MP745: A Long-Term Study of an Oak Pine Forest Ecosystem: A Brief Overview of the Holt Research Forest

Jack W. Witham
Malcolm L. Hunter Jr.
Hollis C. Tedford III
Alan J. Kimball
Alan S. White

See next page for additional authors

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A Long-Term Study of an Oak Pine Forest Ecosystem: A Brief Overview of the Holt Research Forest
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Holt Research Forest Staff

Jack W. Witham
Associate Scientist
Department of Wildlife Ecology

Malcolm L. Hunter, Jr.
Project Leader and Professor of Wildlife Ecology
Libra Professor of Conservation Biology
Department of Wildlife Ecology

Hollis C. Tedford III
Outreach & Education Coordinator
Department of Forest Management

Alan J. Kimball
Associate Professor of Forest Resources
Department of Forest Management

Alan S. White
Associate Professor of Forest Resources
Department of Forest Ecosystem Science

Susan Elias Gerken
Research Assistant
Department of Wildlife Ecology

College of Natural Sciences, Forestry, and Agriculture
University of Maine
Orono, Maine 04469-5755
DEDICATION

This publication is dedicated to Dr. William L. Holt Jr. and F. Rodney Holt. This father and son team were the impetus for the creation of the Holt Woodland Research Foundation and the Holt Research Forest. Their generosity, foresight, and strong commitment to forest research has been demonstrated repeatedly over the many years of this project. Their past and continuing support of the Holt Research Forest has and will continue to provide benefits to students, forestry and wildlife professionals, forest landowners, and forest management in Maine. To these ends, they have served us all.

PREFACE

This publication provides an overview of the long-term forest ecosystem project at the Holt Research Forest in Arrowsic, Maine. It is based on nearly 16 years of work by an interdisciplinary team from the College of Natural Sciences, Forestry, and Agriculture, including faculty, professional staff, visiting scientists, University of Maine graduate students, and undergraduate field assistants. We hope this publication will be useful to other researchers, to our workshop participants, and to others interested in forest ecosystem science.

Many people have worked to make this long-term research project possible. None of this would be happening without the generosity and foresight of the Holt family and the ongoing support of the Holt Woodlands Research Foundation. Funding from the Maine Outdoor Heritage Fund and the Baldwin Foundation made it possible to create the Outreach and Education position and begin our Workshop Series. Our workshop participants provide us with the opportunity to explain our project, share our findings, and obtain valuable feedback on how to most effectively answer today’s questions and help to provide tomorrow’s solutions.

The Holt Research Forest provides University of Maine students the opportunity to gain invaluable work experience in actual field research. Conversely, graduate students who have conducted research at the forest have provided important data and insights to the project. We owe a great deal of thanks to the summer student work crews who have done so much of the field work and offered many suggestions. The manuscript was reviewed by William Ostrofsky and Robert Wagner, faculty members of the College. Barbara Harrity copyedited the manuscript and created the layout using desktop publishing software. The artwork was done by Josephine Ewing.

We welcome comments, questions, and collaborations. Please direct communication to either:

Jack Witham
Holt Research Forest
HC 33 Box 309
Arrowsic, ME 04530
207/443-9438
jwitham@maine.edu

Malcolm Hunter
Department of Wildlife Ecology
5755 Nutting Hall
University of Maine
Orono, ME 04469-5755
207/581-2862
hunter@umenfa.maine.edu
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BACKGROUND AND RATIONALE

Setting

Forests are dynamic ecosystems that have been shaped through time by changes in the biological and physical environment. Long-term climatic variation, natural disturbances (e.g., wildfire and disease epidemics), atmospheric pollution, and our land-use practices have greatly influenced the distribution and abundance of forest organisms, the intensity and cyclic timing of disturbance processes, and the productivity of forest ecosystems (Fuller et al. 1998). Over the past 350 years since European settlement, the rate of ecosystem change has increased dramatically, and the landscape of New England has been correspondingly transformed (Foster et al. 1997).

Much of New England was deforested through the mid- to late 1800s, followed by broad-scale abandonment of agriculture and natural reforestation, despite a rapidly increasing human population. The New England landscape, which once supported scattered, cut-over woodlots in a matrix of fields and pastures, is now covered with "second-growth" forest that covers 60–90% (77–90% in northern New England) of the land area (Griffith and Alerich 1996). In 1840, an estimated 87.1% of Maine was forestland (Irland 1998). As a result of land clearing for agriculture, this figure dropped to an estimated 53.2% in 1872, and today stands at 89.6%.

