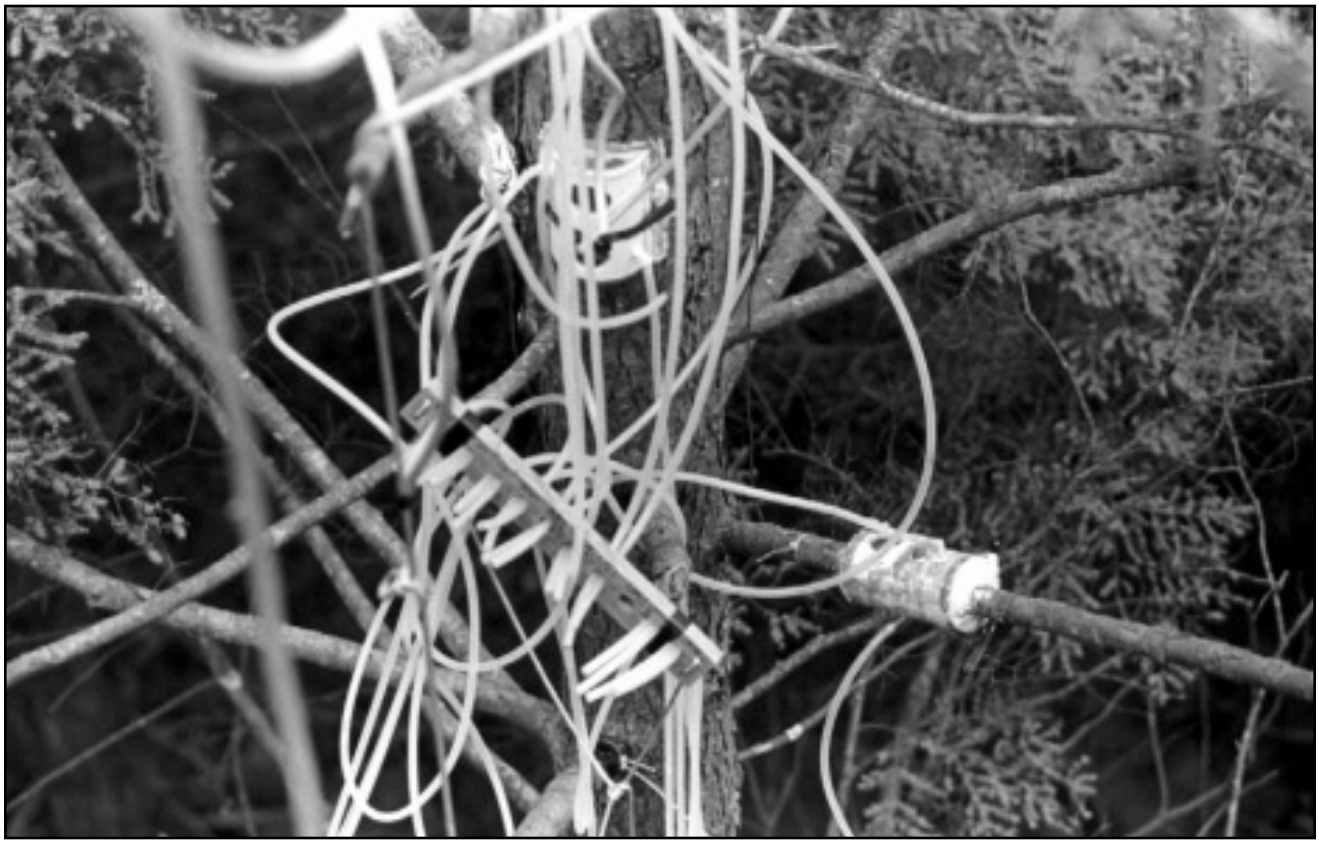
THE HARVARD FOREST 2000–2001

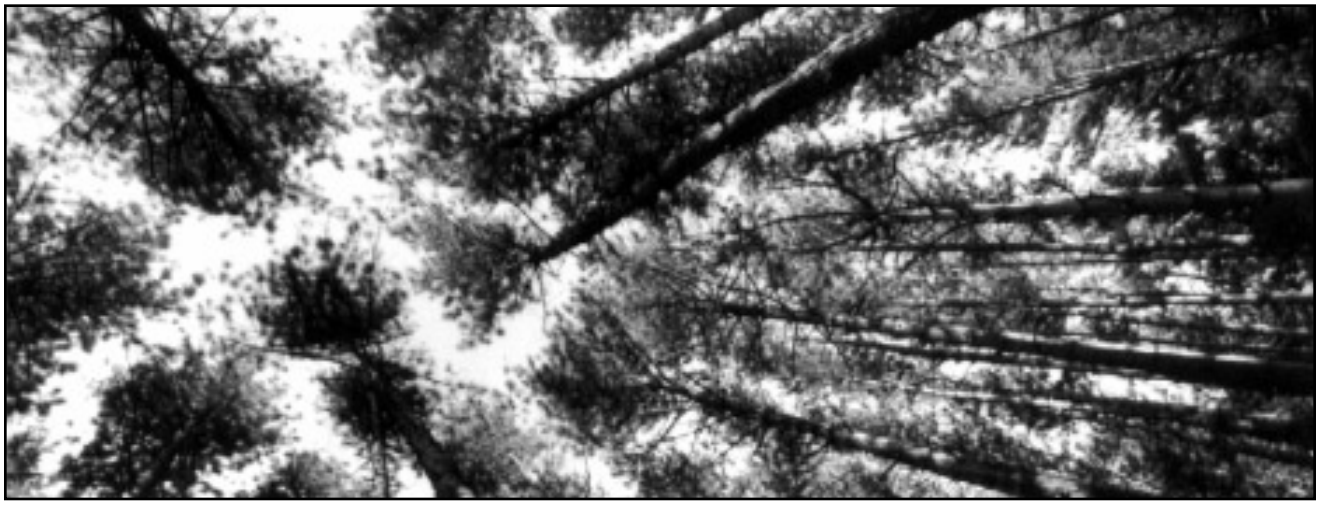
Harvard University

ANNUAL REPORT OF THE HARVARD FOREST, 2000–2001



PERSONNEL AT THE HARVARD FOREST 2000–2001

Rebecca Anderson	M.F.S. Candidate
Audrey Barker Plotkin	Research Assistant
Sylvia Barry Musielewicz	Research Assistant
Gutram Bauer	Post-doctoral Fellow
Jesse Bellemare	MFS Candidate
Emery Boose	Information and Computer Manager
Werner Borken	Post-doctoral Fellow
Jeannette Bowlen	Accountant
Nick Brokaw	Bullard Fellow
John Burk	Archivist
Susan Clayden	Research Assistant
Richard Cobb	Research Assistant
Willard Cole	Woods Crew
Kathleen Donohue	Bullard Fellow
Elaine Doughty	Research Assistant
Robert Eberhardt	MFS Candidate
John Edwards	Forest Manager
Edythe Ellin	Administrator
Ed Faison	Research Assistant
Mary Ann Fajvan	Bullard Fellow
Samantha Farrell	Laboratory Technician
Barbara Flye	Librarian/Secretary
Charles H. W. Foster	Associate
David Foster	Director
Donna Francis	Research Associate
Janice Fuller	Research Associate
Kelli Graves	Secretarial Assistant
Julian Hadley	Research Associate
Brian Hall	Research Assistant
Linda Hampson	Secretarial Assistant
Jon Harrod	Post-doctoral Fellow
Donald Hesselton	Part-time Woods Crew
Malcolm Hughes	Bullard Fellow
Susan Johnson	Research Assistant
Teresa Jones	Assistant Schoolyard Coordinator
David Kittredge	Forest Policy Analyst
Matt Kizlinski	MFS Candidate
Oscar Lacwasan	Custodian
Erin Largay	Research Assistant
Sarah Laubscher	Summer Program Assistant
Manuel Lerdau	Bullard Fellow
Dana MacDonald	Research Assistant
Lisa Marselle	Summer Cook
Lucinda McWeeney	Bullard Fellow
Laurie Miskimins	Research Assistant
Fraser Mitchell	Bullard Fellow
Glenn Motzkin	Plant Ecologist
John O'Keefe	Museum Coordinator
David Orwig	Forest Ecologist
Julie Pallant	Assistant Information and Computer Mgr.
Tim Parshall	Post-doctoral Fellow
Dorothy Recos-Smith	Staff Assistant
Lauren Sack	Post-doctoral Fellow
Jessica Schedlbauer	Research Assistant
Karn Deo Singh	Bullard Fellow
Charles Spooner	Woods Crew
Fred Swanson	Bullard Fellow
Mindy Syfert	Research Assistant
P. Barry Tomlinson	E. C. Jeffrey Professor of Biology
John Wisnewski	Woods Crew
Steven Wofsy	Associate



INTRODUCTION TO THE HARVARD FOREST

Since its establishment in 1907 the Harvard Forest has served as a center for research and education in forest biology. Through the years researchers have focussed on silviculture and forest management, soils and the development of forest site concepts, the biology of temperate and tropical trees, forest ecology, forest economics, landscape history, conservation biology, and ecosystem dynamics. Today, this legacy of research and education continues as faculty, staff, and students seek to understand historical and modern changes in the forests of New England and beyond, resulting from human and natural disturbance processes, and to apply this information to the conservation, management, and appreciation of natural ecosystems. This activity is epitomized by the Harvard Forest Long Term Ecological Research (HF LTER) program, which was established in 1988 through funding by the National Science Foundation (NSF).

Physically, the Harvard Forest is comprised of approximately 3,000 acres of land in the north-central Massachusetts town of Petersham that include mixed hardwood and conifer forests, ponds, extensive spruce and maple swamps, fields and diverse plantations. Additional land holdings include the 25-acre Pisgah Forest in southwestern New Hampshire (located in the 5000-acre Pisgah State Park), a virgin forest of white pine and hemlock that was 300 years old when it blew down in the 1938 Hurricane; the 100-acre Matthews Plantation in Hamilton, Massachusetts, which is largely comprised of plantations and upland forest; and the 90-acre Tall Timbers Forest in Royalston, Massachusetts. In Petersham a complex of buildings that includes Shaler Hall, the Fisher Museum, and the John G. Torrey Laboratories provide office and laboratory space, computer and greenhouse facilities, and a lecture room for seminars and conferences. Nine additional houses provide accommodations for staff, visiting researchers, and students. Extensive records, including long-term data sets, historical information, original field notes, maps, photographic collections, and electronic data are maintained in the Harvard Forest Archives.

Administratively, the Harvard Forest is a department of the Faculty of Arts and Sciences of Harvard University. The Harvard Forest administers the Graduate Program in Forestry that awards a Masters degree in Forest Science and faculty at the Forest offer courses through the Department of Organismic and Evolutionary Biology, the Kennedy School of Government, and the Freshman Seminar Program. Close association at Harvard is also maintained with the Department of Earth and Planetary Sciences , the School of Public Health, and the Graduate School of Design, and with the Department of Natural Resource Conservation at the University of Massachusetts, the Ecosystems Center of the Marine Biological Laboratory at Woods Hole, and the Complex Systems Research Center at the University of New Hampshire.

The staff and visiting faculty of approximately fifty work collaboratively to achieve the research, educational and, management objectives of the Harvard Forest. A management group comprised of the Director, Administrator, Coordinator of the Fisher Museum, and Forest Manager meets monthly to discuss current activities and to plan future programs. Regular meetings with the HF LTER science team, weekly research seminars and lab discussions, and an annual ecology symposium provide for an infusion of outside perspectives. The four-member Woods Crew and Forest Manager undertake forest management and physical plant activities. The Coordinator of the Fisher Museum oversees many educational and outreach programs.

Funding for the Harvard Forest is derived from endowments and FAS, whereas major research support comes primarily from the National Science Foundation, Department of Energy (National Institute for Global Environmental Change), U.S. Department of Agriculture, NASA, and the Andrew W. Mellon Foundation. Our summer Program for Student Research is supported by the National Science Foundation, the A. W. Mellon Foundation, and the R. T. Fisher Fund.

