Professor of Ecology, Department of Biology, Stanford University. Dr. Mooney is a physiological ecologist, internationally known for his comparisons of the morphology and physiology of plants from arid lands, especially California and Chile. He is a member of the National Academy of Sciences, a fellow of the American Academy of Arts and Sciences and has been active in recent years in international scientific programs.

Dr. Gene Likens

Dr. Gene Likens is Vice President of The New York Botanical Garden and Director of the Institute of Ecosystem Studies. Dr. Likens also currently holds academic appointments at both Yale University and Cornell University. He is a co-director of the Hubbard Brook Ecosystem Study and his research includes limnology, the analysis of ecosystems, biogeochemistry and the effects of acid rain on natural ecosystems. Dr. Likens is a member of the National Academy of Sciences, the American Academy of Arts and Sciences, and is a former president of both the American Society of Limnology and Oceanography and the Ecological Society of America.

Dr. William Reiners

Professor and Head of the Department of Botany, University of Wyoming. Dr. Reiners’ research interest centers on biogeochemical phenomena in terrestrial ecosystems in the context of vegetation dynamics and spatial variability. Dr. Reiners has investigated variation in detritus dynamics over elevational gradients in New England and is currently investigating the patterns of nutrient cycling in the rolling landscape of sagebrush steppe, the effects of sagebrush conversion to grassland on biogeochemical processes, and the ecosystem-level implications of the vegetational patch mosaic generated by mass-wasting phenomena in the Grand Teton Mountains.

Dr. Lawrence R. Pomeroy

Professor at the Institute of Ecology, University of Georgia. Dr. Pomeroy is best noted for his research in marine biology, cycling of nutrients, microbes and particles, and energetics and cycles of elements in marine and aquatic ecosystems. Dr. Pomeroy is a past president of the American Society of Limnology and Oceanography.

TOP TO BOTTOM:
Dr. Harold Mooney
Dr. Gene E. Likens
Dr. William A. Reiners
Dr. Lawrence R. Pomeroy


PUBLICATIONS IN PRESS


Fry, B. Sources of carbon and sulfur nutrition for consumers in three meromictic lakes of New York state. Limnology and Oceanography.


Houghton, R.A. Estimating changes in the carbon content of terrestrial ecosys-


Peterson, B.J., T.L. Corliss, J.E. Hobbie, and K. Kriet. Seasonal patterns of discharge, sediment load and nutrient concentration in a tundra river.


TOP: Brian Fry  
CENTER: Bob Michener  
BOTTOM: John Helfrich  

TOP: Tim Yandow  
CENTER: Alicja Mann  
BOTTOM: Roxanne Marino
View of MBL across Eel Pond.
FINANCIAL RESOURCES FOR ECOSYSTEMS RESEARCH AND EDUCATION

The operating budget of the Ecosystems Center remained level in 1985 at $2,370,000. There are two sources of funds for the Center's programs, grants from government agencies for specific research projects and gifts and income from private foundations.

Contract Research

Most of the Center's income is in the form of research grants to individual scientists or groups of scientists from government agencies. Awards for basic research from the National Science Foundation and the Department of Energy make up most of the total.

Other Gifts and Income

The Center was founded with gifts from private foundations; current gifts and income from past general use donations provide the flexibility for the development of new research projects, the carrying out of public policy activities, and the Center's educational programs. During 1985, the Center continued to spend the $340,000 awarded in 1984 by the A.W. Mellon Foundation for the purpose of salary support staff and for developing new projects dealing with the use of stable isotopes in ecological research and with the subtle responses of ecosystems to man's wastes. Additional support was received from the EXXON Corporation for research on trace gas releases from forests. Income from the Ecosystems Reserve Fund, which is approximately the same size as the annual operating budget, helps to defray costs of operations, the consultations of staff with government policy groups, and a seminar program which brings an outside speaker to the Center each Tuesday. In addition, the Reserve Fund supports two postdoctoral fellows, a valuable aid for keeping scientists challenged.
I. National Science Foundation

NSF-BSR-81-10477
“The biota and the global carbon cycle.”
October 1981 — September 1985
Investigators: Hobbie, Houghton, Melillo, Peterson, Shaver
$1,143,656

NSF-BSR-85-09732
“The biota and the global carbon cycle: effects of changes in climate and in global element cycles.”
November 1985 — October 1987
Investigators: Hobbie, Peterson, Houghton, Shaver
$269,218

NSF-DPP-85-42269
“Response of arctic freshwater ecosystems to environmental stress.”
June 1984 — November 1987
Investigators: Hobbie, Peterson
$1,393,970