Excluding northern Maine, the forests of New England today bear much evidence of the agricultural past: stonewalls separating different forest stands, old cellar holes and foundations, collapsed dams, once-cultivated plants gone wild, and old roadbeds. As the forest area and tree size have recovered regionally, so have the native flora, fauna, and ecosystem processes.

Our social, cultural, and economic processes exert ever-increasing pressure on critical forest ecosystem processes in the region. Society demands that forests produce an expanding variety and quantity of goods, services, and values such as clean water and air, habitat for plants and animals, wood products, recreation, and visual aesthetics. To satisfy these demands in a sustainable and integrated manner requires information and insight that are often available only through long-term research. A well-designed research program can provide forest managers with the ability to predict the likely outcomes of various management options. These outcomes can include primary targets such as timber production, as well as nontraditional targets like species richness. Understanding natural forest dynamics in a particular region should be the foundation of every management action (Kotar 1997).

The Study Site

Since 1981, scientists from the University of Maine have been intensively studying a 120-hectare (300-acre) tract of oak-pine forest in Arrowsic (see Figure 1). More than 32,000 trees have been individually tagged and measured; the relative abundance of 260 or more species of vascular plants has been mapped at fine-scale; and the home ranges of more than 30 species of birds have been mapped, using approximately 500,000 observations. At the Holt Research Forest, the central issue being examined is: "How do oak-pine forest ecosystems respond to human-imposed disturbance and natural successional change?" Long-term monitoring projects at the Forest are providing important descriptions of how this forest ecosystem has developed, how particular ecosystem processes operate, and what structural and compositional differences are found in harvested areas versus unharvested "control" areas. Research questions and approaches are framed so that they are relevant to the region's forest management issues and have broad applicability to the understanding of forest ecosystems in general.

The impetus for all this activity came from William (Bill) Holt, who owned and cared for this forest for more than forty years, and his son Rodney Holt, who created the Holt Woodlands Research Foundation. With generous financial support from the Foundation, University of Maine scientists have undertaken a diverse array of research and manage-
Figure 1. The Holt Research Forest is located at 43°52'N, 60°46'W near the center of Arrowsic Island in the Kennebec River. The island falls with Maine's coastal climatic region (Briggs and Lemin 1992) and the midcoast biophysical region of Maine (McMahon 1990). This biophysical region has the highest richness of woody plants in the state, in part because of the coastal influence, and in part because it falls within the transition between the oak-pine forest ecosystem to the west and south and the spruce-fir and northern hardwoods forests to the east and north. Most of the oak-pine forests in this region are the result of old field succession (Kimball et al. 1995).

Photo 1. Bill Holt peeling the bark from a log for the construction of the research facility.
ment activities of particular interest to non-industrial forestland owners. This paper presents an overview of both sets of activities: first describing management of the Holt Forest, and second describing the research program.

MANAGEMENT PROGRAM

A Historical Perspective

To provide a basis for understanding the current management program, it is important to begin with the history of the Holt Forest property. Remnants of stone walls, building foundations, roads, and wire fencing indicate that much of the property once was agricultural land. An 1880 census estimated that 50% of this area of Maine was forested, while in 1995 the estimate was 90% (Irland 1998). Aerial photographs from 1940, 1953, 1973, and 1998, and stand maps completed in 1983 and 1998 show a distinct difference in forest stand types along an old east-west fence line. Barbed wire and woven fencing are still visible. This former property line divides the Holt property into north and south halves (see Figure 2) reflecting the historic existence of two separate farms (Moore and Witham 1996).

William Holt and his wife, Winifred, acquired the south farm in 1941 and the north farm in 1946. A 1940 aerial photograph shows the two farms just prior to the Holt’s purchase of the south farm. There are open fields on the north farm along the east side of the Old Stage Road and around the salt marsh. On the south farm, open fields appear between Sewall Pond and the road. Signs of a 1929 timber cutting on the west side of the road on both farms can be seen. The Holts renovated the Shea farmhouse into a seasonal home and began using the property as a retreat. Over the next four decades, land management activities were minimal and patchy. White pine trees were planted in the old fields of both the north and south farms, and occasionally some partial timber cutting was conducted, focusing on dead and dying trees.

In 1983, the Holts offered use of the property to the University of Maine for research, under the auspices of the Holt Woodlands Research Foundation. The Foundation constructed a research facility on the site of an abandoned well and cellar hole, probably the south farm homestead site. The main structure is a log building made from white pine trees harvested from the Holt Forest.