NEW STAFF

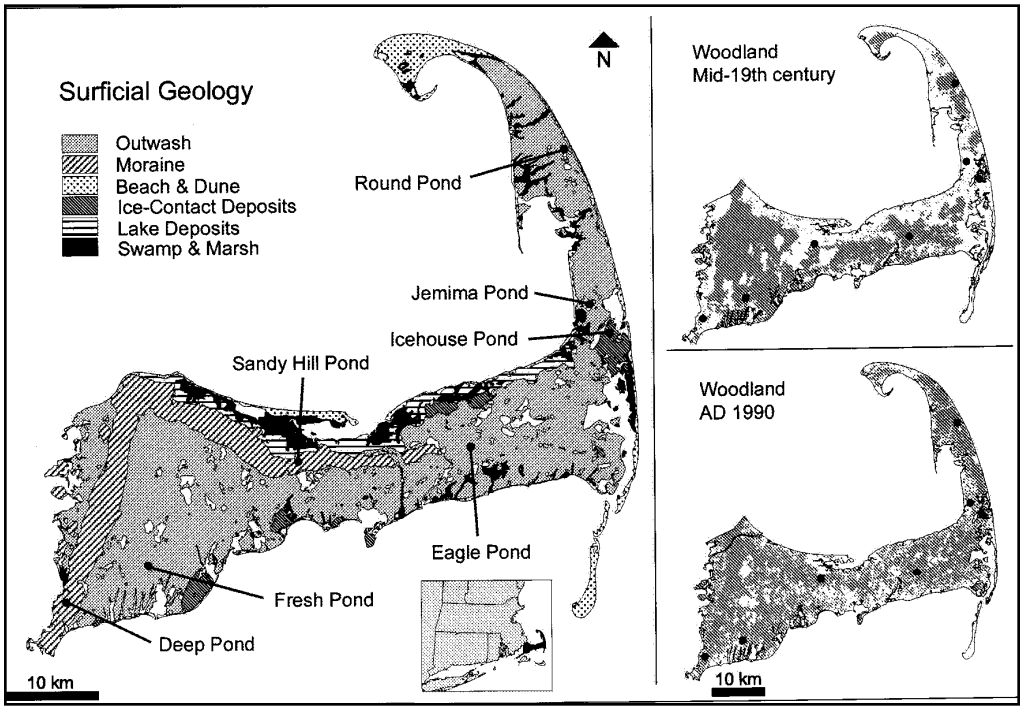
Teresa Jones who received her M.A. in plant biology from UMass-Amherst is the new Assistant LTER Schoolyard Coordinator, involving K through 12 teachers and students in long-term research projects. Jessica Schedlbauer, a graduate of the University of Maine with an M.S. in forest ecology, is working as a research assistant for Julian Hadley on the NIGEC project. Kelli Graves is a new office assistant and receptionist at the Forest.

RESEARCH ACTIVITIES

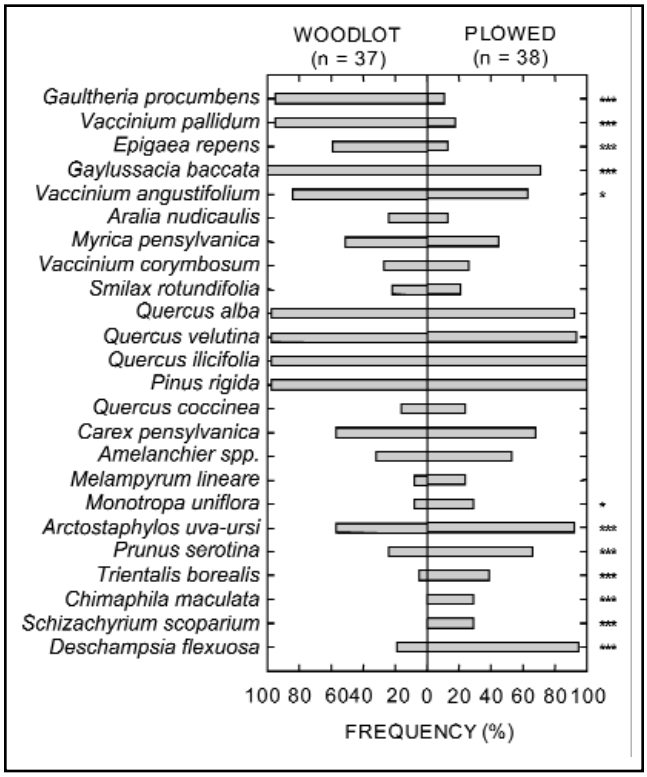
An Historical Approach to Understanding and Conserving the Coastal Region

A major goal of plant ecology is to determine the factors that control species distributions and community composition through time and space. Although vegetation patterns result in part from species-specific responses to environmental conditions and resource availability, actual species distributions at any point in time differ from potential distributions as a result of several factors, especially biotic interactions and the history of natural and human disturbance. Disturbance may influence community patterns by (1) directly altering the environment and resource distributions; (2) creating opportunities for the establishment of new species; or (3) reducing populations of established species. For instance, our previous work has demonstrated that species with slow rates of dispersal or establishment may be absent from a site for decades or centuries, not because the site is inherently unsuitable, but simply because the species were removed by prior disturbance and have not had sufficient time to recolonize. Consequently a major challenge for ecological study is to evaluate the relative contribution of current environmental conditions and historical factors in determining modern vegetation patterns and dynamics.

Following up on our previous studies in central Massachusetts, the Connecticut Valley, and Martha's Vineyard, we are conducting a comprehensive investigation into the history and vegetation of the coastal region that includes Cape Cod, Martha's Vineyard, Nantucket, Block Island, and Long Island. This region is a high priority for conservation because it supports numerous rare or uncommon plant and animal species and communities and because it is highly threatened by development. With support from the National Science Foundation, Mellon Foundation, Massachusetts Biodiversity Initiative, and The Nature Conservancy's Ecological Research



Cape Cod showing major details of the suficial geology and location of pollen analyses (*left*) and woodland cover in the nineteenth and twentieth centuries (*right*).

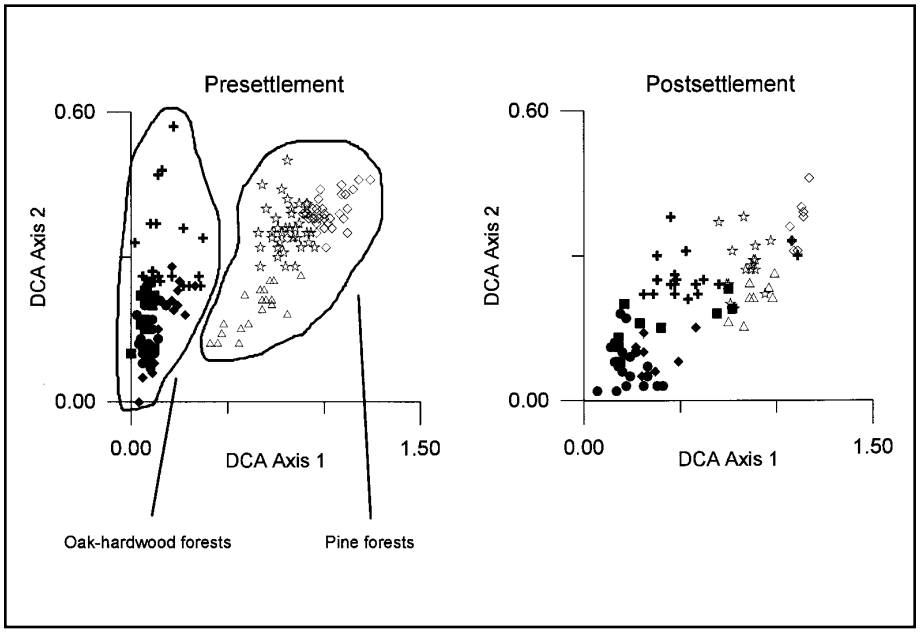


Species distributions in forests on Cape Cod National Seashore are strongly controlled by history, in particular whether the site was continuously woods or subjected to forest clearance, agricultural plowing, and subsequent reforestation.

Program, we are investigating the link between the landscape history and environment of the coastal region and the modern abundance and distribution of upland plant communities, including grasslands, heathlands, barrens, and woodlands. Although the region has a long history of settlement and intensive use, there has been no prior attempt to evaluate rigorously the impact of land-use history on species distributions and community assemblages. Such a regional understanding is critical in order to interpret modern landscape and species patterns, to identify ecological goals for conservation, and to develop management approaches for achieving those objectives.

Our current work emphasizes integrated paleoecological, historical, Geographic Information Systems (GIS), and field studies throughout the coastal region. Tim Parshall and David Foster are conducting paleoecological studies to reconstruct the long-term vegetation and disturbance history of the region, and Brian Hall is gathering a wide range of historical data, including excellent maps for incorporation into a growing GIS database. This past year Brian and John Burk researched historical records, including farm journals and diaries, town records, maps, and publications on Nantucket. A summary of town acts regulating agriculture on the island was compiled, and copies were made of old documents. Rob Eberhardt and Jon Harrod worked closely with David and Glenn Motzkin to evaluate the relationship between modern vegetation variation, site factors, and disturbance history. This past year, Rob finished his Master's thesis on the historical influences on modern forest vegetation on Cape Cod National Seashore. More than half of the National Seashore was cleared for agriculture in the nineteenth century, and although these agricultural lands have long been abandoned, Rob documented substantial differences in vegetation composition between forests on old fields and those on areas that were never cleared. This summer, Dana MacDonald, Lynda Joudrey, and Tricia Burgoyne are sampling forests on Long Island and Martha's Vineyard to provide a broader understanding of factors controlling vegetation variation across the coastal region.

Brent Wolfe, Tim Parshall, and Sylvia Barry Musielewicz taking a sediment core.



Multivariate analysis of all pollen samples from seven sites on Cape Cod. Before European settlement the vegetation exhibited compositional differences whereas, samples from the seventeenth century to the present indicate a much more homogeneous vegetation as a result of land-use impacts.

While the modern and historical studies are providing a detailed picture of ecological changes after the arrival of Europeans, the paleoecological research is uncovering how vegetation, fire, and the environment changed over the past several thousand years. This work, headed by Tim Parshall, also provides a context for interpreting the relative effects of human versus natural factors in driving more recent landscape dynamics. In this study Ed Faison, Dana MacDonald, and Elaine Doughty are looking at fossil pollen and charcoal preserved in the sediments of a series of lakes arrayed so as to sample major variation in geography, soils, and land use across the region. European settlement on Cape Cod in the 1600s shows up clearly in these records as a rise in the amount of pollen from grasses and herbs, reflecting the clearance of forests for pastures and agricultural fields.

Before European settlement, fire and vegetation patterns were closely linked with physiography, soils, and geography. Oaks and other hardwoods were more abundant on moraines, and pitch pine and fire were more abundant on outwash. Fire was also more common on the western Cape, which is broader and more susceptible to the development of large fires. There is no evidence for Indian clearing or agriculture. In contrast, the modern vegetation is less diverse, more regionally homogeneous, and exhibits less variation with the factors important before European settlement. These results are important because they highlight the heterogeneous nature of the early landscape and vegetation and illustrate some of the biotic and physical characteristics that may be targets for conservation and restoration, This research has also developed ways to reconstruct and compare fire histories across New England. Results indicate that before the arrival of Europeans fire was most common on Cape Cod and coastal New England and was much less important in northern hardwood forests in central Massachusetts. Isolated areas with higher fire existed, including the pitch pine-oak forests of the Connecticut Valley.

In a related coastal study Susan Clayden completed a pollen diagram for Harlock Pond on Seven Gates Farm on the western side of Martha's Vineyard. The site is surrounded by open deciduous forest and was once owned by Nathaniel Shaler, professor and dean at Harvard and an original supporter of the concept of a "Harvard Forest." The 2,500-year record indicates that oaks, beech, and birch have been the dominant trees, that fire was uncommon, and, like many of our other records, that there was a significant shift in vegetation 1,500 years ago. Through the past 300 years of European activity there has been an increase in blackgum (*Nyssa sylvatica*), heaths (Ericaceae), and sweet pepperbush (*Clethra alnifolia*), accompanied by a decrease in beech and hemlock. Pollen of Atlantic white cedar was also more abundant prior to settlement.

The Little Ice Age in New England

David Foster, Donna Francis, and Janice Fuller are coordinating a study of changes associated with the

Little Ice Age, a period of cooler and variable climate from approximately 1400–1850 A.D., and human activity. Understanding the factors driving vegetation change that occurred before and following the influence of European settlement is essential for interpreting current vegetation patterns and developing long-term conservation policies for the modern landscape. Signals of climate change, fire, human and natural disturbance, and vegetation change are being investigated in a multiproxy study of eight lakes on a north-south transect from northern Vermont to southern Connecticut. Results from this study will be integrated with those from the coastal project to provide a New England-wide perspective.

Dating, pollen analysis, and chironomid analysis have been completed for six sites. Dörte Köster at Laval University is analyzing sedimentary diatoms and modern diatom assemblages at two sites. Natalie Drake, Susan Clayden, Ed Faison, and Dana MacDonald are doing pollen analysis, and Elaine Doughty and Donna Francis are analyzing chironomids. Brent Wolfe at the University of Waterloo will analyze stable isotopes. Preliminary results of chironomid analyses from 6 ponds indicate a temperature shift of 1.3° C during the time of the Little Ice Age in New England. Two more ponds in Vermont and Massachusetts will be cored to complete the study.

Sylvia Barry Musielewicz coordinated daily activities for the paleoecology lab and participated in fieldwork to recover sediment cores for the Little Ice Age and Cape Cod projects.

Ed Faison.

Brian Hall and Mindy Syfert.

Massachusetts Forest Composition and Distribution through Time: Providing the Context for Ecological and Biodiversity Assessment

Because Massachusetts has a long cultural history, ecological study, conservation, and long-term planning must incorporate an understanding of the past land-use and landscape modification. However, to date, most ecological studies and planning activity have failed to evaluate human history, primarily because information at local and regional scales has been unavailable. With support from the Massachusetts Natural Heritage and Endangered Species Program, David Foster, Glenn Motzkin, Mindy Syfert, and Brian Hall are developing GIS data layers that will allow for rapid assessment of the history of intensive land use throughout the Commonwealth. Using maps that were generated for each town in 1830, we are developing maps indicating forest land, open land, meadows, and cultural features, including roads, mills, meeting houses, etc. Because 1830 was near the period of maximum forest clearance, the resulting data layers will provide a reasonable approximation of the Massachusetts landscape at the height of agricultural activity. Such information will be valuable for research, planning, and management, including evaluation and prioritization of land for conservation, restoration, and long-term

Rebecca Anderson, Jesse Bellemare, and Glenn Motzkin.

ecological management, comparison of primary versus secondary woodlands, and archaeological and cultural resource assessment. Interestingly, the maps show that the greatest extent of forestland in Massachusetts in 1830 occurred in southeastern Massachusetts, where large portions of Plymouth and Bristol Counties and inner Cape Cod remained forested. In contrast with the modern landscape, isolated woodlots in a predominantly agricultural landscape characterized the uplands of central and western Massachusetts.