NSF-BSR-85-09733
“A mass spectrometer facility.”
November 1985 — October 1986
Investigators: Hobbie, Giblin, Houghton, Shaver, Melillo, Peterson
$150,000

NSF-BSR-83-40120
“Controls of the dynamics of sulfur in a salt marsh ecosystem.”
June 1981 — May 1985
Investigators: Peterson, Howarth, Steudler
$996,449

NSF-BSR-85-07493
“Nutrient cycling in an arctic landscape: Interactions between ecosystems along a riverside toposequence.”
September 1985 — February 1987
Investigators: Shaver, Giblin, Hobbie, Nadelhoffer
$816,577

NSF-BSR-83-17531
“Carbon-nitrogen interactions along resource availability gradients in forest ecosystems.”
(Subcontract from University of Wisconsin)
February 1984 — March 1986
Investigator: Melillo
$162,925

NSF-BSR-82-05344
“The relationship of plant relative growth rate to ecosystem processes in Alaskan tundra.”
(Subcontract from University of Alaska)
July 1982 — May 1985
Investigator: Shaver
$121,000

NSF-ATM-85-05480
“Carbonyl sulfide and carbon disulfide emissions from temperate and boreal forests along an acid rain gradient.”
August 1985 — January 1987
Investigators: Steudler, Melillo
$234,700

NSF-OCE-84-15687
“Controls of anoxic decomposition processes in marine sediments.”
February 1985 — January 1987
Investigator: Hobbie
$248,242

NSF-BSR-83-05176
“Molybdenum: An important control on the nitrogen cycle in aquatic ecosystems?”
June 1983 — May 1986
Investigators: Howarth, Giblin
$342,260

NSF-BSR-84-17169
“Controls of forest litter decomposition.”
April 1985 — March 1987
Investigator: Melillo
$288,189

II. Department of Energy

DOE-U8406034
“Nutrient cycling on river floodplains in arctic Alaska: Variation in biogeochemistry and response to disturbance.”
July 1984 — December 1985
Investigator: Shaver
$90,000

DOE-19X-43383C
“Mathematical models for use in defining the role of the terrestrial biota in the global CO₂ cycle.”
August 1983 — September 1986
Investigators: Houghton, Melillo
$661,172

DOE-19X-43393C
“Remote sensing of deforestation in the Amazon Basin.”
December 1983 — December 1986
Investigators: Houghton, Hobbie, Woodwell
$665,027

VI. Department of Defense

U.S. Army Research Office
DAAG-29-82-K-0140
“Revegetation of Alaskan disturbed sites by native tundra species.”
(Subcontract from University of Alaska)
May 1982 — April 1985
Investigator: Shaver
$45,000

III. NASA

NASA/JPL (Jet Propulsion Laboratory)
“An analysis of deforestation/ reforestation in the Amazon Basin using shuttle imagery radar (SIR-B).”
(Subcontract from the Woods Hole Research Center)
September 1984 — September 1985
Investigator: Stone
$75,200

NASA-NAGH-453
“Planetary biogeochemical cycles and their perturbation by humans.”
(Subcontract from University of New Hampshire)
February 1983 — January 1986
Investigators: Melillo, Peterson
$277,465

V. Miscellaneous

Institute of Ecosystem Studies
New York Botanical Garden
“The role of sulfate reduction and sulfur storage in generating alkalinity in lakes.”
September 1984 — September 1986
Investigators: Giblin, Howarth
$19,975

Exxon Corporation
“Trace gas emissions from temperate and boreal forests.”
November 1985 — October 1987
Investigators: Melillo, Steudler
$50,000
SOURCES OF SUPPORT FOR RESEARCH AND EDUCATION

The Center is financed through a series of private grants made directly in support of the Center and through federal grants in support of specific research topics. Since its inception, the Center has received funding from the following foundations:

Atlantic Richfield Foundation  
Robert Sterling Clark Foundation  
Clowes Fund  
Charles E. Culpeper Foundation, Inc.  
Arthur Vining Davis Foundations  
Henry L. and Grace Doherty Charitable Foundations  
Exxon Corporation  
Max C. Fleischmann Foundation  
Ford Foundation  
General Electric Foundation  
Grace Foundation, Inc.  
Grass Foundation  
Charles Hayden Foundation  
International Business Machines Corporation  
Charles A. Lindbergh Fund  
Andrew W. Mellon Foundation  
NL Industries Foundation, Inc.  
Jessie Smith Noyes Foundation, Inc.  
Rockefeller Brothers Fund  
Rockefeller Foundation  
Rowland Foundation  
Scherman Foundation, Inc.  
Surdna Foundation, Inc.  
Woods Hole Oceanographic Institution  
World Wildlife Fund  
National Resources Defense Council