CHAPTER 4

The Environmental and Human History of New England


Although sketched in broad outline above, the history of environmental dynamics, natural disturbance, and cultural changes provides major ecological insights and is a subject of intensive study for Harvard Forest researchers. In particular, an overview based largely on results from these studies underscores the historical interactions of climate change, human activity, and natural disturbance that continue to control modern ecological patterns and processes.

Long-Term Climate and Vegetation Change

Interpretations based primarily on records of pollen and other fossils preserved in the sediments of lakes and wetlands confirm that the environment and vegetation of New England have changed continually through time. Although the rate and extent of change have varied since the last Ice Age, precipitation, temperature, storminess, and growing season length have all been dynamic as a consequence of long-term changes in solar, orbital, global, and atmospheric processes (Figure 4.1). The changing environment has initiated shifts, some subtle and others quite substantial, in the range and relative abundance of plant and animal species and in the composition, structure, and function of forest ecosystems. The magnitude of these changes over time and the different and unusual combinations of organisms that have grown together in the past support the notion that forest ecosystems are highly variable in composition and resilient to many natural perturbations.

This long-term perspective underscores the complexity of environmental change and ecosystem response and the challenges that we face as we seek to interpret past scenarios and to anticipate the future. Early environmental reconstructions were largely based on the notion that the climate changes in a relatively simple fashion—for example, from cool and wet conditions to drier and warmer ones. These interpretations often assumed that analogs to past conditions could generally be matched by modern environments elsewhere on Earth. However, we now recog-
Figure 4.1. Pollen diagram from the Black Gum Swamp on the Prospect Hill tract of the Harvard Forest depicting the major changes in the vegetation over the past 14,000 years (see Figure 2.8 for location). Tundra vegetation was replaced by boreal spruce forest and then by temperate species, including pine, oak, hemlock, and beech approximately 9,000 years ago under a climate regime that was slightly warmer than today. A slight cooling over the past 2,000 years is apparent in the recent increase in spruce. Although most of the changes are driven by climate and species’ migrations, the decline in hemlock about 5,000 years ago is the consequence of an insect pest. Pollen diagram, by T. Zebrzyk, adapted from Foster and Zebrzyk 1993, with permission from the Ecological Society of America.

nize that environmental changes are multifaceted and complex and often lack any modern equivalents. Not only the amount but also the seasonal and daily distribution of rainfall or temperature change through time, and these may vary as factors, such as storminess, atmospheric CO₂ concentrations, or animal and human populations, also change. As a consequence, the environmental conditions that have occurred in the past, and will develop in the future, may have no close parallels in any current landscape. In fact, the continual development of novel environmental settings through time is a major reason that fossil and other historical records attest to a long and changing sequence of unique and “nonanalog” plant and animal assemblages and ecosystem dynamics.

Changes in vegetation and the environment are most obvious over the relatively long time since the last glacial period. In the near-glacial environment that accompanied the wasting of the Laurentide ice sheet covering northern North America, the New England landscape stood in stark contrast to today. A major southward shift of the jet stream and dominance of the regional climate by arctic air masses favored a forest-tundra landscape in which herb, grass, and shrub communities dominated the uplands, and boreal forests of spruce, birch, and then pine were interspersed in sheltered sites. Large mammals, including mastodons, mammoths, giant beavers, and sloths, roamed the region, and extensive glacial lakes filled the valleys of the Connecticut, Champlain, Merrimack, and Nashua drainages. Broad coastal areas were exposed be-
cause of the drop in sea level, connecting Martha's Vineyard, Nantucket, and Block Island directly to the mainland. The resulting coastline configuration and detailed physiography were quite distinct from the present. Relatively rapid and large changes in precipitation, temperature, and wind conditions occurred about 10,000 years ago in response to regional and global shrinking of ice sheets and the northward shift of the warm Gulf Stream toward northern Canada, Greenland, and northwestern Europe.

By 8,000 years ago, temperate climatic conditions broadly similar to those of the present were established, and the major forest zones with which we are familiar today were in place — conifer forests in the mountains and across northern New England; mixed forest of broadleaf and conifer species in central New England; and oak-hardwood forest in southern New England (see Figure 2.2). Since that time, however, climate has continued to fluctuate, and important changes in forest composition and tree-species distributions have occurred. From 8,000 to approximately 5,000 years ago, conditions apparently 1° to 2°C warmer than today resulted in an expanded northern range and elevational extent of hemlock and white pine and a decrease in the abundance of boreal species, including spruce, across the region. Under warmer conditions many of our common tree species (for example, red maple, beech, and hickory) migrated into New England from southern ranges that they occupied through the glacial period.

Over the past 1,500 to 2,000 years, climate cooling across the Northeast has initiated significant changes in vegetation. A reduction in the latitudinal and elevational range of some trees was accompanied by a regional increase in spruce, presumably resulting from the expansion of populations that had persisted in local sites like wetlands (Figure 4.1). In one of the greater anomalies of New England vegetation history, at approximately the same time that spruce, a northern species, was increasing, chestnut, which has a southern and Appalachian distribution, made a delayed appearance and increased across Connecticut and Massachusetts. Subsequently, within the past 500 to 750 years, there has been a general decline in hemlock and beech, two trees that were abundant across central and northern New England and are locally important in many forests today.