Figure 2. Property map of the current Holt Research Forest, with building locations, frontage on Sewall Pond and the Back River, and the fence line which was the boundary line between the two historic farms.
Foundation-University Management

After some initial field work in 1981, the University's College of Forest Resources presented "A Proposal for Research and Management of the Holt Forest" to the Holt Woodlands Research Foundation in February of 1983. The proposal articulates two broad goals for directing the activities at the Holt Research Forest. The first goal relates to forest ecosystem research: "undertake long-term research to understand the structure and dynamics of an oak-pine forest ecosystem." The second goal relates to forest management: "develop a demonstration forest where state-of-the-art management techniques can be presented to the public." The two goals work together as a program in which ecosystem studies monitor the long-term effects of careful timber management practices. Full-time work began on the Holt Forest in 1983. A grid system was established on a 40-hectare (96-acre) area, and baseline studies of ecosystem components were begun. Half of the study area was designated for timber management, with the other half set aside as a control area where no timber management would take place.

Forest Management Goal and Objectives

The overall goal of forest management at the Holt Research Forest is to increase the structural diversity and to arrive at a balanced age-class distribution. In so doing, we want to identify methods of extracting timber from the forest that do not greatly alter the development of natural forest communities. To pursue this broad goal, we must continue to learn more about long-term forest ecosystem processes and how forest communities develop under varying conditions.

Our three forest management objectives are also those most commonly expressed by non-industrial forestland owners in Maine:

1. Financial. To provide a sustainable economic return from the sale of high-quality timber products.
2. Wildlife. To maintain the diversity and abundance of wildlife.
3. Aesthetic. To maintain the aesthetic appeal of the forest.

Harvest Design

In 1983, most of the forest stands at the Holt Research Forest were single-storied (one vertical level formed by tree foliage) or two-storied, even-aged stands resulting from old field succession. Following five years of baseline data collection, 10 of the 20 1-hectare (2.5-acre) blocks in the managed half of the study area, and 11 adjacent blocks outside the study area, were partially cut during the winter of 1987–88. Blocks were chosen for cutting based on randomized pairs to assure a good distribution across the managed portion of the study area. Silviculturally, the rationale behind marking
trees for removal incorporated a combination of timber stand improvement and group selection methods.

This initial harvest removed large, poorly formed trees, created openings in the canopy ("harvest gaps") of sufficient size to release advanced regeneration, and encouraged natural regeneration in areas containing few or no tree seedlings (see Figure 3). These gaps were also designed to add a new age class to the forest. The purpose of this new age class was twofold: increase habitat diversity by adding a new vertical layer of vegetation, and help generate a more even flow of forest products by moving the even-aged stands toward an uneven-aged structure. It was our hope that the relatively small size of the harvest gaps would not significantly reduce near-term aesthetic appeal, and that the added vertical layer would eventually increase aesthetic appeal, of the harvested areas. Overall, the initial harvest removed approximately 44% of the basal area from the treated blocks, typifying the extent of removal common on managed woodlots throughout this region.

While harvest design was influenced by research goals, the approach is a good one for landowners who share the three management objectives listed above. A forest with a wider range of vertical structure can support a more diverse array of plants and animals, occupying different niches that are created by vertical separation (Hunter 1990). The timber stand improvement practices will eventually increase the timber value of the residual trees by creating better growing conditions for the straighter, healthier, faster-growing trees. If carefully undertaken, this management regime can maintain most of the aesthetic qualities of the forest, although some short-term unsightliness from harvesting is very difficult to avoid.

Regional Context

Growing awareness of the open-ended nature of forest ecosystems is moving forest management toward landscape-level planning to ensure the diversity and sustainability of working forests. Landscape management has typically been focused on huge tracts of public or industrial forest land. However, most of New England's forest land now exists as a mosaic of thousands of small (less than 5,000 acres), privately owned forest tracts (Griffith and Alerich 1996), which require different strategies for landscape-level planning. The Holt Research Forest is demographically well-positioned to explore land-

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Figure 3. Location of different forest canopy gaps in managed and control areas. Gaps created by the 1987–88 harvest are distinguished from natural tree gaps and ledge openings.
scape-level approaches to planning and management for this fragmented ownership pattern. Conservation efforts on lands near the Holt Research Forest also provide opportunities for expanding research and demonstrating the value of conservation lands within the landscape.