Other databases were created from historical records for every town in Massachusetts to evaluate controls on vegetation composition during this time. The largest was a detailed summary table of all agricultural and woodland data in the state census and UMass/MacConnell land-use records from 1801 to the present. From the 1885 state census, a separate table was generated for forest cutting data by species. Other databases were created for the early twentieth century county forest surveys, the 1907 state forester's report, and historical population.

John Burk worked with David, Glenn, and Brian to gather data on forest composition in southern New England at the time of European settlement by researching surveyor records across Massachusetts, Connecticut, and Rhode Island. All but one survey were proprietor or deed lot layouts, which provide detailed species information. Survey dates range from the 1620s for the coast and Connecticut Valley to 1830s for interior hill towns. In Connecticut, 44,000 trees were tallied covering three-quarters of the towns, with gaps in Hartford and Fairfield counties where trees were rarely used in surveys. In Rhode Island 85 percent of towns had useful records, resulting in a tally of 2,700 trees and a gap in six southeastern coastal and island towns. In Massachusetts, the total was 58,000 trees from 84 percent of the 351 towns. Several towns in the region had over 3,000 trees, with a high of 4,500 in Killingworth, Connecticut. These data will provide a detailed understanding of early forest composition in southern New England as well as changes that resulted from historical land use and climate change. In this project we are collaborating with Charlie Cogbill at Hubbard Brook who has similar data for northern New England to evaluate forest composition across the entire region.

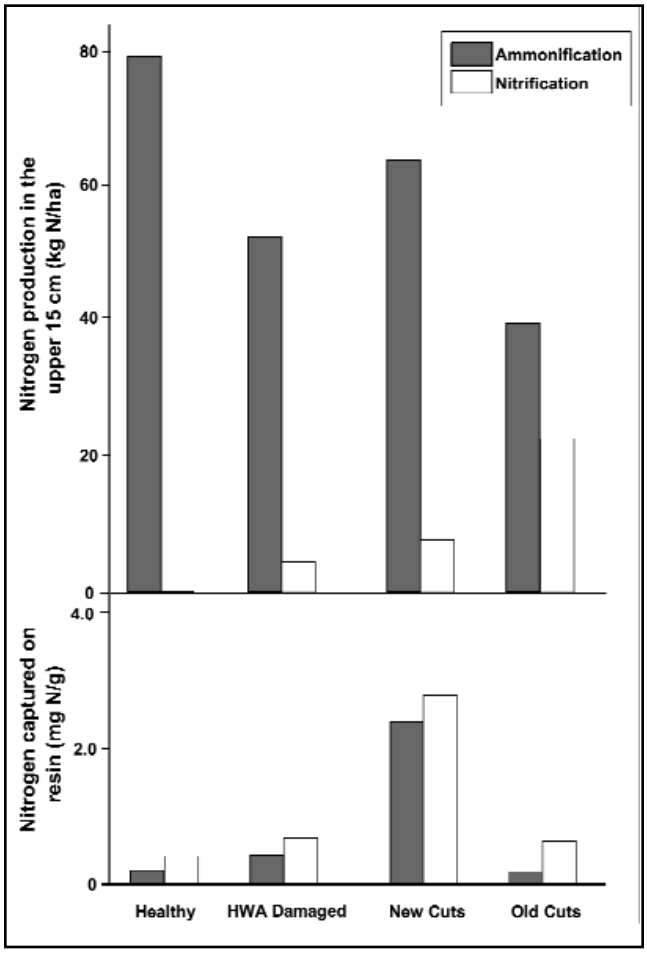
In these and related studies Brian Hall continued supporting our role for GIS activities. He generated figures for presentations and publications, analyzed spatial data with a GIS, and worked on systems development. As GIS becomes increasingly important in research, we have added a second digitizing table to speed conversion of paper maps into digital format. This past year we have also purchased a high-quality Global Positioning Satellite (GPS) receiver, which allows determinations to within a few meters; this will be helpful in locating and relocating study sites as well as mapping Harvard Forest properties.

Forest History and Modern Species Distributions: A Comparison of Plant Life History Characteristics from Europe and Eastern North America

Glenn Motzkin and David Foster are collaborating with Kris Verheyen, Olivier Honnay, and Martin Hermy from the University of Leuven in Belgium on a comparative study of the life history characteristics of plant species whose current distributions are strongly linked to historical land-use practices. In Europe and eastern North America, several species are characteristic of primary woodlands that were never cleared for agriculture, but are missing in secondary woodlands that developed on former agricultural lands. Although the floras on the two continents differ substantially, our analyses are evaluating whether particular plant traits (e.g., number of seeds, dispersal mechanism, etc.) are characteristic of species that are slow to colonize after disturbance.

Hemlock Woolly Adelgid Impacts on New England Forests: Changes in Forest Structure, Ecosystem Function, and Bird Communities

This summer Dave Orwig, Richard Cobb, and summer students Katie Theoharides and Spencer Meyer resampled permanent plots on eight sites established in 1997 to examine the effect of hemlock decline and mortality on the timing and extent of nitrogen cycling changes associated with the introduced hemlock woolly adelgid (HWA). Soil analyses including pH, temperature, carbon to nitrogen ratios, texture, and total soil organic matter were completed and measurement of the rates of nitrogen mineralization in a subset of sites is ongoing. After several years of HWA infestation, tree crowns became damaged, allowing greater light to reach the forest floor, such that stands



Seasonal nitrogen mineralization in healthy hemlock stands, HWA damaged stands, and new and old hemlock harvest sites (*upper*). Mobile nitrogen in soil solution captured in buried resin bags (*lower*). Note different scales. Higher nitrification rates are common in disturbed ecosystems where nutrient cycles have been altered. A lack of vegetative uptake in new harvests allows more nitrogren to move deeper into the soil, possibly leaving the system. Despite high nitrification rates, little nitrogen is leaving the upper soil horizons in old harvests.

with heavy infestations had lower surface soil moisture levels, higher soil temperatures, and higher net nitrogen mineralization and net nitrification rates than slightly damaged or uninfested stands. Resin bags buried in the soil at damaged sites also captured higher amounts of ammonium and nitrate than in uninfested stands, indicating that nitrogen is becoming more available as a result of the microenvironmental changes associated with HWA damage. Sampling will continue to examine the long-term changes in nitrogen (N) cycling associated with hemlock mortality and replacement. Dave and Katie

resampled plots established in 1995 to examine forest structure changes associated with HWA. Hemlock continues to deteriorate in all stands and black birch saplings in several stands are three to five meters tall.

Last fall Richard Cobb, Dave, and former REU student Steve Currie, completed an eighteen-month study of HWA impacts on foliar decomposition. Litter decomposition is a major pathway of nutrient cycling and organic matter accumulation in forest soils and has a strong influence on forest productivity and soils. Decomposition of hemlock foliage was measured at eight sites with varying degrees of HWA damage. Stands with substantial canopy damage had lower rates of decomposition as a result of warm, dry surface soil conditions, a finding that contradicted our hypothesis that increased soil temperature would accelerate decomposition. However, dry soil conditions retard the establishment of fungal decomposer communities in the surface soil. Microbes and fungal communities are a large sink of N in healthy forests and reduced microbial establishment or biomass may be contributing to N losses in these damaged forests. To expand this investigation we are comparing decomposition rates at the soil surface versus the organic-mineral soil interface at twelve sites in Connecticut and Massachusetts. We have also begun a reciprocal litter study comparing hemlock, black birch, and mixed-litter decomposition. Black birch is the most prolific species establishing as hemlocks deteriorate and its foliar chemistry is substantially different from that of hemlock. Comparing species differences and potential species interactions will improve our understanding of how ecosystem processes change with hemlock decline.

As a follow-up to last year's pilot study, Becky Field and returning summer student Morgan Tingley investigated bird species richness and composition changes associated with hemlock deterioration from HWA. Several species including black-throated green warblers, hermit thrushes, and blue-headed vireos exhibit significant declines with the loss of hemlock, while tufted titmice, red-eyed vireos, and American goldfinches increased as hemlocks were replaced by hardwoods.

Vegetation Dynamics of Ridgetop Pitch Pine and Red Pine Communities

As part of a broader investigation of ridgetop communities in the Northeast, Dave Orwig, Glenn Motzkin, and David Foster initiated a study examining the history, development, and vegetation dynamics of Mt. Everett and nearby summits in the southern Taconic region of southwest Massachusetts. We

Jessica Schedlbauer adjusting photosynthesis equipment in the hemlock canopy tower.

are using a combination of dendroecological, historical, and field studies to address several questions: (1) What is the history of fire, natural disturbance, and human activity and how has this influenced vegetation composition, structure, and age distribution? And (2) How do the composition, structure, and dynamics of Mt. Everett compare with similar sites across central New England?

We have visited several sites and intensively sampled the dwarf pitch pine community on Mt. Everett. This rare forest type, occurring in only a few locations in the northeastern U.S., is characterized by exposed bedrock, shallow soil depths of 10 to 18 cm, and abundant stunted pitch pine 0.5 to 2.0 m tall. The uneven-aged stand includes red maple, red oak, and birches. Pitch pine exhibits continuous recruitment since the 1830s and ranges from 12 to 170 years old. Hardwoods were established in most decades since 1860 and in higher densities in the 1950s and 1960s. Diameter is a poor predictor of age as trees with diameters of only 10 cm differ in age by more than 100 years. Many pines exhibit multiple stems, prostrate growth forms, and evidence of terminal branch damage. There is no historical or visual evidence of fire or human impacts in this forest, but on this exposed summit (795 m a.s.l.), wind, snow, and ice damage are dominant disturbance factors. Pitch pine ring-width patterns displayed extremely slow growth, with many individuals averaging < 0.40 mm yr^{-1}, and a few growing only 0.08 to 0.30 mm yr^{-1} for periods of up to fifty years. The unusual structure, extremely slow growth rates, and continuous recruitment in the absence of recent fire suggest that weather and harsh site conditions continue to maintain this unique community of disturbance-adapted species.

Forest Policy

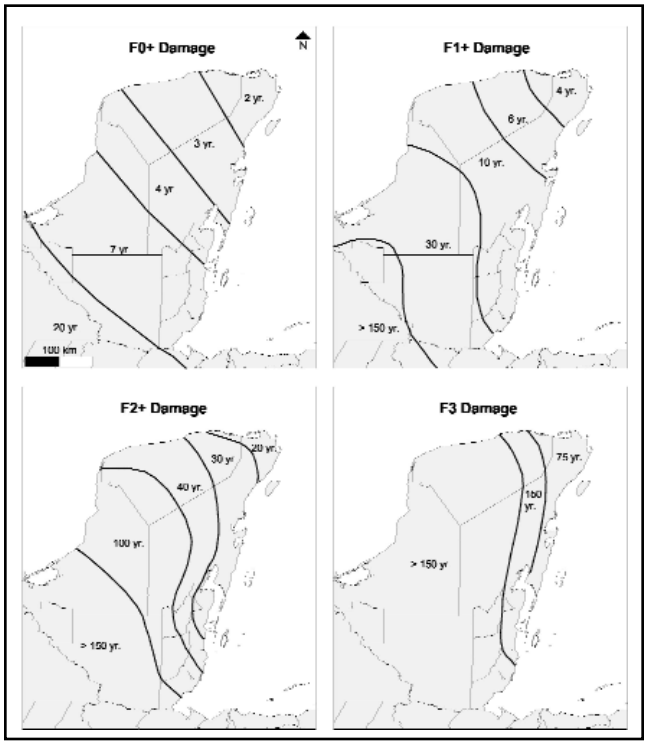
Dave Kittredge continued exploring patterns of land protection, forest owner attitudes, and forest management in the North Quabbin landscape of central Massachusetts. Research on owner attitudes and behaviors expanded this year with the acquisition of all private forest management plans for North Quabbin properties enrolled in Chapter 61, the forest property tax program. When added to the map of other state lands under management, and the previously acquired data on harvest activity, an improved view of the extent and type of forest management will be developed for this diverse sample region.

Carbon Exchange of Old-growth Hemlock Forests

This fall Julian Hadley initiated long-term measurements of carbon exchange in the old-growth hemlock forest in the center of the Prospect Hill tract. Initial results indicate that these forests stored substantial amounts of carbon in October and early November, but negligible amounts thereafter through mid-March. Carbon storage ceased on November 20 following the first daily minimum temperature below –5°C. This result corresponds well with measurements of photosynthesis on individual hemlock shoots in previous years, which showed a sharp decline after nights below –2° C and near-zero photosynthesis after a minimum of –8° C. Such a low rate of photosynthesis could easily be balanced by respiration of the soil and trees, leading to no net carbon storage. Although the evergreen hemlock forest did not show any net carbon storage in winter, carbon storage in the fall after leaf drop by deciduous trees amounted to about 15 percent of average annual carbon storage in nearby deciduous forests. Clearly evergreen trees can derive substantial benefit from photosynthesis in mid- to late autumn.