This history of plant and animal migrations over thousands of kilometers in response to global climate change is one of the great biological stories of our landscape; it offers unusual insights into the selective pressures that have operated on species as well as their remarkable capacity for coping with major changes in the environment. It also underscores the humbling recognition that the conditions and ecosystems that we study today are only a minor subset of the range of possible or even typical conditions. Indeed, the species that live together in New England forests today occupied distinctly different distributions and envi-
ronments from each other during the glacial period. As the climate warmed, these species, which differ in important life history traits such as longevity, seed production, and dispersal, migrated northward quite independently, along different routes and at different rates. The ability of tree, shrub, and herb species to move relatively rapidly (for example, at sustained rates of 400 to 1,000 meters per year) over a continental scale; the differential responses that they exhibit to climate change; and the fact that they may have undergone such migrations some twenty times over the past 2 million years present compelling evidence that biotic systems are composed of individualistic species highly adapted to environmental change.

Within the historical period since European settlement, the climate has continued to fluctuate, although the extent of alteration in vegetation and landscape by land-use activities makes it difficult to ascertain the role of climate in forest dynamics. Anecdotal and historical accounts of snow depth, ice cover, and temperature indicate that the New England climate was colder and more variable in the seventeenth through the nineteenth centuries than it is today. Ingenious approaches to climate reconstruction based on rigorous interpretations of the daily journals of farmers and rural residents confirm that this period witnessed much greater variation in the length of the growing season. In particular, late spring and early fall frosts were more frequent than today. These unpredictable conditions caused fluctuating crop yields and jeopardized human enterprises such as early settlements in coastal Virginia and New England, but their influence on native vegetation and environmental processes is largely conjectural. Similarly, we have limited information on rain or snowfall patterns before the first meteorological records of the mid-nineteenth century. One of the longest New England records comes from Amherst, Massachusetts, 45 kilometers to the south of Petersham. Here we see little overall change in precipitation since 1835 but notable droughts, especially in the 1960s. For temperature, there is a lengthy trend of an increase of approximately 1.5°C in mean annual temperature to the present (Figure 4.2). Interestingly, a comparison of the earliest forty-year period with an equivalent period a century later indicates a consistent increase in temperature for all months of the year. This long-term record roughly parallels the global average, which depicts rapid rises in the late 1800s, 1910–40, and since 1980 as well as many short-term fluctuations.

Thus, at a resolution of decades to thousands of years and on a landscape to regional scale, the record of vegetation and environment in New England is one of change. These changes have not involved a simple or progressive trend. Rather, they include complex alterations in interrelated environmental factors that trigger independent responses of individual plant and animal species. The relatively continuous and
Figure 4.2. Long-term fluctuations in annual temperature (top) and precipitation (middle) as recorded at Amherst College, 40 kilometers southwest of the Harvard Forest, and global annual surface air temperature (bottom). The latter is depicted as the anomalies from the period 1961–90. Top panels, data from Bradley et al. 1987 and unpublished (used with permission of the author; Amherst data); bottom panel, data from the University of East Anglia Climate Research Unit.
complex nature of these changes is notable, as is the ability of organisms to shift in abundance and location in order to acclimatize to them. A question that we will address in detail is, within this broad setting of progressively changing climate, what additional factors controlled the patterns of vegetation across the landscape at a finer scale?

**Natural Disturbance Processes**

Although the evidence remains geographically and historically incomplete, disturbances such as wind, pathogens, fire, and Native American activity were ecologically important factors in the pre-European landscape. The relative importance of each disturbance varied regionally and with changes in the climate and vegetation. For example, fire was apparently frequent and widespread during the period of boreal forest dominance approximately 10,000 years ago, for this was a time when flammable vegetation of spruce and pine and relatively dry weather created ideal conditions for large and intense crown fires. Fires were ignited by lightning and people and presumably created mosaics of vegetation and wildlife habitat, much as occur today in boreal wilderness areas from Alaska to Labrador. As temperatures warmed and hardwood species increased, the incidence of fire declined. High moisture levels in forests of broad-leaved trees keep flammability low until the fall or following spring when dry leaf litter provides fuel and open forest conditions increase air movement and decrease humidity. Consequently, dormant-season (early spring, late fall) surface fires dominate the broad-leaved forests of New England. Importantly, however, the potential for Indian activity to influence this regional fire regime will require us to reconsider fire in detail as we turn to prehistoric human activity later in this chapter.

It seems reasonable that meteorologically driven disturbances such as hurricanes, downbursts, thunderstorms, and ice and snow damage also varied through the postglacial period as the vegetation and climate changed. For example, research on tropical storms shows that the frequency and intensity of hurricanes along the Eastern seaboard are sensitive to such broadscale climatic factors as synoptic weather patterns in sub-Saharan Africa, surface temperatures of the Atlantic Ocean, and the position of the Bermuda high-pressure system. As these and other climatic parameters changed in the past, there should have been corresponding variation in the hurricane regime and its impact on our forest ecosystems. However, data to address this notion are scanty, and, in general, information regarding prehistoric disturbance regimes is poor. Consequently, as we discuss our findings on natural disturbance regimes here and in subsequent chapters, we try to highlight the questions that remain and that help to shape our ongoing studies.
Wind Damage