To take one example, a quiet but concerted, cooperative effort is underway to protect the Back River Estuary from potentially damaging changes in the use of abutting uplands. A local land trust (Lower Kennebec Regional Land Trust), in cooperation with other nonprofit conservation organizations and state and federal agencies, has successfully applied to the North American Wetlands Conservation Council (NAWCC) for more than $1,400,000 to purchase properties and easements in the lower Kennebec River region, with the Back River as the highest priority. Though the purchases are specifically aimed at tidal wetlands and adjacent upland buffers, larger tracts are sometimes acquired. The 170-acre parcel just south of the Holt Research Forest study area is now owned by Maine Department of Inland Fisheries and Wildlife and was purchased primarily with these funds. This and other lands along the Back River that are being protected by purchase or conservation easements will form a large area of mostly intact, undivided forest land. To date, more than 700 acres of tidal marshes and uplands have been protected.

Demonstration Areas

Development of demonstration areas (Figure 4) was begun on the Holt Research Forest in the fall of 1998 as part of the Outreach and Education Program. A walking trail is now located on the east side of Old Stage Road in Blocks 1K, 2K, and 3K with stops for discussing research efforts and selected 1988 harvest sites. Another trail is located on the west side of the road in Blocks 1J, 1K, 11K, and 11J. Stations along this trail are designated for discussing a timber harvest conducted during the winter of 1998–99, and to explain how scientific investigations are conducted under conditions found on the actual research areas. This most recent harvest was conducted by following the same guidelines used during the initial harvest.

Figure 4. Location of demonstration areas at the Holt Research Forest.
Photo 3. Demonstration of a "Swedcaddy" (a small wood hauler) as part of a landowner workshop.

Photo 4. A discussion of the research program with visitors from the Ecosystem Conservation Society—Japan.
RESEARCH PROGRAM

Introduction
Given our basic research goal of understanding how this forest is changing in response to timber harvesting, vegetation succession, climate change, and other factors, time plays a central role in our research design. In particular, we have designed most of our research projects so that they can be carried out consistently and efficiently over extended periods. This approach gave us the opportunity to document the forest carefully before we began harvest treatments. Five years of baseline data were collected before the harvest treatment in the winter of 1987–88. From 1988 onward we have continued to monitor how the forest is changing in response to that harvest and other factors. Such long-term data sets provide us with an excellent context; it allows us to see changes that occurred due to the harvesting against a backdrop of changes that are due to other factors. For example, to understand how small mammals might be affected by a timber harvest it is essential that we understand how they are responding to a much more critical factor, the abundance of acorns in a given year.

Our research design also has a strong spatial component because the studies occur on both the “natural” and “managed” portions of the forest. Unharvested areas serve as “controls” or benchmarks for understanding the effects of our timber management activities (Figure 3). The studies take place at three scales: comparing the 20-hectare (50-acre) managed area to the 20-hectare control area; comparing the 10 blocks that were harvested to the 30 blocks that were not; and comparing the particular canopy gaps created by harvesting to those gaps created by ledges and trees dying of natural causes.

To assure that our data are collected consistently over long periods, a detailed techniques manual has been prepared for conducting research at the Holt Research Forest (Witham et al. 1993). The manual provides quality assurance and quality control for data collected, facilitates the comparing and sharing of data with other research projects, and is used as a model for researchers involved in other forest ecosystem studies.

Selected Studies: Description, Methods, and Results

The following studies are selected to represent the range of long-term projects being conducted at the Holt Research Forest. The descriptions also serve to highlight some of the methodologies being used, to present interesting results-to-date, and to point to future research needs.

1. Land-use history and vegetation study
The composition and structure of forest ecosystems are often associated with physical factors (e.g., moisture, nutrients, and light) and biological factors (e.g., competition between plants and consumption by animals). Disturbances are also important and may affect plants directly or indirectly, by altering the physical and biological factors. We often fail to appreciate the length of time these disturbances continue to influence the ecosystem. In fact, sometimes our only clue to past disturbances may come from characteristics of the forest itself, long after visible signs of the disturbance have faded.

The land-use history of the Holt Research Forest provides a good example of how past disturbances continue to influence today’s forest. As described above, the core study area is bisected by a former property line that separated the “North Farm” from the “South Farm” (Figure 2). The farms differed in many respects, including the amount of land cleared for agriculture and cut for forest products, and the date of farm abandonment. These differences are reflected in both the composition and structure of the forest on either side of the line. As an example, spinulose woodfern is far more abundant in the understory of the north, whereas trailing arbutus primarily occurs in the south (Figure 5).

A study by graduate student Tammy Clark (1996) found that the historical development of two forest stands on either side of the line was different. In the northern stand, most of the white pine reached
breast height (130 cm) from 1910 to 1930. Their big­limbed structure and wide early growth rings indi­cate that they established under open conditions. The red oak in this stand did not reach breast height until the 1940s. In contrast, the pines and oaks in the southern stand established more or less to­gether between 1910 and 1930. In both stands, periods of light cutting are indicated by abrupt increases in radial growth, primarily of the pine.