Ecological Impacts of Hurricanes Across the Yucatan Peninsula

The ecological impacts of hurricanes across the Yucatan Peninsula in Mexico were investigated by Emery Boose, David Foster, Audrey Barker Plotkin, and Brian Hall, using a simple meteorological model (HURRECON) developed at the Harvard Forest and a database of historical hurricane data (HURDAT) maintained by the U.S. National Hurricane Center. A total of 105 hurricanes over the period 1851–2000 were reconstructed to produce estimates of wind damage on the Fujita scale (a common scale of damage for tornadoes and hurricanes) across the region. Results showed considerable annual and decadal variation in hurricanes, while at the half-century scale there was an increase in hurricane intensity since the mid-nineteenth century. Ninety percent of the hurricanes causing F1 damage or higher (i.e., more than scattered individual windthrows) occurred in the months of August, September, and October. A strong spatial gradient in hurricane frequency and intensity extended across the region from northeast to southwest, resulting from the greater number of hurricanes to the north, the east to west movement of most hurricanes across the area, and the tendency for



Smoothed regional gradients in reconstructed hurricane damage across the Yucatan Peninsula, Mexico, showing average return intervals at different damage levels (1851–2000). Damage ranges from F0 (loss of leaves and small branches) to F3 (most trees blown down).

most hurricanes to weaken significantly after landfall. For example, over 150 years, northeastern parts of the peninsula experienced a minimum of one F3 hurricane, six F2 hurricanes, and thirty F1 hurricanes, while southwestern parts experienced no F2 or F3 damage and fewer than five F1 storms. Though a significant disturbance across much of the Yucatan, hurricanes may have shorter-lived and less severe ecological impacts than fire or human land use. However the interaction of these factors (e.g., fires following hurricanes) may be significant and deserves further study.

Forest Response to an Experimental Hurricane

The hurricane experiment simulates the forest impact of an intense storm like the 1938 Hurricane. In October 1990 canopy trees were pulled over using a winch, based on data from 1938, resulting in direct and indirect damage to nearly 70 percent of the stand. Vegetation response has been studied over ten years and this year all new trees greater than 5 cm diameter were measured by Audrey Barker Plotkin. Most saplings are advance regeneration that was present in the understory of the stand before the manipulation. Regeneration is dominated by black birch, followed by red maple and yellow birch. Red

Summer student Kristin Wilson and Audrey Barker Plotkin.

oak was dominant in the pre-manipulation forest, but only one red oak has reached the 5-cm size class since 1990. This compositional shift is dampened somewhat by survival of some of the original canopy, which currently comprise more than one-third of trees ≥ 5 cm diameter. These survivors include prostrate stems, bent and leaning trees that are rebuilding their crowns, and vigorous undamaged trees. The largest trees are undamaged red oaks (46 stems/ha), which dominate the area's basal area. Smaller red maples have persisted as well. The current forest stand has a multi-layered structure, with dense saplings forming a lower stratum below a middle layer of recovering trees, and scattered tall emergent stems from the original stand.

The manipulation exerted a large effect on the understory as increased light reached the forest floor for several years, uprooting of trees resulted in patches of disturbed soil, and pits and mounds covered 8 percent of the area. Although overall floristic change was slight, new species were especially common in plots containing a pit or mound. Two exotic and potentially invasive species (Morrow's honeysuckle and Oriental bittersweet) have been found in one part of the experiment; this area will be monitored closely but they are not expected to increase due to the dense forest conditions. Raspberry species appeared in the experimental site, probably from buried seed but are now declining. Hay-scented fern (*Dennstaedtia punctilobula*) and starflower (*Trientalis borealis*) increased markedly after the manipulation, but are now declining, indicating that understory conditions may be returning to pre-disturbance conditions. However, two abundant shrub species, shadbush (*Amelanchier* spp.) and hazel (*Corylus cornuta*) continue to increase. The landscape context of the site (surrounded by intact forest) and rapid recovery of the forest canopy via advance regeneration and sprouting contribute to the observed stability.

Thirty-two Years of Change in a New England Forest

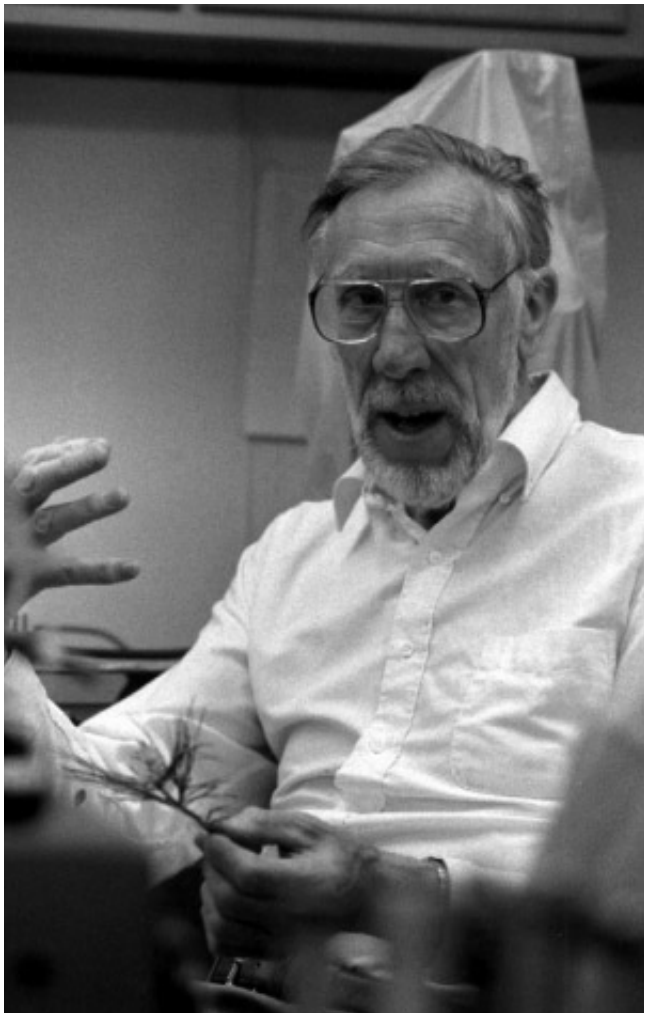
Permanent plots allow the long-term study of changes in forest composition and structure; however, few datasets extend beyond thirty years. In 1969, soil scientist Walter Lyford established a a seven acre permanent grid on the Prospect Hill tract in mixed hardwood forest that originated after an old-field white pine stand was cut in about 1890. The site was chosen as typical of many upland forests and Lyford mapped the locations and sizes of all trees, downed wood, tip-up mounds, human artifacts (e.g., stonewalls, prior experiments), and soils. With resurveys on approximately ten-year intervals the area provides an opportunity to track forest dynamics on a fine spatial scale, and to relate vegetation to environmental variation and past disturbance. Audrey Barker Plotkin is sampling the area to complete a thirty-two year spatial database of change.

Mice and Songbirds: Vertical Distributions and Predator-Prey Interactions in Oak Forests

For the past four summers, Cathy Langtimm and Becky Field have studied songbirds and white-footed mice (*Peromyscus leucopus*) in forests on Prospect Hill and in Tom Swamp addressing the possibility that mice are important predators on the eggs of open-nesting songbirds. White-footed mice are found throughout New England forests with both positive and negative effects on the mixed conifer-deciduous ecosystem. They may help to control insect infestations by eating many insects including the pupae of gypsy moths. They also eat seeds, which can either assist with regeneration from buried seed caches or reduce regeneration of plant species. Mice are also part of the cycle of transmitting Lyme disease; infected mice can pass on the bacteria to deer ticks.

A little studied aspect of these mice is their climbing behavior. During this study, small mammals were live-trapped on the ground, in shrubs, and in the crowns of canopy oak trees. All years have shown marked differences in population densities and weather conditions. Mice were captured in canopy oak trees, although at low frequencies. Climbing activity in the understory increased from summer into fall as the number of insects, fruit, and seeds on plants increased.

Nest predation is a major mortality factor in open-nesting songbirds. Yet, most studies on nest success have looked at predation in ground or shrub nests. Important data are missing for nest predation and types of predation above shrub height. We have compared relative nest predation rates in ground, shrub, lower canopy, and higher canopy levels, using artificial nests baited with plasticine eggs set out in May, June, and July. In the summer of 2000, this work continued with the help of Scott Demers, a summer student supported by Harvard Forest and the Department of Natural Resource Conservation, University of Massachusetts. Preliminary analysis showed that annual predation rates appeared to fluc-



P. Barry Tomlinson,
E. C. Jeffrey Professor of Biology, *Emeritus.*

tuate with changes in rainfall during the summers. "Bird predation," defined by complete removal of both eggs, appeared to be higher in the upper strata and in May trials. "Small mammal predation" was identified by chewed plasticine eggs, many of which had tooth marks from white-footed mice. This type of predation tended to be higher at lower heights although still evident in the higher strata. These trends suggest that there are differences in predation at different heights and that small mammals are capable of climbing into the canopy and preying upon songbird nests.

Acorns are important for winter survival of mice and estimates of acorn abundance at both trapping sites continued in a collaborative study with John O'Keefe. Estimates for fall 1998 and 1999 success fully predicted mouse population numbers the following years.

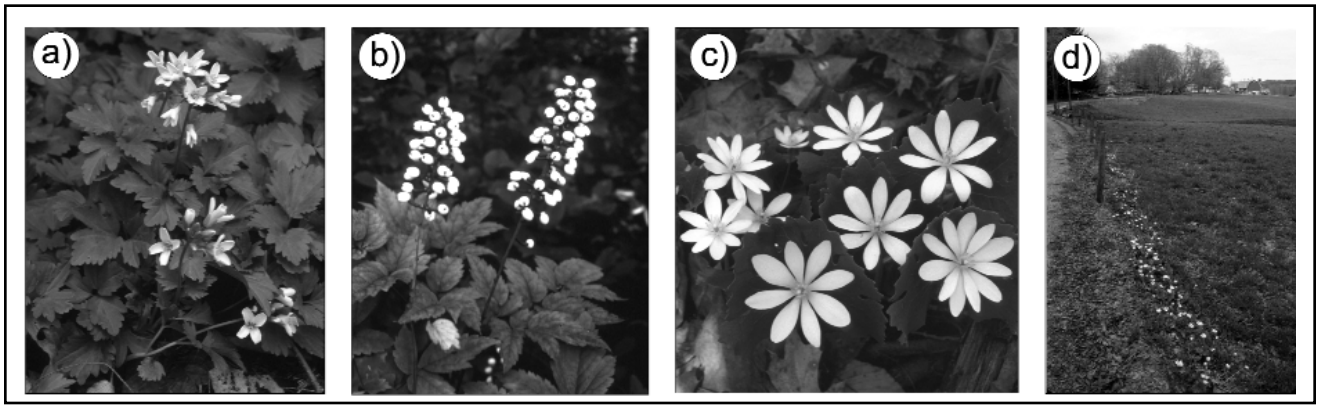
Botanical Studies

Barry Tomlinson continued work on *Calamus,* the rattan cane of commerce, to show how the unusual vascular anatomy originates in the developing shoot. These results clearly show that vascular bundles are initiated long before the leaves they supply. It was established that the unusual gymnosperm *Gnetum* has reaction fibers (gelatinous fibers) like those in woody angiosperms. However, the fibers are extra-xylary and play an important role in establishing and maintaining the distinctive architecture of this plant.

Graduate Student Research

Rebecca Anderson completed fieldwork for her MFS study of the role of climate and succession on the development and lateral expansion of forested peatlands in New England. Work on three peatlands involved detailed mapping of the basin morphometry, characterization of the underlying sediments, and radiocarbon dating of major changes in development. The sites have similar histories, evolving from an open lake to sedge and shrub wetlands and then to swamp forest that spread from the original basin onto the surrounding upland. While sediment samples are being dated, Rebecca is developing a model for forest peatland development and is beginning to interpret the influence of climate on this history.

Jesse Bellemare continued his thesis research investigating the impacts of past land-use on rich mesic forests (RMF) in western Massachusetts. RMF are uncommon communities dominated by sugar maple and white ash, with a lush herb layer including spring ephemerals and unusual fern species. The community has high conservation value due to the diversity of uncommon species. The potential sensitivity of woodland herbs to past human disturbance, particularly nineteenth century forest clearance for agriculture, has led researchers to speculate that the composition of RMF may be strongly linked to past land use. However, the absence of detailed historical records has precluded an accurate assessment of these effects in much of the eastern United States. Jesse is using the 1830 land use, together with twentieth century data, to reconstruct forest cover over the past two centuries. Vegetation sampling on RMF sites with differing histories is documenting varied species responses to past land use. These responses appear to result from species-specific life history



Typical rich mesic forest plant species showing differering distribution patterns in response to past land use. Three-leaved toothwort (*Dentaria maxima*) (a) is a vegetatively-reproducing species that rarely produces seed; it occurs commonly in primary forest, but is absent from secondary stands. White baneberry (*Actaea pachypoda*) (b) and red baneberry (*A. rubra*) produce seeds abundantly in the form of bird-dispersed berries; they occur commonly in both primary and secondary stands. Bloodroot (*Sanguinaria canadensis*) (c) produces seeds that are ant-dispersed, suggesting that the species could experience difficulty recolonizing secondary forest. However, bloodroot has persisted and thrived throughout the agricultural landscape in hedgerows (d), from which it has successfully recolonized many secondary stands.

traits, including characteristics such as seed production rate and dispersal mode. Certain ant-dispersed and gravity-dispersed species are strongly associated with continually forested sites (primary forests), whereas bird-dispersed and wind-dispersed species tend to be present in these as well as in sites that were historically cleared for agriculture (secondary forests).