Wind damage was clearly important in the precolonial landscape. Soil evidence for the uprooting of forest trees dates back nearly 1,000 years in sites across the Northeast, and the uneven mound and pit topography that characterizes old-growth and primary (that is, permanently forested) forests confirms the ubiquity of windthrows (Figure 4.3). However, the ecological role of wind varies greatly with the type, intensity, and frequency of the meteorological event; it is therefore critical that we interpret the actual details of wind occurrence across New England as thoroughly as possible. For example, tornados create a narrow track of intense damage tens to hundreds of meters wide that may skip irregularly over the ground to create a roughly linear pattern with little relationship to topography or vegetation structure. Downbursts, intense unidirectional winds often associated with frontal storms, may cover tens to hundreds of square kilometers and interact with vegetation and topography to form complex patterns. Meanwhile, tropical storms that reach hurricane intensity (greater than 74 miles per hour or 64 knots) may blow down extensive forest areas along tracks that are 50 to 100 kilometers in breadth and extend the length of New England. These extreme events contrast with our more typical winds that are generated by thunderstorms, northwesterlies, and frontal systems and break branches or blow down small groups of trees and confined patches of forest.

To assess the ecological importance of intense windstorms, two innovative approaches were developed over time at the Harvard Forest: the historical reconstructive technique and meteorological modeling and reconstruction. Both have advanced our understanding of disturbance and forest dynamics and both are suited for use in many different areas of the globe. Since intense wind events occur infrequently, these techniques seek to develop records that are centuries long.

THE HISTORICAL RECONSTRUCTIVE TECHNIQUE
The first approach that we use regularly in many studies is site based and provides a local record of disturbance and forest change. It was developed in the 1940s by Earl Stephens, a doctoral student working with Hugh Raup. This technique goes beyond a simple determination of past wind events as it involves the assembly and interpretation of essentially all of the biological and physical clues to forest history contained in the vegetation, soils, and site itself. In many ways it formalizes the long tradition of historical observation and ecological detective work practiced by natural historians such as Henry Thoreau, John Muir, Frederick Clements, and George Nichols. Stephens termed it the historical reconstructive technique, and over more than five years he applied it in
painstaking detail to a 20-by-20-foot area that occupies the wooded slope east of the meadow.

From historical documents, it is assumed that the site had been continuously wooded; indeed, none of the evidence of past clearings, such as fallen trees, or a soil surface smooth from grazing, suggests a history of agriculture. By field reconnaissance, by mapping all of the trees, he could determine the size, number, and age of each individual tree. By counting the growth rings of each tree, he could reconstruct the tree’s history. By combining this history with detailed observations of site topography, he could assemble these individual records to piece together the development of the forest stand.

Subsequent biological studies of fallen trees and woody debris, of the relict stands, and of the site topography down to a 6-inch section of the soil profile, provided the means to dissected the pit and mound chronology of the forest stand. The tree studies by Earle Stephens, a doctoral student working with Raup, were able to ascertain a minimum date for storm events and assess the rate at which soils recovered after such major disturbances. The photo, from the Harvard Forest Archives, was taken adjacent to Stephens’s intensive study site (see Figure 2.8).

Figure 4.3. Professor Hugh Raup next to a large black birch growing atop a mound created through the uprooting of an old-growth hemlock tree by a strong storm. As the soil mound erodes through time, the birch must continually adjust to changes in the substrate, producing large shallow roots. By determining the age of such trees, Earl Stephens, a doctoral student working with Raup, was able to ascertain a minimum date for storm events and assess the rate at which soils recovered after such major disturbances. The photo, from the Harvard Forest Archives, was taken adjacent to Stephens's intensive study site (see Figure 2.8).

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METEOROLOGICAL MODELING AND DATA COLLECTION

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painstaking detail to a 20-by-60-meter area in an old hemlock forest that occupies the wooded slope east of Harvard Pond and Tom Swamp.

From historical documents, including deeds and old maps, Stephens concluded that the site supported what we call primary forest; that is, it had been continuously wooded through the settlement period and had never been cleared for agriculture. Stephens’s interpretation was corroborated by field reconnaissance, which showed that the rocky slope bore none of the evidence of past clearing such as stone walls, open-grown trees, or a soil surface smoothed by plowing or lengthy pasturing. After mapping all of the trees, he cut them down and sectioned them at 4-foot intervals. By counting the growth rings at each section, Stephens could reconstruct the tree’s history of vertical and diameter growth and then assemble these individual records into maps and diagrams of forest stand development. Subsequently, he mapped, aged, and removed all fallen trees and woody debris, raked off the leaf litter, and surveyed the site topography down to a 6-inch contour. Having mapped all uproot mounds and pits appearing on the soil surface, he determined a minimum age for each feature from the age of trees growing on it and then dissected the pit and mound complex with deep soil trenches. Through careful study of the soil profiles, Stephens confirmed that the uprooting of trees mixes the soil substantially and that new soil horizons develop gradually over 500 years or more. A comprehensive record of forest dynamics in response to cutting as well as wind disturbance emerged from this compilation of historical, soil, and biotic records.