2. Forest canopy gap study
Most of our gap-related forest research focuses on the dynamics (e.g., vegetative response) associated with openings in the forest canopy: both natural openings and harvest openings. This focus is applicable to many concerns of natural resource professionals who work with the forest. For in­stance, silviculture defines the various methods used to naturally regenerate forests in terms of the degree of canopy opening the harvest produces. Foresters often debate the size and arrangement of canopy openings necessary to regenerate a given tree species or to have a desired age/size distribu­tion. Wildlife biologists often debate how to design canopy openings to best manage for a particular wildlife species or to maintain species richness.

One study examined the partial harvest con­ducted during the winter of 1987–88. All canopy gaps created by the harvest were inventoried and mapped 14 months after the harvest. Naturally occurring ledge gaps (caused by the absence of canopy trees due to extremely shallow soils or exposed bedrock) and tree gaps (caused by the natural loss of trees in the canopy) were mapped and measured on 30 adjacent, untreated hectares (Figure 3). Figure 6 depicts the range of sizes of the three gap types. As can be seen, tree gaps covered only 0.7% and ledge gaps only 3.2% of the uncut forest whereas the harvest-created gaps covered 26.5% of the partially cut forest. After four growing seasons, the forest floor vegetation of the three types of gaps differed significantly with junipers dominating ledge gaps, ferns and tree seedlings dominating tree gaps, and tree seedlings, forbs, and slash (downed woody material left from timber harvest) dominating har­vest-created gaps.
3. Study of structure and composition of forest stands

The Holt Research Forest falls within the transition between the oak-pine forest to the west and south and the coastal spruce-fir forest to the east and north (McMahon 1990). The soils are typically derived from shallow glacial deposits on ridges and deep glaciomarine sediments in low-lying areas. Our study area is covered with post-agricultural oak-pine and coastal spruce-fir stands typical of the region. Much of the cleared land was abandoned by the early 1900s, resulting in a canopy dominated by 60 to 80 year-old trees. The oldest trees in the study area are heavy-limbed eastern white pines and eastern hemlocks that grew along fence rows and drainage ways. Even these trees are less than 125 years old. Within the study area, 51% of the land is covered by mixed stands growing on mesic (moist) sites, 10% is covered by mixed stands growing on xeric (dry) sites, 8% is covered by deciduous stands growing on mesic sites, 17% is covered by coniferous stands growing on mesic sites, and 14% is covered by coniferous stands growing on xeric sites (Figure 7).

We have made three 100% inventories of the study area for all trees larger than the 10-cm-(4-in.)
dbh class. The principal tree species, in order of their contribution to both trees per hectare and total stand basal area within the study area, are eastern white pine, red maple, northern red oak, and red spruce. In 1984, white pine accounted for the most stems, basal area, and volume per hectare. Red maple was the next most abundant and was also second with respect to basal area and total merchantable volume per acre (Figure 8).

The harvest conducted during the winter of 1987–88 removed 44% of the overall basal area in the harvest blocks. That harvest reduced the volume and relative abundance of the large, rough white pines (down from 44% to 38% of the merchantable volume) and increased the relative abundance of the red oak (up from 16% to 22% of the cords/acre). The total volume removed included 210 cords of firewood, 304 cords of pulpwood, and 117 mbf of sawlogs. Between 1988 and 1996, all of the tree species gained in volume except the “other” softwood group in the control blocks. The other softwood group in the control blocks suffered enough mortality over the eight years that it had a negative annual growth rate (-3% in cords/acre and -5% in board feet/}

Figure 7. Forest cover type map for the 40-hectare study area at the Holt Research Forest.
Figure 8. Comparison of number of stems, basal area, and volume for the harvest blocks and control blocks, as determined by three successive 100% inventories. The data for 1984 were gathered four years prior to the partial harvest made during the winter of 1987–88. The data from 1988 were gathered immediately after harvest, and the data from 1996 were gathered eight years after the harvest.
In contrast, red maple and red oak are growing at slightly over 6% annually in board feet/acre in the harvested blocks (Figure 9).

The sustainability of managed forests depends as much on the establishment and culture of seedlings and saplings as it does on the growth of the residual overstory trees. Since 1984 we have monitored the recruitment and development of new trees using several sampling designs, both in the forest as a whole, and in the canopy gaps. To date we have discovered that white pine, red maple, and red oak are all more abundant and taller in the canopy gaps than under the undisturbed canopy (control) adjacent to the gaps (see Figure 10). This trend holds true whether we consider stump sprouts or seedlings. Red maple and white pine are both more abundant and taller than the red oak. Much of this difference appears to be due to deer preferentially browsing the red oak seedlings and sprouts (see Figure 11).