A striking illustration of this pattern can be seen in the contrasting distributions of three-leaved toothwort (*Dentaria maxima*), a clonal species which produces little or no seed, and baneberry *(Actaea rubra* and *A. pachypoda*), which produces abundant bird-dispersed fruits. Three-leaved toothwort is common in primary RMF, but rarely occurs in secondary stands, likely due to seed limitation. In contrast, baneberry can successfully disperse its berries by birds and mammals into secondary forests. One striking exception to this trend is provided by bloodroot, (*Sanguinaria canadensis*), an ant-dispersed species typical of RMF, which is more abundant in secondary forest than in primary. This unusual distribution pattern is apparently due to bloodroot's ability to persist and thrive in the high-light environment of hedgerows, from which it has successfully recolonized secondary stands as they develop. This study stresses the varied responses of species to past disturbance, underscores the legacies of land use, and highlights the importance of considering history when evaluating the factors influencing plant community composition and species distributions.

Rob Eberhardt completed his MFS thesis on the influences of land-use history, fire, and environmental conditions on patterns of forest vegetation on Cape Cod National Seashore and submitted a manuscript for publication. He is continuing to work on analyses for the entire Cape with Glenn Motzkin and David Foster.

Matt Kizlinski completed his field and laboratory work for his MFS thesis examining vegetation and ecosystem responses following hemlock logging. In response to the expanding infestation of hemlock woolly adelgid (HWA), extensive hemlock forests are being logged, often before infestation. Since hemlock has not been a valuable timber species and has been largely ignored by silvicultural research, the long-term fate of these logged sites is unknown. To better understand recovery from logging, ten sites ranging from one to thirteen years of post-logging succession were chosen for intensive vegetation and ecosystem study. Vegetation quickly establishes in the high-light environment created by logging. Unlike the slower, less uniform vegetation response accompanying HWA infestation, nearly the entire harvested area responds with vegetation regrowth. Species not normally found in healthy hemlock forests become common, such as thickets of blackberry and raspberry. Within a few years, black birch seedlings dominate and grow to form a low dense canopy, shading out the early successional species.

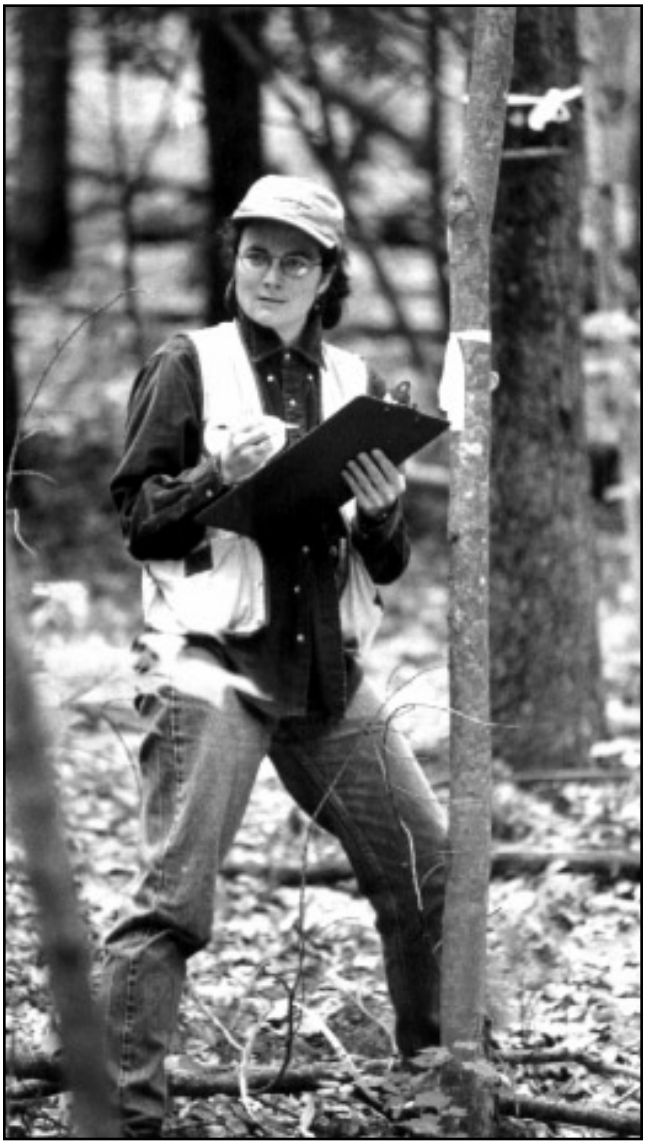
Ecosystem changes following hemlock logging are equally dramatic. The thick soil layer of hemlock

needles is gradually replaced by a thin layer of deciduous leaves. Despite this large loss in total forest floor mass, old cuts maintain total nitrogen mineralization rates that are similar to intact hemlock stands. However, a much larger proportion of the nitrogen is in the form of nitrate, which is uncommon in intact ecosystems in the northeast. Higher nitrification rates can also be seen in younger cuts; due to a lack of plant uptake, nitrate could possibly be leaching out of the system. This project links previous and ongoing research at the Harvard Forest. Studies of the direct impact of HWA on ecosystem properties, combined with HWA's indirect effect of increased hemlock logging, highlight the widespread and severe impact this insect's introduction is having on hemlock forests.

Harvard Forest LTER Program

The Harvard Forest is one of twenty-five sites in the Long Term Ecological Research (LTER) program sponsored by the National Science Foundation. Each site addresses questions of a long-term nature; collectively the sites undertake comparative studies across ecosystems. Representatives from each site and NSF meet twice annually to coordinate network-wide activities and to collaborate. The central theme of the Harvard Forest LTER is interpretation of the structure, composition, and function of forest ecosystems in terms of their history of natural and human disturbance and environmental change. This research is being addressed at the stand, landscape, sub-region (e.g., central Massachusetts), and regional (New England) scale.

The research program involves soil scientists, atmospheric chemists, and ecologists studying physiological, population, community, and ecosystem processes. Investigators represent the Department of Biology (F. Bazzaz), Earth and Planetary Sciences (S. Wofsy, B. Munger), and Harvard Forest (D. Foster, D. Kittredge, G. Motzkin, D. Orwig) at Harvard University as well as the Ecosystems Center-MBL, Woods Hole (J. Melillo, K. Nadelhoffer, P. Steudler), the Complex Systems Research Center at the University of New Hampshire (J. Aber) and the University of Massachusetts (M. Mulholland). Emery Boose is the LTER Data Manager with assistance from Julie Pallant. The research is organized to maximize the interactions among scientists from different disciplines. Four major scientific approaches include: (1) retrospective studies of historical changes in the environment and ecosystems; (2) long-term measurements of forest structure and function; (3) experimental manipulations; and (4) synthesis and modeling. The LTER science group meets approximately monthly. The Harvard Forest Ecology Symposium is held to present current research with abstracts published annually. The program for the 2001 symposium is included in this report.



Heidi Lux on the soil warming plots.

Each year, in addition to results generated by Harvard Forest researchers we highlight studies by our collaborators in the HF LTER Symposium program that underscore the value of long-term studies.

Nitrogen Saturation in Temperate Forest Ecosystems

Human activity has augmented the cycling of nitrogen through the biosphere more than any other

element. As the pivotal element in amino acids, proteins, nucleic acid, chlorophyll and other biomolecules, nitrogen has profound effects on ecosystem function. As a component of nitric acid, nitrogen is a key element in the acidification of soils and streams due to acid deposition.

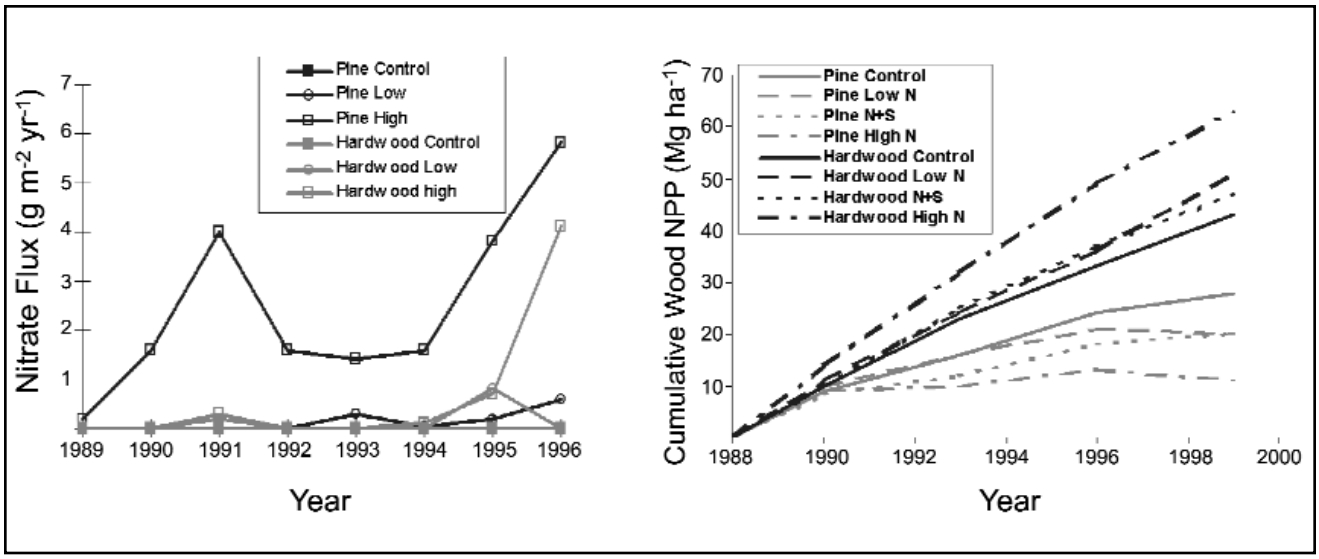
In 1989, the LTER group from the University of New Hampshire, led by John Aber, published a series of hypotheses concerning the expected responses of N-limited forest ecosystems to chronically elevated N deposition. Central to these was the expectation of highly non-linear or threshold responses in the induction of nitrification and nitrate leaching. They also predicted that excess N deposition would eventually reduce tree growth and lead to forest decline. However, there was no real expectation that this would happen in a short period of time.

In 1998 John's group revisited these initial hypotheses. Two of the most important ones have been supported by the findings. It is indeed possible to induce nitrification and nitrate leaching with chronic N additions, although this took much longer in the very N-poor hardwood stand than we expected. Mechanisms by which large amounts of added N are retained in these systems are now a key area of study. In addition, and rather surprisingly, the application of nitrogen did induce significant reductions in growth rates in the pine stand. By the year 2001, the pine stand receiving the highest level of N deposition was effectively dead. To date there has not been any growth decline in deciduous, broad-leaved stands. This result may assist us in interpreting historical episodes of forest decline and anticipating future trends in forest health in areas of high N deposition.

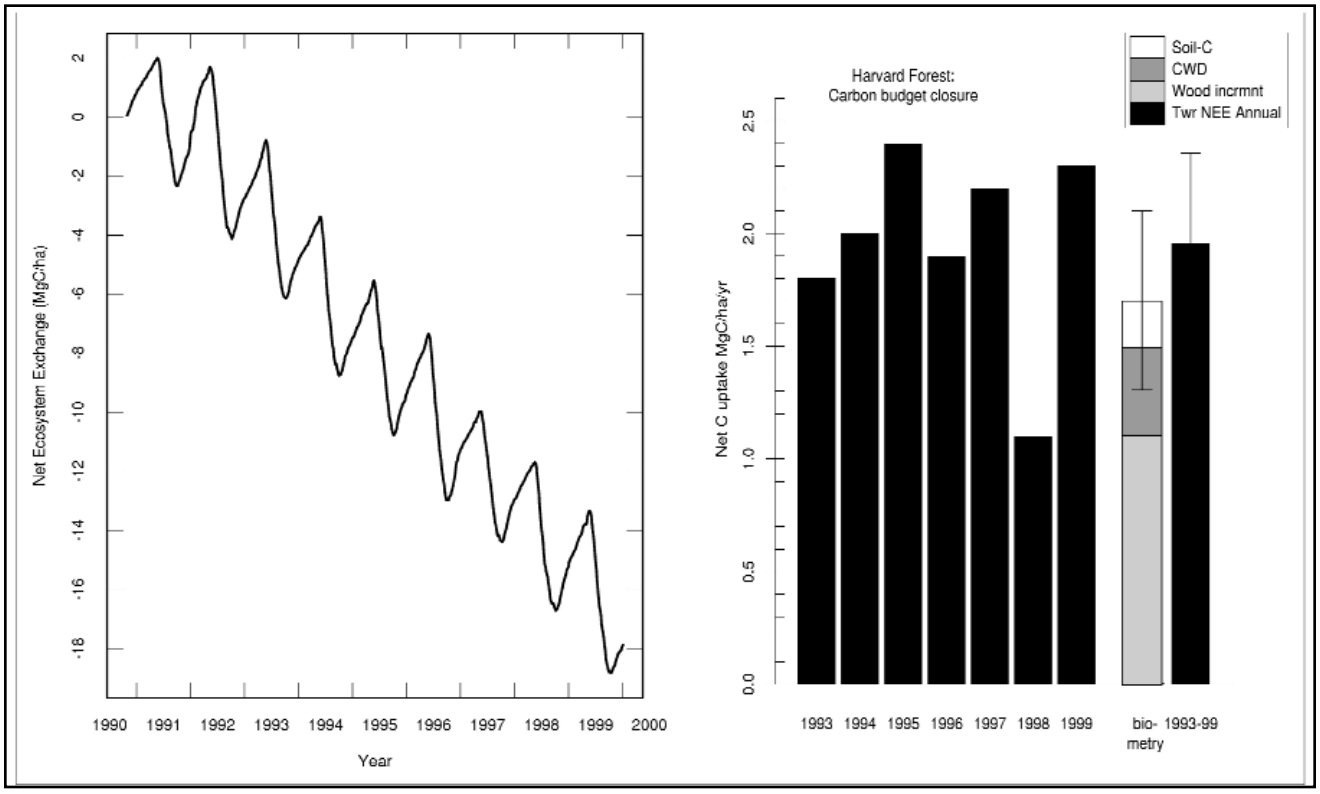
Carbon Sequestration by Temperate Forests