Stephens emerged from his classic study with a new technique and a history of the stand and its dynamics that was linked to hurricanes in the 1400s, the 1600s, 1815, and 1938 as well as a series of logging activities. Subsequently, David Henry, a graduate student working with Mark Swan in the 1960s, used Stephens’s approach at the old-growth Pisgah Forest, a stand of 300-year-old white pine and hemlock that was windthrown in the 1938 hurricane (Figure 4.4). The outcome was a detailed chronology of fire, wind events, and forest dynamics for this virgin stand, set within a landscape perspective that had emerged from earlier studies by Richard Fisher, Al Cline, Steve Spurr, and their students. The studies by Stephens and Henry are landmarks in our understanding of northeastern forest process and history. For example, Henry and Swan documented that the old-growth forest that was windthrown in 1938 had itself developed after a major disturbance in the early 1600s, most likely a windstorm followed by fire. Both studies profoundly influenced ecological thinking concerning forest ecosystems by underscoring the importance of natural disturbance and forest dynamics.

METEOROLOGICAL MODELING AND RECONSTRUCTION
Although we use the historical reconstructive technique regularly in all of our field studies, we are also keenly interested in understanding
broader patterns of wind disturbance. Recognizing the futility of pursuing detailed site reconstructions across the New England landscape, we turned to the more than 300-year-old regional historical and meteorological record to develop an approach for quantifying regional gradients and landscape variation in hurricane impacts. This approach is based on the fact that although tropical storm behavior is difficult to predict in advance, hurricane meteorology can be reconstructed and explained fairly simply after the event. Using this knowledge, Emery Boose developed an approach to reconstruct the hurricane disturbance regime for New England through modeling coupled with historical research. The ultimate objective was to compile a complete chronology of all historical hurricanes that caused damage to the forests. We used the technique to analyze sixty-one damaging hurricanes in great detail; thirty-seven

storms during the modern period. Our records are fairly complete, at least for a period extending back to Europe.

The historical analysis that we undertook is based on contemporary accounts from standardized newspapers since the early 1700s and extensive research by David Ludlum before 1871. For each storm, reporting bias and other property were collected, and each was assigned a damage rating analogous to those proposed by Theodore Fujita at the University of Chicago for tornado and hurricane damage. A damage rating for each hurricane was created for each town in the region. Of course, there are methodological problems— for example, bias in reporting makes it difficult to identify urban areas, fewer reports are available, and different constructions practices from urban to rural areas. In addition, confusion surrounding wind damage and flooding elsewhere, and possible post-storm modifications to maps were geographic anomalies. On the other hand, we expect, showing the greater variability of the region from town to town (where the forward and rotational

Figure 4.4. Standing snag of an old-growth white pine tree killed by the 1938 hurricane at the Harvard Pisgah tract in southwestern New Hampshire. Photograph by D. R. Foster.

Figure 4.5. Tracks and dates of the major damaging hurricanes. Modified from Boose et al. 2001, with permission.
storms during the modern period (1871–1997), when meteorological records are fairly complete, and twenty-four storms during the earlier period extending back to European settlement (1620–1870; Figure 4.5).

The historical analysis that initiated the reconstruction was based on contemporary accounts from sources across the region, primarily newspapers since the early 1700s and diaries for earlier storms. In particular, extensive research by David Ludlum was invaluable for locating sources before 1871. For each storm, reports of wind damage to trees, buildings, and other property were collected and indexed by town. Each report was assigned a damage rating on the Fujita or F-scale, a scheme proposed by Theodore Fujita at the University of Chicago for assessing tornado and hurricane damage. A regional map of observed wind damage for each hurricane was created using the maximum damage class for each town in the region. Of course, limitations are inherent in this method—for example, bias in the large numbers of observations from populated areas, fewer reports for earlier storms, variations in building construction practices from urban to rural areas and through time, difficulties separating wind from storm-surge damage in coastal towns or flooding elsewhere, and possible inaccuracies. Nonetheless, the resulting damage maps were geographically consistent with meteorological expectations, showing the greatest impacts to the right of the storm track (where the forward and rotational motions of the wind coincide) and a

![Figure 4.5. Tracks and dates of the major damaging hurricanes in New England since 1620. Modified from Booce et al. 2001, with permission from the Ecological Society of America.](image-url)
lessening of damage across the region inland and to the north as hurricanes weakened over land (compare Figure 1.4). As expected, the completeness of the resulting maps was greater for severe and/or recent hurricanes.

To reconstruct the meteorology of each hurricane, we developed a simple model of hurricane surface winds (HURRECON) that utilized information on storm track, size, and intensity to predict the wind speed, direction, and damage. The model also takes into account whether the storm is over the land or water, as storms weaken and change in meteorology because of surface friction with the land and a loss of warm and moist sea air. The model generates estimates of wind characteristics for particular sites as well as regional maps of the characteristics and effects. The meteorological data that our reconstructions are based on come from the National Oceanic and Atmospheric Administration for the modern period (1871–1997) or from contemporary accounts of peak wind direction, storm surge, and wind damage for earlier storms (1620–1870). The reconstruction of each storm was checked against independent meteorological data and interpretations as well as the maps of actual wind damage. Results from individual storms were subsequently compiled into regional maps of hurricane frequency and intensity and time lines of events at particular locations.