The year 1993 was a major seed year for red oak throughout Maine. Beginning in 1994, Tammy Clark (1996) used our permanent seedling plots to follow the fate of oak seedlings that germinated following the 1993 mast year and found that while new seedlings were abundant under mature oaks and at the base of slopes, few new seedlings occurred in the canopy gaps. Because the only way for acorns to get into gap areas would be through animal (e.g., blue jays and chipmunks) dispersal, it is assumed that these animals chose not to cache acorns in the relatively open environment of the gaps. In contrast, oak seedlings that were established prior to the harvests appear to grow well in gaps, but only if they are not browsed by deer. Thus, oak mast years probably are important in establishing oak seedlings under the forest canopy, but for those seedlings to make it into the canopy, they must be released from competition and protected from deer.

![Graph](image-url)

**Figure 9.** Comparison of the annual percentage rate of growth in volume per unit area for the harvest and the control blocks over the eight years following the 1987-88 partial harvest. This growth rate is calculated based on two 100% inventories of all live trees 10 cm dbh and larger.
Figure 10. Comparison of the density of seedlings and saplings growing in the harvest-created canopy gaps and adjacent closed canopy (control) stands, 10 years after the partial harvest.
Figure 11. Relative severity of hardwood seedling and sapling browsing by whitetail deer. Sampling was conducted 10 years after the 1987–88 partial harvest. Numbers above bars are the number of seedlings counted.

Photo 5. Measuring the diameter of a small tree with a tree fork.
4. Small mammal study

Small mammals have been the focus of intensive research at the Holt Forest because they are among the most abundant vertebrate inhabitants of the forest and have wide-ranging effects on forest ecology. For example, several species are important predators of tree seeds and gypsy moths. Small mammal populations are monitored by live-trapping twice per year: in April to observe a low-point in their annual fluxes, and August to observe a high-point. Two traps are placed at each of 144 stations for five nights and all small mammals caught are measured and individually marked. After a two day hiatus, trapping continues for three more nights at 140 different locations. Individuals caught during the first period are often recaptured during the second period, thus allowing us to examine the spatial distribution and movements of individuals.

Captures and recaptures of nearly 15,000 small mammals during 16 years have revealed some interesting patterns, particularly for the most abundant species: white-footed mice (Figure 12). As seen in the graphs, the white-footed mouse population varies enormously from season to season. For example, in August of 1986 there were at least 329 mice in the trapping area; by the following April, this number had fallen to two; and by August of 1987, the population had only recovered to 44. Detailed work by Karen McCracken (1996) revealed one of the primary drivers of this pattern: oak masting years. Karen found significant correlations between fall acorn crop production and the number and body condition (as measured by weight) of white-footed mice the following spring. Their propensity for storing large numbers of acorns during acorn-rich falls is probably responsible for this pattern.

Figure 12. Abundance of white-footed mice in spring (A) and summer (B) are plotted against the number of acorns that fell in the autumn.
On top of these major fluctuations, the effects of the 1987–88 timber harvest are not even detectable for white-footed mice. This is not surprising because they are habitat generalists that thrive in a variety of conditions. Their broad taste in habitat probably also explains why we have found that the rates at which seeds of white pines, red maples, and red oaks are preyed upon do not differ among different types of forest openings and closed-canopy forest.

The 1987–88 harvest coincided with a shift from predominantly northern flying squirrels on the study area to a different species, the southern flying squirrel. However, it seems likely that this shift occurred because of regional population changes rather than our changes to the forest structure.

5. Bird study

One hundred and twenty-four species of birds have been observed at the Holt Forest and more than 35 of these species are known to breed here. Birds are an important and readily seen component of the forest ecosystem, playing a role as consumers of insects, as distributors and predators of seeds, and as possible indicators of forest condition. Both territory mapping (during the breeding season) and censusing (done year-round) have been used to monitor bird populations here. Territory mapping is a commonly used, labor-intensive method. Repeated visits are made to the study area and on each visit the location of all observations is marked on a map. The mapped locations are recorded with a computer system and from these data bases, either territory maps (based on clusters of observations over the breeding season) or data sets of numbers of observations are created for each species. Bird censusing consists of walking census lines and recording the location and distance from the line for each bird detected. These data sets can also be used to estimate population sizes.

Among the questions of interest to the research team are the response of the bird community to forest harvesting, long-term population changes, and how population trends at the Holt Research Forest compare to regional trends. Over the length of the study, bird populations have remained relatively stable. Some of the graphs in Figure 13 illustrate the relative stability of some species while others indicate the positive and negative responses to forest harvesting.