Northern mid-latitude forests appear to be important sinks for as much as 25 percent of the CO_2 added to the atmosphere by fossil fuel burning since 1980. The net sink varies inter-annually by a factor of two or more, correlating with global-scale climate variations, and possibly accelerating in the 1990s. When the Harvard Forest LTER was initiated in 1989, the group from Harvard's Department of Earth and Planetary Sciences headed by Steve Wofsy set out to determine whether typical New England forests were a net sink for CO_2, how large the sink was, and what processes controlled it. Various factors have been suggested: previous land use, fire and forest management are factors that are subject to deliberate modification; longer growing seasons due to climate warming, fertilization by elevated CO_2 and N deposition are environmental influences not subject to direct manipulation.

Rates for Net Ecosystem Exchange (NEE) of CO_2 at Harvard Forest have been measured by Steve's research group each hour since 1990, using the eddy covariance technique, along with extensive biometric measurements of species-specific changes



Long-term results from the nitrogen saturation experiment document the impact of two different doses of nitrogen (low, high) on pine and hardwood stands. The pine stands exhibited the greatest response in terms of nitrate leaching from the soils (*left*) and reduction in wood net primary production *(right)*.



(Left): Cumulative net carbon exchange at Harvard Forest, the sum of hourly data for nine years; *(right):* Comparison of annual sums of net carbon exchange with ecological data showing long-term changes in carbon pools. These data establish the accuracy of long-term eddy flux measurements using conventional biometry, provided that averaging times are sufficient (~five to eight years).

in the C stored in live and dead wood. These long-term observations allow assessment of the accuracy of the C budget derived from hourly flux data, and quantitative analysis of the observed response of the ecosystem to environmental variation for time scales from instantaneous (hourly) to decadal.

The long-term record of NEE shows average net uptake of 2.0±0.4 Mg C $ha^{-1}yr^{-1}$, with inter-annual variations exceeding 50 percent Cumulative uptake compared well with biometric data that indicated storage of 1.6±0.4 Mg C ha^{-1} yr^{-1} over eight years, 60 percent in live biomass and the balance in coarse woody debris and soils. Very different processes control carbon uptake on long and short time scales. Ecosystem responses to weather and climate (e.g., variations in growing season length or cloudiness) regulated seasonal and annual fluctuations. Legacies of prior disturbance and land use, especially stand age and composition, dominated longer time scales. Thus short-term variations of NEE at Harvard Forest reflect prompt forest response to environmental influences, while inter-annual variations reflect interactions of climate variations with ecosystem properties on annual time scales, affecting tree mortality, respiration rates, length of the growing season, and available light. Since seasonal and annual climatic anomalies are often coherent over large spatial scales, the processes described here are significant in mediating inter-annual variations of the rate of increase of atmospheric CO_2. The long-term carbon budget at Harvard Forest reflects the slowest-changing ecosystem properties: stand age and composition, soil fertility, and coarse woody debris. The enormous areas occupied by mid-successional forests (30–100 years old) in the U.S. have been cited as the major factor in present terrestrial uptake of carbon, for which these studies provide strong quantitative support and mechanistic understanding.

Anderson, R. Development and lateral expansion of peatlands in central New England.
Barford, C. et al. Eddy covariance and biometric measurements of CO_2 exchange at the Harvard Forest.
Barker Plotkin, A. and *D. Foster.* Long-term forest monitoring at Harvard Forest.
Barker Plotkin, A. and *D. Foster.* Understory dynamics in the experimental hurricane.
Barker Plotkin, A. , S. Martell, and *D. Foster.* Forest development after an experimental hurricane.
Barnes, D. and *S. Wofsy.* Evaluation of greenhouse and ozone-depleting gases in rural New England.
Bauer, G. et al. Is increased nitrogen availability predictive for long-term forest carbon sequestration?
Bellemare, J., G. Motzkin, and *D. Foster.* History and species composition of rich mesic forests.
Boose, E. The new Harvard Forest meteorological station.
Borken, W., E. Davidson, K. Savage, and *K. Angeloni.* Response of CO_2 release to dry/wet cycles.
Burk, J., G. Motzkin and *D. Foster.* The historical landscape of southern New England in early records.
Cobb, R., D. Orwig, and *S. Currie.* Effects of hemlock woolly adelgid on foliar decomposition.
Colman, B., K. Nadelhoffer, and *W. Currie.* Decadal scale recovery of ^{15}n tracers in bolewood.
Currie, W., K. Nadelhoffer, and *B. Colman.* Woody detritus, land use and long-term C and N interactions.
Dail, D., E. Davidson, J. Chorover, L. Dria, and *P. Hatcher.* Rapid abiotic transformation of nitrate in soils.
Davidson, E., K. Savage, and *S. Trumbore.* Interannual variation of CO_2 production in the O horizon.
Dria, K. et al. Changes observed by NMR and pyrolysis gc/ms of Harvard Forest soils.
Eberhardt, R. et al. Land-use legacies in the vegetation of Cape Cod national seashore.
Fitzjarrald, D. and *K. Moore et al.* Forest-atmosphere exchange processes: report on activities 2000-2001.
Francis, D. et al. Climate change in New England inferred from Chironomid remains in lake sediments.
Fuller, J. et al. Recent climate reconstruction in New England forests.
Hadley, J. and *J. Schedlbauer.* Ecosystem carbon exchange in an old-growth hemlock forest.
Horii, C., J. Munger, S. Wofsy, and *M. Zahniser.* Atmospheric reactive N partitioning and fluxes.
Kaufman, S. and *F. Bazzaz.* Effects of n deposition on *Alliaria petiolata* and indigenous species.
Kittredge, D. and *A. Finley.* North Quabbin region's chapter 61 spatial database.
Kittredge, D., A. Finley, and *D. Foster.* Pattern of timber harvest in a complex forest landscape.
Kizlinski, M. et al. Ecosystem and vegetation response to hemlock logging.
Köster, D. and *R. Pienitz.* Paleoecological and ecological studies on diatoms in four New England lakes.
Lewis, K. and *F. Bazzaz.* Responses of invasive species to release from herbivory.
Lux, H., J. Melillo, T. Ahrens, P. Steudler, and *F. Bowles.* Warming, C storage, and feedbacks to vegetation.
Magill, A. and *J. Aber.* Chronic nitrogen additions to two forest stands.
Micks, P. and *L. Nadelhoffer.* Forest soil respiration and organic matter dynamics.
Min, Q. and *K. Moore.* Regional climatology of cloud and aerosol for forest-atmosphere exchange.
Moore, K., D. Fitzjarrald, and *Q. Min.* Modeling the effect of diffuse light on canopy CO_2 uptake.
Munger, J., J. Field, J. Budney, and *S. Wofsy.* Peroxyacetylnitrate concentrations at Harvard Forest.
Muth, C. and *F. Bazzaz.* Tree seedling canopy responses to conflicting photosensory cues.
Muth, C., K. Capecelatro, and *F. Bazzaz.* Influence of branch processes on tree canopy displacement.
O'Keefe, J. Regeneration following clearcutting of red pine overstory – year 11.
O'Keefe, J. and *S. Johnson.* Woody species phenology, Prospect Hill tract, Harvard Forest – 2000.
Orwig, D., D. Foster, and *D. Mausel.* Patterns of hemlock decline due to the hemlock woolly adelgid.
Orwig, D., G. Motzkin and *D. Foster.* Vegetation and history of ridgetop pitch pine and red pine.
Orwig, D., R. Cobb, M. Kizlinski, and *D. Foster.* Ecosystem analyses of hemlock woolly adelgid.
Parshall, T. et al. Landscape-scale history of vegetation and fire on Cape Cod, Massachusetts.
Parshall, T. Variability in the long-term occurrence of fire in New England.
Syfert, M., G. Motzkin, and *B. Hall.* Massachusetts in 1830: woodlands and cultural events.
Verheyen, L. and *M. Hermy.* A comparison of European and North American ancient forest plant species.

National Institute for Global Environmental Change (NIGEC)

Harvard University is the Northeastern Regional Center for the NIGEC program sponsored by the Department of Energy. NIGEC research seeks to improve the understanding of mechanisms of global environmental change, to develop experimental and observational programs that enhance the understanding of ecosystem and regional scale processes contributing to global change, and to provide educational opportunities in global environmental change research. The Center is administered by the Division of Applied Sciences at Harvard and most of the field studies are conducted at the Harvard Forest. Researchers include many of the LTER scientists (Bazzaz, Foster, Melillo, Nadelhoffer, Wofsy) in addition to faculty from the State University of New York (D. Fitzjarrald, K. Moore), Woods Hole Research Center (E. Davidson), University of California (S. Trumbore), U.S. Geological Survey (E. Sundquist) and Harvard Forest (J. Hadley).

BULLARD FELLOWS

Kathleen Donohue (University of Kentucky) conducted research on the population biology and evolutionary ecology of seed dispersal and germination. She established a large field experiment in Kentucky and New England to compare the adaptive value and genetic basis of germination behavior between these sites. She also initiated studies of the quantitative genetic basis of seed dispersal and its plasticity. Kathleen presented seminars at Cornell University and Utah State University and developed manuscripts concerning the influence of dispersal on multilevel natural selection, the influence of germination on life-history expression and evolution, the physiological basis of germination responses to seasonal cues, and natural selection in heterogeneous environments.

Mary Ann Fajvan (West Virginia University) analyzed the ten years of regeneration data from the Tom Swamp Hurricane study. She developed models to describe the height growth response of key tree species and is using spatial statistics to describe regeneration establishment patterns. With Audrey Barker Plotkin, she is preparing two manuscripts from the analyses. She also was an invited speaker at the Pennsylvania State University Forestry Issues Conference on sustainable forest management practices.

Manuel Lerdau (State University of New York, Stony Brook) began two projects in the Departments of Earth and Planetary Sciences and Organismic and Evolutionary Biology: (1) development of a coupled tunable diode laser absorption spectrometer with a controlled environment leaf chamber and infrared gas analyzers for the measurement of the physiological regulation of nitrogen dioxide exchange between plants and the atmosphere; and (2) examination of the role of phylogeny and phenology in regulating leaf chemistry, decomposition, and nutrient release in the tropical deciduous forest of Costa Rica.

Lucinda McWeeney (Yale University) completed four manuscripts on archaeology and environmental reconstruction in New England and processed northern New Hampshire sediment cores for macrofossils and pollen and archaeological sediments for charcoal and phytoliths. Lucinda participated in a regional paleoenvironment workshop at the Peabody Museum, Andover and presented seminars at the Society for American Archaeology Annual Meeting in New Orleans. She traveled to South Carolina and Virginia to gather sediment samples for future paleoecology projects relating to pre-Clovis habitation sites in the southeast.

Fraser Mitchell (Trinity College, Dublin) investigated long-term stand dynamics in relation to disturbance regimes in temperate forests in New England. He investigated and attempted to quantify the impact of human versus natural disturbance to the forest at the Pisgah old-growth stand in southern New Hampshire, a site at higher altitude than the Massachusetts sites, but more significantly, suffering minimal impact from European settlement. Results of pollen analysis from two sites at Pisgah have revealed that forest composition today is remarkably similar to that of the pre-European settlement (and pre-immigration of chestnut) forest. The most striking difference between Pisgah and the Massachusetts sites is that beech has remained as an important component at Pisgah while it has declined following European settlement in Massachusetts. More intensive data analysis is planned to quantify this difference. These results raise questions about the tolerance of beech to disturbance and in particular its ability to recolonize. This issue is particularly relevant to the potential impact of fungal pathogens on the long-term survival of beech in New England. Fraser completed pollen analysis on samples from a site in Scotland. He interacted with staff members in the area of charcoal analysis. This is a area of paleoecology that has been

under-investigated in Ireland but certainly worthy of attention in the future.

Karn Deo Singh (Harvard University) prepared guidelines for assessment of forest biological diversity and phase one of a research proposal integrating biological diversity conservation in forest management planning in Malaysia, which is currently being implemented by specialists from the Forest Research Institute of Malaysia and Harvard University.