Across New England there are strong gradients from the southeast to northwest in maximum storm intensity and the frequency of storms of a given intensity (Figure 4.6). The highest values of both occur along the shore of eastern Connecticut, Rhode Island, and southeastern Massachusetts, whereas the lowest values are in northern New England near the Canadian border. These gradients result from the rather consistent direction of the storm tracks (hurricanes approach New England from the south), the shape of the coastline (southern New England juts out into the path of these storm tracks), and the tendency for hurricanes to weaken rapidly over land or over the cold ocean water north of the Gulf Stream. Average return intervals across New England for F0 damage (defoliation, branch break, occasional blowdowns) range from 5 to 110 years; for F1 damage (isolated blowdowns), from about 10 years to none in 110 years; and for F2 damage (extensive blowdowns), from about 100 years to none in 375 years. Undoubtedly, the actual effects of each of the historical storms were influenced to some extent by differences in regional forest types, but there are few historical data to verify this.

On a landscape scale, local topography may modify wind flow considerably and exert a strong influence on damage patterns. In particular, hills or ridges may protect leeward areas and create sharp discontinuities in forest damage. In New England the most damaging hurricane winds normally come from the southeast because of the direction of the storm tracks (south to north), the rapid forward motion of the storms (which shifts the highest winds to the right of the storm track), and the
Figure 4.6. Gradients in hurricane frequency and intensity across New England since 1620. The Fujita scale provides an estimated range of damage from wind: F0—branches broken, trees damaged; F1—trees blown down; F2—extensive blowdowns; F3 (not shown)—most trees blown down. Reprinted from Boose et al. 2001, with permission from the Ecological Society of America.
inward, counterclockwise spiraling of winds at the land surface. To investigate these landscape patterns, Emery developed a simple model of exposure to wind (EXPOS) that utilizes digital elevation maps to predict which sites on a landscape are exposed to or protected from a given wind direction. The usefulness of this approach was demonstrated in two ways: by comparing predicted patterns of wind exposure with observed patterns of forest damage in two different settings—the Great 1938 Hurricane in New England and Hurricane Hugo in Puerto Rico—and by examining the distribution of white pine, a species that is highly susceptible to wind damage, in the town of Petersham before and after the 1938 hurricane. Results from the Petersham study showed that tall stands of mature white pine that survived the hurricane, and the large individual white pines that remain in the landscape today, are located almost exclusively in small areas that are topographically protected from southeast winds.

Forest response to winds of a given speed varies considerably as a function of the size, arrangement, and types of trees. Our early studies, based on data collected by graduate student Willett Rowlands in the windthrown landscape after the 1938 hurricane, showed that damage increased with forest height but that conifers (mostly white pine) sustained much greater damage than hardwoods of comparable height and exposure (Figure 4.7). Thus site factors (for example, geographic location, topographic position, soils) and prior disturbance history (such as wind, fire, disease, and land use, all of which influence forest age, height, and type) play a critical role in determining forest response to wind. In central New England, for example, the two most powerful hurricanes since European settlement (1815 and 1938) had strikingly different effects because of significant differences in land-use history and forest conditions. In 1815, most of New England was open agricultural land. The forests, which covered less than 30 percent of the area, were relatively young and short, cut-over stands with low susceptibility to wind damage. In contrast, in 1938, more than 60 percent of the landscape was forested, and an unusual abundance of highly susceptible white pine was established in abandoned pastures and fields. Although the two storms were of comparable strength (see Figure 4.8), the hurricane of 1938 thus caused much greater regional damage to forests.

The historical record shows considerable temporal variation in hurricane frequency (Figure 4.8). It is not unusual for New England to be struck by two or even three hurricanes in the same year, and at other times no hurricanes may occur for one or more decades. Longer-term trends on a scale of centuries are difficult to identify because there are fewer reports over a more restricted area in the earlier period. The total number of hurricanes reported does tend to increase somewhat over the entire 375-year period. This trend may simply reflect the bias of available historical data, but it may also indicate (at least in part) a real increase in storm frequency caused, inter alia, by warming associated with the late nineteenth century. The most severe storms, which produced the greatest damage, occurred in the late nineteenth and early twentieth centuries. Today storms are less severe, but major storms are unlikely to have escaped the observations of the last century.

At the local scale, hurricane damage is great: large trees are snapped, and extensive areas are left denuded and defoliated. In fact, large hurricanes are powerful enough to create small patches of varying size, with high intensity of damage. For example, areas with high-intensity damage have been cleared and the forest has regrown to a low intensity. However, frequent crown damage and small patches are distributed more widely throughout the New England landscape. The forest damage and windthrow may be more severe in some area types, and some species (wind-tolerant) are better able to withstand the effects of wind. The effects of repeated small branches are not well understood, but they are likely to be combined with other stresses such as fire or disease.

There is little doubt that the hurricane hazard has varied in the past and will vary in the future, depending on climate. If sea surface temperatures in the Gulf of Mexico and the eastern Caribbean increase and the frequency of hurricanes increases, then the likelihood of severe hurricane damage will increase. If sea temperatures decrease, then the probability of hurricanes may decrease.
Figure 4.7. Relationship between damage from the 1938 hurricane and forest age (which is closely related to height) for white pine forests and oak–hickory–red maple forests at the Harvard Forest. White pine is among the most wind-prone tree species in the New England landscape. The intensity of the storm and the abundance of old-field white pine forests in 1938 due to succession on old farmland led to widespread forest damage. Modified from Foster 1988a, published by Blackwell Scientific Publications, by permission of the British Ecological Society.

increase in storm frequency caused by factors such as climate change, including warming associated with the end of the Little Ice Age in the nineteenth century. The most severe hurricanes are fairly evenly distributed in time, with the greatest number occurring in the 1800s; such major storms are unlikely to have escaped notice in the historical record.