Some forest interior bird species have shown a population decrease in harvested areas but have remained stable elsewhere, while other species’ populations have remained stable in most areas. Examples of forest interior birds include the ovenbird, black-throated green warbler, and eastern pewee. Early-successional species such as common yellowthroat and white-throated sparrows have increased in harvest areas. Winter wrens, a species that had not been previously observed at Holt Forest, was a first-year post-harvest surprise when five pair were detected. The wrens were using the micro-habitat created by slash in the harvested areas and gradually disappeared over several years as the slash decomposed.

While the overall impact of timber harvesting on the bird community needs more in-depth analysis, our initial observations indicate that the harvesting conducted at Holt Research Forest has not dramatically altered the structure of the bird com-
Figure 13. Relative abundance of six bird species on harvested and control areas, before and after the 1987–88 harvest (indicated by vertical bar). Abundance estimates are based on the percentage of quadrats occupied by a given species.
community within the 40-hectare study area. This is not to say that there were no effects, but that the overall effect may have been minimized by dispersing the harvest and creating discontinuous small openings in the forest canopy.

6. Salamander study

Many species of amphibians and reptiles occur on the Holt Forest, but only one of these—the redback salamander—is common enough to study readily. In fact, several surveys of redback populations indicate that they are extraordinarily abundant with population densities of roughly 10,000 per hectare (more than 4,000 per acre). This makes redback salamanders by far the most abundant vertebrate animal on the Holt Research Forest, and given that they occur in forests throughout Maine, it is easy to predict that they are Maine’s most abundant vertebrate animal. Details of the redbacks’ ecological role are not well known, but given their abundance, habitat (forest floor litter), and diet (litter invertebrates), it is likely that they are quite important. One study indicates that by preying on the invertebrates that shred leaf litter, redbacks slow the rate of litter decomposition (Wyman 1998).

After a few years of surveys designed to estimate the actual population densities of redbacks, the research focus shifted to monitoring an index of population changes. This involved establishing 120 stations where six cedar shingles are placed on the ground. Stations are monitored weekly during the growing season to count and measure the salamanders that have sought cover under the shingles.

Photo 6. Conducting a quadrat search for redback salamanders.
Figure 14. Comparison of the average number of salamanders found in harvested vs nonharvested areas. A: Average number of salamanders found per 1 m$^2$ plot in 1983–86, 1991, and 1995. (Note: Two visits per year were conducted during 1985 and 1986, with one visit per year otherwise.) B: Average number of salamanders found under artificial cover objects at 60 stations between 1987 and 1998.
Interpreting these data is complicated because the number of salamanders detected is very sensitive to rainfall patterns: more salamanders are near the surface during wet months such as May and during wet years. Nevertheless, analyses by graduate student Laura Monti (1997) suggest that redback salamander populations are probably reduced in the harvested portion of the forest compared to the control side (Figure 14). This topic will require further research because it is possible, albeit unlikely, that the number of redbacks on the harvested area are not diminished; they may merely be living deeper in the soil and thus are harder to detect.

7. Ancillary studies

Many studies of shorter duration have taken place at the Holt Forest, particularly by University of Maine graduate students. In addition to the graduate studies mentioned previously, the following studies have also taken place at HRF:

- Jim Rudnicky (1992) studied the effects of forest harvesting on tree regeneration and associated microsite conditions, i.e., sunlight, temperature, soil nutrients, and water availability;
- Mary Small (1986) investigated the distribution of birds and small mammals near forest edges and avian nest predation in forest openings; and
- Andy Whitman (1992) studied the role of birds and mammals as fruit consumers and therefore seed dispersers for several plants.

Currently,

- Dawn Nelson is studying issues relating to invertebrate populations and dead tree conservation;
- Martha Schumann is comparing vegetation in harvest gaps with vegetation in unharvested controls; and
- Steve Campbell is examining the effects of the harvest gaps on the bird community.

Researchers outside the core team have undertaken a variety of ancillary studies at the Holt Forest. For example,

- Bill Ostrofsky with the Maine Cooperative Forest Research Unit worked with Al Kimball on a study of tree vigor to determine the effects of harvesting on the residual trees;
- Nat Wheelwright of Bowdoin College conducted a study of the reproductive effort of 15 species of herbs and shrubs; and
- Peter Rand and Robert Smith Jr. of the Maine Medical Center are using ticks collected from small mammals for their research examining how Lyme disease is distributed among different species of ticks.