Fred Swanson (U.S. Forest Service, Pacific Northwest Research Station) worked on the Andrews Forest LTER synthesis volume and manuscripts concerning ecosystem response to the 1980 eruptions of Mount St. Helens, road ecology, and the dynamics of wood in rivers. Collaboration with David Foster on a paper concerning LTER studies of land-use legacies drew significantly on their perspectives from cultural, managed, and wild landscapes of New England and the Pacific Northwest. He gave seminars and class lectures at Harvard, University of Massachusetts, University of Vermont, Cornell, and the Institute of Ecosystem Studies.

Bullard Fellows for 2001–2002 include Alison Berry (University of California, Davis), Elizabeth Colburn (Massachusetts Audubon Society), Aaron Ellison (Mt. Holyoke College), Colin Orians (Tufts University), Akile Pite (Scientific Commission in Forestry, Albania), Kimberly Smith (University of Arkansas) and Navjot Sodhi (National University of Singapore).

EDUCATIONAL ACTIVITIES

Barry Tomlinson taught Harvard courses, Biosciences 51, "Integrative Biology of Organisms" in the fall semester and Biosciences 24, "Biology of Plants" during the spring semester. He also conducted a workshop in "Tropical Plant Biology" at the Fairchild Tropical Garden, Miami, Florida, during summer 2000. David Foster taught Biology 160, "Forest Ecology" and Biology 199r, "Forest Practice and Research." Barry, David, John O'Keefe and other staff members led the Harvard Forest seminar of eleven students in the spring. David served on thesis committees of three undergraduate students at Harvard and graduate students at the University of Massachusetts, University of Maine, and Laval University. Glenn Motzkin, Dave Orwig, and David supervised the four students in the Masters of Forest Science program. Dave Kittredge and David Foster worked closely with former Harvard undergraduate Mary Berlik to revise her thesis into a Harvard Forest Paper.

David Kittredge
and
Andy Finley.

Summer Research Program

The Harvard Forest Summer Student Research program, coordinated by Edythe Ellin and assisted by Sarah Laubscher, attracted a diverse group of students to receive training in scientific investigations, and experience in long-term ecological research. Students work closely with researchers and many conduct their own independent studies. The program includes weekly seminars from resident and visiting scientists, discussions on career issues in science and field exercises on soils, land-use history, and plant identification. An annual field trip is made to the Institute of Ecosystem Studies (Millbrook, N.Y.) to participate in a Forum on Careers in Ecology. Students present major results of their work at the Annual Summer Student Research Symposium.

Summer Students 2001

Christian Arabia	Allegheny College
Tricia Burgoyne	University of Wisconsin
Peter Cowan	Kalamazoo College
Bridgid Curry	University of Notre Dame
Caitlin Dwyer-Huppert	Clark University
Susan Italiano	Gettysburg College
Lynda Joudrey	University of New Hampshire
Spencer Meyer	Dartmouth College
Rosa Navarro	Stanford University
Julia Silvis	Harvard University
Kathleen Theoharides	Dartmouth College
Morgan Tingley	Harvard University
Linda Jane Wan	University of Pennsylvania
Kristin Wilson	Middlebury College
Truus Thomas	Benedict College

Front (*left to right*): Sarah Laubscher (Proctor), Spencer Meyer, Rosa Navarro. Middle (*left to right*): Susan Italiano, Truus Thomas, Linda Jane Wan, Bridgid Curry. Back (*left to right*): Christian Arabia, Caitlin Dwyer-Huppert, Kathleen Theoharides, Kristin Wilson, Julia Silvis. (*Missing from photo:* Tricia Burgoyne, Peter Cowan, Lynda Joudrey, and Morgan Tingley.)

ACTIVITIES OF THE FISHER MUSEUM

The Fisher Museum plays an important role in the educational mission of the Harvard Forest by providing a public outlet for research in ecology, conservation, and management. The Museum also provides a unique setting for conferences and workshops sponsored by the Forest and outside organizations. Dr. John O'Keefe has primary responsibility for the development of activities and coordination of the use of the Museum.

The Museum enjoyed another very successful weekend schedule last year, welcoming over 1,100 visitors on Saturday and Sunday afternoons, May through October. Mary Ann Walker again received special thanks for her continuing, enthusiastic work as volunteer coordinator. Bill and Marianna Berry, Hector Cameron, Walt Davidson and Martha Siccardi received special recognition for being the most active volunteers during the season. On a more solemn note, this past spring the group was deeply saddened by the death of Helen Gronich. who served as volunteer coordinator for our first six years.

In late April Teresa Jones assumed the part-time position as Assistant Schoolyard LTER coordinator, responsible for coordinating Harvard Forest's collaboration in ecological studies with schools in the region. Teresa is updating the interpretation on our nature trails and will develop new a interpretation for the boardwalk through Black Gum Swamp.

During the year the Museum provided programs for twenty-four elementary and secondary schools, forty-three college and university classes, and twenty-three community and professional groups. In September the Forest hosted a group of Chinese LTER scientists touring selected North American LTER sites to learn about our research programs. In November more than forty silviculture professors visited the Forest as part of a field trip in conjunction with the National Society of American Foresters convention in Washington, D.C., and in June the Forest and Museum hosted a field trip in conjunction with the American Geophysical Union meeting in Boston.

Meetings, Seminars, Conferences

The Twelfth Annual Harvard Forest Long Term Ecological Research Symposium was held in the Museum on April 23 followed by the National Institute for Global Environmental Change meeting on April 24. Other meetings at Harvard Forest included meetings of the North Quabbin Regional Landscape Partnership, Massachusetts Watershed Coalition, Massachusetts Extension Service Coverts Project, Massachusetts Department of Environmental Management Logging Safety Workshop, Massachusetts Land Trust Coalition, Massachusetts Association of Professional Foresters, Massachusetts Executive Office of Environmental Affairs, Millers River Watershed Council, Natural Resources Conservation Service, New England Chapter of the Wildlife Society, Northeastern Loggers Association, Predator Conservation Alliance, Project Learning Tree, Vegetation Control Service, Athol Bird and Nature Club, and the Nature Conservancy. The Forest hosted faculty retreats for the University of Massachusetts Department of Natural Resource Conservation and Harvard's Department of Organismic and Evolutionary Biology.

Speakers in the Harvard Forest Seminar series:

Carl Beierkuhnlein	University of Rostock, Germany
Dick Boisvert	Deputy State Archaeologist for New Hampshire
Julie Brigham-Grette	University of Massachusetts
Kim Brosofske	University of Rhode Island
Dena Dincauze	University of Massachusetts
Kathleen Donohue	University of Kentucky
Mary Ann Fajvan	West Virginia University
Adrien Finzi	Boston University
Richard Forman	Harvard University
Megan Griffiths	Tufts University
Olivier Honnay	Catholic University, Belgium
Malcolm Hughes	University of Arizona
Brian Jones	Mashantucket Pequot Museum
Manuel Lerdau	State Univ. of New York
Glenn Matlack	University of S. Mississippi
Lucinda McWeeney	Yale University
Wyatt Oswald	University of Washington
Stéphanie Pellerin	Université Laval
Nathan Phillips	Boston University
Michael Reed	Tufts University
Bryan Schuman	Brown University
K. D. Singh	Harvard University
Peter Siver	Connecticut College
Fred Swanson	H. J. Andrews Experimental Forest
Steven Trombulak	Middlebury College
Kris Verheyen	Catholic Univ., Belgium

FOREST MANAGEMENT AND MAINTENANCE

After more than twenty years of service to Harvard Forest, Charles "Pete" Spooner retired from the woods crew in January. The contributions Pete has made to the Forest are manifold and can be seen best in the local landscapes he has helped to shape and change. Pete has been a mainstay here, always there to lend a hand or supply advice. Many technical problems in research and equipment have been solved with Pete's expertise and his knowledge of the local countryside. His welding and steel fabrication skills are evident throughout the physical plant. We are fortunate to be able to rely on Pete for part-time assistance in the future.

This past spring we completed the final landscaping details on the courtyard connecting Shaler Hall, Torrey Lab, and the Archives. These improvements have received many positive comments and inspired us to continue to the front of Shaler Hall where we are widening the parking lot and adding new lighting, walkways, paving, and granite edging. This effort is part of a three-phase project to improve access and parking for growing numbers of visitors and staff.

Other efforts include the clearing and fencing for pasture of a new field on the west slope below Fisher House, the installation of our new weather station, permanent 110 volt AC power to the new canopy tower in the hemlock stand, as well as continued thinning and improvement cutting in the softwood plantation complex at the western edge of Harvard Pond.

LONG TERM DATA MANAGEMENT
Harvard Forest Archives

The Archives, which represents the map, document, photographic, correspondence, and research sample center of our data management system, serves as a daily resource for Harvard Forest researchers and visitors from many colleges and historical, ecological, and conservation organizations. As part of the effort to develop a management plan for the Harvard Forest properties, historical deed, map, and correspondence files were researched for land-use provisions and historical information. A summary of all property transactions from 1907 to the present was expanded and a simplified property and deeds file was created, combining documents from many sources. Several hundred building and highway plans were also added to the map files. Other additions to the map collection included comprehensive coverage of the nineteenth century Coast and Geodetic

Charles "Pete" Spooner and David Foster
discussing the renovation of the front of Shaler Hall.

surveys for the coastal region from New York to Cape Cod, and twentieth century U.S.G.S. topographic quadrangles. In conjunction with the Massachusetts 1830s mapping project, the entire series was acquired from the state archives, giving Harvard Forest a complete set of this unique and valuable resource. To create a central archive database, files documenting maps, samples, aerial photos, research files, and publications were inventoried, updated, and converted to the ProCite bibliographic format.

Historical and current slides and photographs were used to create a detailed photo gallery on the Harvard Forest Web site. Lantern slides were sorted and cataloged, with several high-quality prints produced from the glass originals. A large series of photographs of Cape Cod and the Islands was added to the aerial photo collection and many historical photos were duplicated or scanned for use in projects. Records for the Sanderson family, which farmed portions of Prospect Hill in the eighteenth and nineteenth centuries, were strengthened by acquisition of the family's original account book from a local bookdealer, providing a primary account of agricultural activity on the tract. In addition, Kathleen Hunter, a Sanderson descendant, made several research visits and donated a copy of the family genealogy records to the archives.

Approximately 70 boxes of new material were added to the sample archive, including soils from the coastal, soil warming, and adelgid studies, and tree cookies from the ancient Gribben forest in Michigan.

Computers

Major improvements to our computer facilities continued this year with funding from NSF and internal sources. The network was extended to the Fisher, Raup, and Community Houses (via optical fiber) and to the EMS Tower (via DSL modems). Four Windows 2000 servers, a high-capacity tape drive, and a CD-Tower were purchased, as well as three new staff computers. New graphics equipment included a portable computer projector and laptop computer, digital camera, and a large-format optical scanner. A second computer projector will be included in the remodeled Seminar Room. Several long-term bibliographic databases were consolidated and converted to a common format (ProCite) for improved access and maintenance.

(*Left*): Emery Boose and the new meteorological station, (*right*): The old met station.

ACTIVITIES OF THE HARVARD FOREST STAFF

Rebecca Anderson presented a poster at the LTER All Scientist's Meeting (ASM) in Snowbird, Utah. She led field trips to local peatlands for classes from the Harvard School of Landscape Architecture, Harvard College, and Mount Holyoke College and a tour of Harvard Forest's Black Gum Swamp for state Biodiversity Days. Audrey Barker Plotkin presented a poster at the LTER ASM, attended the Forest Stewards Guild Annual Meeting in Silver Bay, New York, and presented a seminar, "Forest Response to Simulated Hurricane Damage," at the University of Massachusetts, Boston.

John Burk participated in conservation meetings and conferences, including the inaugural Mount Holyoke "Summit on the Range" for the Connecticut Valley, and led a tour of the Quabbin Reservoir for REU students and staff. He served as Petersham coordinator for the Massachusetts Biodiversity weekend.

Susan Clayden attended the Eighth International Paleolimnology Symposium at Queen's University, Kingston, Ontario.

Richard Cobb presented talks at the Ecological Society of America (ESA) meeting and at the University of Maine Cooperative Extension Workshop for practicing foresters.

David Foster presented lectures at the Landscape Legacies of Human Land Use symposium at Duke, Ecotarium (Worcester Natural History Society), and Sturbridge Village, based on LTER research, *Thoreau's Country,* and *New England Forests Through Time*. He joined Eric Chivian and Paul Epstein from Harvard's Program for Human Health and the Global Environment at Aerlie House in Virginia for a two-day briefing of congressional aides on environmental issues, where he discussed issues relating to fire ecology and management. David represented HF at LTER Coordinating Committee meetings and was interviewed by Jamie Sayen for Wild Earth and Northern Forest Forum. David continued in his capacity as editor for Ecosystems, Progress in Physical Geography, and Northeastern Naturalist, board member for the Conservation Research Foundation, advisor to the Highstead Arboretum, and became a trustee of the Trustees of Reservations. At Harvard he serves as the Director of Graduate Studies for the M.F.S. program, an executive committee member for the NIGEC program, and served on a faculty search committee for OEB. He travelled with a Harvard Museums of Natural History (HMNH) group to Patagonia, and with the Alumni Association and HMNH to the Galapagos Islands.

Donna Francis presented a seminar at the Geological Society of America, Northeast Section, in Burlington, Vermont.