At the local scale, hurricane damage is quite heterogeneous. Even the most severe storms, which produce broadscale blowdowns (F2 damage), leave extensive areas with only scattered tree falls, branch break, and defoliation. In fact, large hurricanes tend to produce a preponderance of small patches of varying damage intensity (Figure 4.9). Consequently, it appears that the role of hurricanes in producing frequent local and low-intensity damage has been largely overlooked by ecologists who have focused on the intensively damaged areas generated by occasional catastrophic storms. However, our results suggest that relatively frequent crown damage and small gap dynamics are also important attributes of the New England hurricane regime. The long-term impacts of forest damage and windthrow may include changes in structure, composition, coarse woody debris, soil topography, and susceptibility to fire (Figure 4.10). The effects of repeated minor damage (loss of leaves and small branches) are not well understood but may be significant when combined with other stresses such as drought or disease.

There is little doubt that the hurricane regime in New England has varied in the past and will vary in the future with changes in Earth’s climate. If sea surface temperatures increase with global warming, for ex-
ample, then the theoretical upper limit on hurricane intensity will increase, but the effects on average hurricane intensity, frequency, and size remain unclear. Similarly, there is little evidence on which to predict whether the regions affected by hurricanes will expand or contract. In fact, some modeling results actually show a counterintuitive result of a decrease in predicted hurricane frequency under a doubled CO₂ (and therefore warmer climatic) regime. An alternative and empirical approach to the problem is to expand our understanding and climate regimes of the past, through the use of historical and prehistoric hurricane records.

**Pests and Pathogens in Forests**

The great number of insects introduced in the Northeast in recent history has had a significant effect on the effect of natural and exogenous factors on forest structure and function. To illustrate, the infestation of a forest by an insect outbreak can have major consequences on the health of the ecosystem (Figure 4.11). This event provides further insight into the dynamics and landscape history at the very local scale and has long-lasting impacts on forest communities and aquatic ecosystems. The outbreak also yields a sobering backdrop for today's landscape security.

Beginning approximately 4,800 years ago, there was a synchronous decrease in eastern coniferous forest cover and a corresponding increase in deciduous forest in eastern North America.
Figure 4.10. Orientation and damage type (uprooted, snapped, unknown origin of fall) of downed trees in the old-growth Pisgah Forest resulting from the 1938 hurricane. Whereas trees directly blown down by the storm are oriented to the west-northwest, trees that died standing and subsequently snapped and fell exhibit random orientations. Because of the prevalence of strong winds from the east and south in 1938, there is a distinct northwesterly orientation of old downed trees across much of New England. Modified from Foster 1988b, published by Blackwell Scientific Publications, by permission of the British Ecological Society.

approach to the problem is to expand our understanding of the hurricane and climate regimes of the past, thus lending new significance to studies of historical and prehistoric hurricanes.

Pests and Pathogens in Prehistory

The great number of insects and diseases that have been introduced in the Northeast in recent history raises many questions concerning the effect of natural and exotic pests and pathogens in controlling forest structure and function. To date, evidence exists for only a single major infestation by a forest pest in North America before European settlement: an insect outbreak on hemlock trees nearly 5,000 years ago (Figure 4.11). This event provides fascinating insights into ecosystem dynamics and landscape history as the insect inflicted broadscale and long-lasting impacts on forest composition and initiated many changes in forest and aquatic ecosystems. This mid-Holocene hemlock decline also yields a sobering backdrop for our efforts to assess the effects of the introduced hemlock woolly adelgid on northeastern forests.

Beginning approximately 4,800 years ago, a major and apparently synchronous decrease in eastern hemlock occurred across the tree’s entire range in eastern North America. Although initially interpreted as a
response to mid-Holocene climate warming, the rapidity and range-wide nature of the decline in a single species eventually led Margaret Davis to propose that the cause was a species-specific pest or pathogen. In fact, she eventually singled out the eastern hemlock looper, a native insect that occasionally irrupts in outbreaks that defoliate localized areas of hemlock today, as a likely culprit. Corroboration of Davis’s ideas came in the 1990s when large numbers of looper fossils were identified by Najat Bhiry and Louise Filion in sediments that date to the time of the hemlock decline and contain chewed hemlock needles.

Following its abrupt decline, hemlock persisted at low though variable levels across its range for nearly 1,000 years before recovering. During this period, other taxa increased, notably sugar maple and beech in northern New England and oak to the south. What finally enabled hemlock to recover? Although we may never know for sure, it is possible that the species evolved a partial resistance to the looper through natural selection. Alternatively, the presence of beetle-killed trees enabled looper populations to recover, allowing it to expand its range and populations to rebound.