Photo 7. Recording data on the flowering status of herbaceous plants.
the role of their rodent hosts, and the implications of ecological constraints. We have even ventured into the realms of social science through the work of Kevin Boyle and Genevieve Pullis with the University of Maine's Department of Resource Economics and Policy. They conducted research to test public perceptions of forest management activities conducted at the Holt Research Forest and found considerable differences among different segments of the public but overall strong support for policies that balance timber harvesting and setting land aside from harvesting (Pullis 1998).

FUTURE PLANS
Long-term research is vital to understanding ecosystems, especially forests that take decades and centuries to develop. Unfortunately, unpredictable funding and changing personnel usually make long-term research a difficult undertaking. These realities mean that the efforts at the Holt Research Forest are particularly unusual and valuable. They dictate that our first priority for future research is to continue the forest-monitoring program initiated in 1983, thereby documenting the changes that will occur due to harvesting, natural disturbances, climate change, and ecological succession. This focus does not constrain innovative research activity. We have always incorporated a variety of short-term, ancillary projects, and we will continue to do so. Furthermore, there are many ways to "mine the lode" of information we are gathering to answer new questions. For example, will the plant response to our current harvest patterns differ between the areas that were the north and south farms? Or, how does the death and decay of trees shape habitat for species such as woodpeckers that require snags?

Our future management of the forest may also generate new research opportunities. For example, if our next harvest were done mechanically we could investigate how these methods may differ from conventional harvests conducted with chainsaws and skidders. We could also design the next harvest to accelerate natural stand development processes, perhaps by making future harvest openings more similar to natural gaps, and compare these gaps to those created by our first harvest. Intermediate treatments, such as a timber stand improvement treatment to thin the red maple sprouts generated by our first harvest, will also provide opportunities for new research.

Looking outward, we hope to play an increasingly important role in the forestry circles of southern Maine where owners of small woodlots and oak-pine forests tend to dominate the landscape. Our primary role will be sharing what we have learned about the Holt Forest. In time, with more resources, we would like to be able to expand our research to other forests in the region and begin to understand forest dynamics at a landscape scale. We can also provide a model of forest management on at least three different levels. Within the Holt Forest itself we can demonstrate, in our management area, practices that generate timber yet minimize ecological and aesthetic impacts, while in our control area we can show what a forest left to natural processes looks like. Given our place in the conservation endeavors along the Back River, we can also provide a landscape-scale example of an effort to maintain forests and other "open space".

Viewed from a regional perspective the Holt Forest may be a very small patch of forest, but we hope that our work will play a large role in maintaining and improving the ecological integrity of the region's forests and the well-being of the region's people.

STUDENTS AT THE HOLT RESEARCH FOREST

Graduate Students
Six graduate students have undertaken their master of science thesis work at the Holt Research Forest: Tammy Clark and Martha Schumann with the Department of Ecosystem Science; Mary Small, Andy Whitman, and Laura Monti with the Depart-
ment of Wildlife Ecology; and Genevieve Pullis with the Department of Resource Economics and Policy. Four graduate students have undertaken their doctoral thesis work here: Jim Rudnicky with the Department of Ecosystem Science; and Karen McCracken, Dawn Nelson, and Steve Campbell with the Department of Wildlife Ecology.

**Student Assistants**

Three undergraduates have prepared senior honors theses based on work they did at the Holt Research Forest: Martha Wood, Stuart Gardiner, and Shawn Crawley. In addition, a total of 58 students listed in chronological order, mostly undergraduates from the University of Maine, have worked on the Holt Research Forest: Mary Gaudette, Don Barrett, Bill Jarvis, Mark Andrews, Rich Vannozi, Heather Almquist, James Favereau, Cheri Meinson, Shawn Carlson, David Kane, Jeffrey Slahor, Kathleen Meddleton, Brian Peters, Sally Stockwell, Peter Wagner, Ralph Keyes, David Libby, Mary K. Meimam, Sharon Abrams, Tina Stillings, Jeremy Blaiklock, Susan Bobowitz, Steve Bongiorno, Kim Figlar, Cindy Garman, Peter Reaman, Tami Rudnicky, Stacy Proudman, Amy Mehan, Xiadong Meng, Al Meister, David Landry, Tracey Walls, Adam Carmichael, LarryLee, Jeff Williams, Sixto Garache, Dan Scott, Christine Petibou, Scott Houle, Carroll Cooper, Michael Baer, Melissa Laser, Christine Wooley, Brandon Montgomery, Matt Montgomery, Walter Veselka, Shane Gauber, and Matt Montgomery.

**LITERATURE CITED**