Julian Hadley presented talks at ESA and attended the annual Ameriflux meeting in Atlanta where he presented the first direct measurements of carbon exchange in an eastern hemlock forest.

Brian Hall continued as the weather station observer, adding to eighty-eight years of weather records at Harvard Forest. This year we are collecting data at the old, manual site and at the new, automated meteorological station concurrently for one year to allow evaluation of data compatibility.

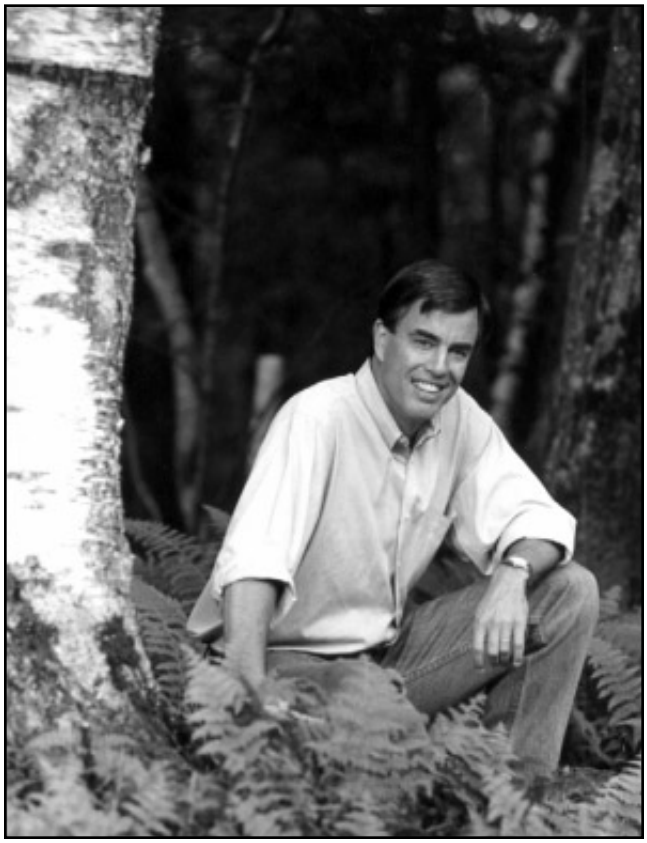
Dave Kittredge served as invited keynote speaker on forest policy at Penn State's Forest Issues conference. The Ford Foundation awarded Dave a research fellowship to study forms of private owner cooperation in temperate forest systems. He will use this opportunity to spend his upcoming sabbatical year at the Forest pursuing these ideas, and examples from around the world.

Matt Kizlinski presented his research at a seminar at the Arnold Arboretum.

Glenn Motzkin presented a poster on coastal research at ESA and attended the Long Island Pine Barrens Research Forum at Brookhaven National Laboratory. He led a field trip through the Connecticut Valley for David Foster's Forest Ecology class and a trip to Montague Plain for the Conway School of Landscape Design. Glenn served on the graduate committees of Rebecca Anderson, Jesse Bellemare, and Rob Eberhardt at Harvard Forest and Sally Shaw from the University of Massachusetts. Glenn was featured in an interview on forest resilience and recovery in the *Woodland Steward*. He continued to serve as an Ecology Advisor for The Trustees of Reservations and was appointed as an Associate Member of the Massachusetts Natural Heritage and Endangered Species Program Advisory Committee.

Sylvia Barry Musielewicz received her Master's degree from the University of Minnesota and presented a poster on her work in Malawi at a meeting of the Geological Society of America.

John O'Keefe gave talks on the history of northeastern forests at the University of Massachusetts, Fruitlands Museums, Shelburne Farms in Vermont in

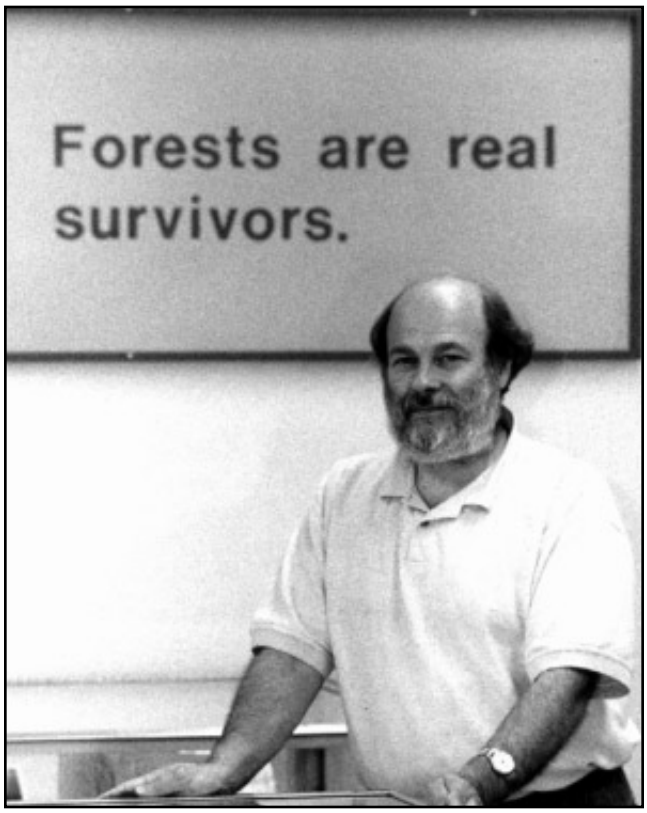


David Foster.

conjunction with the National Park Service Conservation Institute, SUNY, Albany, Mount Holyoke College's Sense of Place lectures, the New England Museum Association meeting in Portland, Maine, and the New England Society of American Foresters' Advances in Forest Biology Workshop. He represented Harvard Forest on the ENFOR Distance Learning in Forestry planning group, cosponsored by the Lincoln Institute of Land Policy and the Kennedy School of Government. John attended the LTER ASM and ESA in Snowbird, Utah, presented a poster on the long-term impacts of land use history at the joint American Society for Environmental History/Forest History Society meeting in Durham, N.C. and attended the NSF LTER Coordinating Committee meeting in Phoenix. He was a judge at the Mahar High School Science Fair, and serves on the boards of the Millers River Watershed Council and Mount Grace Land Conservation Trust, where he is currently vice president, and on the executive committee of the North Quabbin Regional Landscape Partnership. He also continues to serve on the Quabbin Science and Technical Advisory Committee and Secretary Durand's Advisory Group on Environmental Education.

Dave Orwig attended the LTER ASM and presented a talk at ESA. He presented hemlock woolly adelgid (HWA) research findings at a public hearing organized by State Senator Brewer at Mount Wachusett Community College, at the North American Forest Insect Work Conference in Edmonton, Canada, and at the Massachusetts Forestry Association Annual meeting. Dave helped lead a field tour at Harvard Forest to the Visiting Silviculture Instructors tour. In addition, he gave a seminar on old-growth forests and led a trip to Mount Wachusett for the Massachusetts Audubon Society. He was appointed Chairman of the Silvicultural Recommendations section of the U.S.D.A. HWA Strategic Management Plan and serves on Matt Kizlinski's M.F.S. committee.

Tim Parshall gave talks at the American Geophysical Union and the Pine Barrens Symposium in Brookhaven, N.Y. and presented research results at the ESA. He participated in a workshop for the Massachusetts Department of Environmental Protection on sediment coring protocol for determining mercury level in Massachusetts lakes.



John O'Keefe.

VISITING RESEARCH SCIENTISTS AT THE HARVARD FOREST 2000–2001

A large number of Harvard University and outside scientists use Harvard Forest facilities and research sites. Many of these scientists are involved in the Harvard Forest LTER or NIGEC programs.

John Aber	University of New Hampshire
Toby Ahrens	Ecosystems Center – MBL
Mark Ashton	Yale University
William Bain	Harvard University
Peter Bakwin	Harvard University
Carol Barford	University of Wisconsin
Diana Barnes	Harvard University
Fakhri Bazzaz	Harvard University
Dennis Balocchi	NOAA/ARL/Oak Ridge, Tenn.
K. Boering	Harvard University
Richard Bowden	Allegheny College
Frank Bowles	Ecosystems Center – MBL
Alfram Bright	Harvard University
Sean Burrows	University of Wisconsin
Jeannine C-Bares	Harvard University
Michael Canfield	Harvard University
Chaur-Fong Chen	Oregon State University
Alan Coleman	Harvard University
William Currie	Virginia Polytechnic Univ.
David B. Dail	University of Georgia
Eric Davidson	Woods Hole Research Center
Bruce Daube	Harvard University
Frederik Debaeke	Kuleuven, Belgium
Marty Downs	Ecosystems Center – MBL
Todd Drummey	Ecosystems Center – MBL
Jim Ehleringer	University of Utah
Bob Evans	U.S.D.A. Forest Service
Rebecca Field	University of Massachusetts
David Fitzjarrald	SUNY, Albany
Son-Maio Fan	Harvard University
Andrew Finley	University of Massachusetts
Richard Forman	Harvard University
Steven Frolking	University of New Hampshire
Julia Gaudinski	UCLA, Irvine
Elaine Gottleib	Harvard University
Gonzalo Giribet	Harvard University
Mark Helmlinger	NASA Jet Propulsion Laboratory
Joseph Hendricks	University of New Hampshire
Michelle Holbrook	Harvard University
David Hollinger	U.S.D.A. Forest Service
Daniel Jacob	Harvard University
Christine Jones	Harvard University
Sylvia Kaufman	Harvard Unversity
Chris Kerfoot	Ecosystems Center – MBL
Otto Klemm	Univ. of New Hampshire
Juri Knjazikhin	Boston University
Takashi Kohyama	Hokkaido University
Chun-Ta Lai	University of Utah
Cathy Langtimm	U.S.G.S.; Holy Cross College
Barry Lefer	Univ. of New Hampshire
Heidi Lux	Ecosystems Center – MBL
Alison Magill	Univ. of New Hampshire
Els Malfait	Kuleuven, Belgium
Lynn Margulis	University of Massachusetts
Mary Martin	Univ. of New Hampshire
Jerry Melillo	Ecosystems Center – MBL
Jennie Moody	University of Virginia
Kathleen Moore	SUNY, Albany
Jeff Morisette	NASA
Sarah Morisseau	Ecosystems Center – MBL
Mitch Mulholland	University of Massachusetts
Ranga Myneni	Boston University
J. William Munger	Harvard University
Christine Muth	Harvard University
Knute Nadelhoffer	Ecosystems Center – MBL
Jeffrey Parker	Smithsonian Environ. Res.
Sophie Parker	Ecosystems Center – MBL
Ronald Prinn	M.I.T.
Elizabeth Pyle	Harvard University
Michael Rogers	GA Institute of Technology
Kathleen Savage	Woods Hole Research Center
David Schaub	University of Arizona
Tim Sipe	Franklin & Marshall College
Paul Steudler	Ecosystems Center – MBL
Britt Stephens	Harvard University
Kristin Stinson	Harvard University
Eric Sundquist	U.S. Geological Survey
Robert Talbot	Univ. of New Hampshire
Matt Thompson	Harvard University
Susan Trumbore	University of California
Mel Tyree	University of Vermont
Aya Uraguchi	Hokkaido University
Shawn Urbanski	Harvard University
Kris Verheyen	Kuleuven, Belgium
Lisa Windham	Lehigh University
Greg Winston	U.S. Geological Survey

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ACKNOWLEDGMENT OF SUPPORT

Activities described in this Annual Report are supported by funds provided by the following sources, to which we are indebted:

Friends of the Harvard Forest
Commonwealth of Massachusetts
- Department of Environmental Management
- Division of Fisheries and Wildlife
- Biodiversity Initiative
- Ecological Restoration program
- Natural Heritage and Endangered Species Program

Andrew W. Mellon Foundation
National Science Foundation
- Biological Field Stations and Marine
- Laboratories
- Ecosystem Studies
- International Programs
- Long-term Studies
- Ecology Program
- Research Experience for Undergraduates

The Family of Richard Thornton Fisher
U.S.D.A. Competitive Research Grants, Forestry
Department of Energy – NIGEC
Southern Taconics Research and Conservation Center

GIFTS

The Library at Harvard Forest welcomed more gifts of books to its collection. Brian Hall, a Research Assistant, donated eight books, which included Lucy Braun's *Deciduous Forests of Eastern North America*. Sarah Cooper-Ellis, a former staff member, donated books on Plant Hormones, Plant Development, Vegetation Dynamics, and Global Change. Jim Baird has again donated later issues of *The Auk*.

Aimee Peterson donated to the archive map collection a copy of the Petersham Historical Society's "Historical Map of Petersham," which was originally created with the help of the Harvard Forest.

NEW FUNDING

D. R. Foster. Long Term Ecological Research at Harvard Forest (LTER III). National Science Foundation. $4,255,000.

D. R. Foster, D. A. Orwig, and D. B. Kittredge. Forest Response to the Introduced Hemlock Woolly Adelgid: Development of Silvicultural Guidelines. U.S.D.A. Northeastern Area Federal Focus Funding. $35,000.

D. R. Foster and J. Hadley. Evaluating the effects of diverse vegetation types and soil drainage classes on net carbon exchange of a landscape mosaic with mobile and fixed eddy covariance systems. NIGEC. $165,000.

David R. Foster
Director

Petersham, Massachusetts
August 2001