At the Harvard Forest, a site with an excellent pollen record from paired sites, ongoing studies of the biology of the eastern hemlock looper and its natural enemies, and data from many other sites, are helping to unravel the factors that triggered the collapse of hemlock forests and its recovery. The swamp record indicates that periodically the eastern hemlock looper was replaced by oak, white pine, and other species, though hemlock was persistent though low levels. There is compelling evidence that a population of beetle-killed hemlock has persisted in the landscape, and that hemlock was eventually recovered after the insect outbreak. As hemlock gradually increased in abundance, it may have displaced species such as oak and pine increased as hemlock declined. In contrast, hemlock was again in decline, hemlock was again recolonizing. These patterns were noted in sediments in the area, suggesting that the high levels of charcoal in the sediment are not just due to fire, but also to beetle-killed hemlock. This phenomenon is often interpreted as a sign of the fire severity of the fire, and the linkage between fire and beetle-killed hemlock is an important one. Evidently tree mortality is a consequence of beetle-killed hemlock, and its ability to provide an abundance of fuel for fires.

This unique and ancient feature of the history of the eastern hemlock forests offers some interesting insights into the dynamics of hemlock forests and their response to disturbance. Notably, (1) the abrupt decline of eastern hemlock decline differed across sites, and (2) changes in forest composition after the hemlock decline were not caused by beetle-killed hemlock. Rather, hemlock populations recovered after the outbreak, perhaps because the hemlock population was able to recover and recolonize the area. This is a significant observation, as it suggests that the eastern hemlock population is able to recover from beetle-killed hemlock. The hemlock decline provides an important example of the importance of studying the dynamics of natural systems and their response to disturbance.
lection. Alternatively, the particular environmental conditions that enabled looper populations to thrive may have changed, allowing hemlock populations to rebound.

At the Harvard Forest, a paleoenvironmental study that analyzed pollen records from paired sites, one a swamp that records vegetation dynamics from a broad area and the other a small vernal pool whose sedimentary record tracks local changes in the hemlock woodlot (see Figures 4.1, 6.2, and 6.6), enables us to evaluate many details of the hemlock decline. The swamp record indicates that across the region hemlock was replaced by oak, white pine, hickory, and sugar maple. Interestingly, the persistent though low levels of hemlock pollen through the decline suggests that a population of hemlock trees survived, perhaps in the forested swamp where the core was obtained. However, hemlock recovers only moderately in the ensuing millennia and never returns to its former abundance in the landscape. In contrast, in the hemlock woodlot, oak and pine increased as hemlock decreased, but subsequently hemlock recovered its prior abundance. Approximately 1,500 years after the initial decline, hemlock was again the dominant tree in this stand. In this record the decline in hemlock pollen also coincides with a discrete layer of charcoal in the sediments. This provides one unusual example of a phenomenon that is often discussed in the ecological literature: the linkage between fire and other disturbances, such as windstorm or pathogens. Evidently tree mortality and the accumulated leaf litter provided an abundance of fuel for an intense surface fire.

This unique and ancient history of forest response to an insect pest offers some interesting insights into the dynamics and history of forest ecosystems. Notably, (1) the response of forest communities to the hemlock decline differed across New England and the range of hemlock as various tree species benefited from hemlock's demise in different areas; (2) changes in forest composition continued for more than 500 years after hemlock began to decline, indicating a long-term adjustment of forest ecosystems to the loss of a dominant species; (3) in most areas hemlock populations recovered, but the species never resumed its former abundance, possibly because of slight environmental changes that occurred during the ensuing period; and (4) ecosystem-level responses in soil and stream chemistry and lake productivity were apparently minor, despite the loss of a major forest species. Finally, although hemlock populations did recover rather remarkably, this story offers little optimism for our modern forests that are under the onslaught of new pests and pathogens. The sobering reality is that the recovery process for hemlock required more than 1,000 years to play out.

The hemlock decline provides an important contrast to some natural disturbance processes, such as hurricanes and fire, in terms of the extended duration and geographical scope of its effect. It also underscores the importance of studying the consequences of modern pathogens and

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sects, such as the white pine blister rust, Dutch elm disease, chestnut blight, gypsy moth, and beech bark disease, in order to understand the changes that even unintentional human activity may bring to our forest ecosystems. The recent spread of the hemlock woolly adelgid, which is decimating hemlock stands across southern New England and the Appalachians, provides an unfortunate opportunity to evaluate insect spread to and impact on biotic systems (see below, Figure 4.27).

Native American Impacts and the Importance of Fire

One central but enigmatic issue in our quest to understand factors shaping the pre-European landscape is the effect of Native Americans on fire regimes, wildlife, and vegetation patterns. Since Indians did not have domesticated grazing animals and only used horticulture on a supplemental and localized basis, fire was the major mechanism through which they could affect forests on a broad scale. Understanding the prehistoric distribution and effect of Indians is directly pertinent to our interpretation of the "primeval" New England landscape and thereby figures into current discussions of conservation goals and management approaches. In fact, prescribed fire is increasingly used by organizations such as The Nature Conservancy, National Park Service, and state Natural Heritage and Endangered Species programs to manage lands for uncommon plants and animals, based largely on the notion that Indian fire was an important environmental factor structuring pre-European landscapes.

Recent major revisions in estimates of pre-Columbian Indian populations, coupled with new archaeological and paleoecological interpretations, have led to a reassessment of Indian impacts on American landscapes (Figure 4.12). Estimates for the population of the Americas in the fifteenth century range between 40 and 65 million inhabitants, nearly equal to that of the Old World at the time. These estimates exceed previous values, in large part because they account for the extraordinary effects that introduced disease exerted on Indian populations before they were chronicled by early explorers. However, this population was unevenly distributed across two massive continents, and its heterogeneity precludes generalization. Indeed, there were strong latitudinal gradients in human density and land-use impact, with approximately 20 million people spread across Mexico and Central America, 25 million in the Andes and lowland South America, 3 million in the Caribbean, and only 3.8 million (or fewer) in the entire North American continent. In North America the heaviest concentrations of people occurred in the South, Midwest, and Mississippi drainages. Consequently, whereas Aztec Mexico and the Mayan Lowlands supported cities such as Tenochtitlan, which in A.D. 200 exceeding the size of London a millennium later, northeastern Indians were scattered in small, seasonal encampments.
Figure 4.12. Distribution of major Indian groups at the time of European contact in New England. General locations of known sites are indicated along with an estimate of the group's population size and density (people per square mile). With the exception of some of the coastal islands, the population is estimated to be low (approximately 75,000 total) and dispersed in small groups. Compiled from Braun and Braun 1994, Cook 1976, and Whitney 1994.
Similar regional differences existed in the timing, development, and extent of important cultural innovations, including agriculture.

New England occupation extends over 10,000 years to the time when archaic people occupied the boreal landscape after the melting of the massive ice sheets. These and subsequent inhabitants were seasonally mobile, gathering diverse plant foods and hunting and fishing for a wide range of animals. Substantial shifts in regional populations and distribution occurred through time, presumably because of the changing availability of plants, such as nut-bearing trees, and wildlife and variation in climate. Streams, ponds, and coastal areas were important sources of fish and shellfish; freshwater and saltwater wetlands, which developed extensively 3,000 to 5,000 years ago, provided diverse waterfowl, small animals, and plants; and upland forests harbored nuts, plants, and game.

Important tools and foods that we often associate with New England Indians arrived or developed surprisingly recently and were accompanied by significant changes in culture and perhaps in ecological impact. In fact, the past 1,000 years embraced an especially dynamic period. In particular, so many fundamental changes are broadly coincident with European contact in the sixteenth century that a major challenge arises in reconciling archaeological and ethnographic sources of information for this complex period. Before 1,000 years ago, the spear and atlatl (spear thrower) were major hunting tools. Introduction of the bow and arrow since then improved hunting efficiency greatly. However, the most important cultural transition accompanied the adoption of corn, or maize, a Central American plant.

Archaeological sites before A.D. 1000 indicate limited horticulture based on the use of plants such as beans, squash, marsh elder, sunflowers, and knotwood. Evidence for maize appears sporadically across southern New England only about five centuries before extensive European contact. New England Indians evidently adopted corn agriculture slowly and unevenly, and people embracing agriculture may have become more sedentary. However, there is little evidence for large, semi-permanent villages and large population centers even in broad valleys like the Connecticut or along the coast where marine, freshwater, and terrestrial resources were abundant. Meanwhile, across the interior uplands, populations remained small, and hunting and gathering appear to have predominated.

By the mid-1500s, a distinctive pattern of distribution and activity had developed, with recognizable subregional differences among coastal, riverine, and upland groups (Figure 4.12). Approximately 70,000 Indians occupied New England, with more than three-quarters concentrated in Connecticut, Massachusetts, Rhode Island, and southern New Hampshire. The densest populations occurred along the coast and major river valleys, but trail networks connected these regions with inland areas and seasonal camps. By 1600, perhaps 150,000 may have represented a population of New England that was 30% greater than their European counterparts. Meanwhile, infectious diseases characteristic of the Old World, and thus Indigenous First Nations, have episodes of mortality such as the Black Plague and the Influenza epidemic in 1578 in medieval Europe. That picture is complicated by, as Alfred Crosby has pointed out, that New World peoples, which had been colonies of alcohoholics, were diseases transported from Europe, including bubonic and pneumonic plague, smallpox, typhoid, whooping cough, and measles.

Diseases were transmitted across the landscape that some of the greatest losses. European arrival in 1620 of the Mayflower brought waves of colonists were often unprepared for colonial society and social organizations. Of note is the fact that the economic and social organizations and other factors that contribute to this population, and thus the number of people that colonized New England. By the time of his death in 1607, the land was in ruins, and the English settlers had a different agricultural practices that he taught the local populations. This knowledge was indigenous to the lands and its inhabitants and experience in the region.

Early epidemics presumably explorers and fishermen. John Cabot, in 1497, and French explorers in the late 1600s introduced the earliest coastal settlements. Jacques Cartier (1535–41) and Samuel de Champlain, and others. Meanwhile, the English settlers, the Dutch, and the Maritime Provinces and New Englanders for using trade as a means of...
inland areas and seasonal encampments. The period from A.D. 1100 to 1500 may have represented the greatest extent of pre-European inhabitation of New England; however, by the time explorers and colonists provided detailed descriptions of Indian activities, the native population had been decimated by disease and was changing rapidly.

Forensic archaeology suggests that pre-European-contact Indians had a life expectancy of approximately thirty-seven years, comparable to that of contemporary Europeans; older Indians actually lived longer than their European counterparts. North America was largely free of the contagious diseases characteristic of the dense population centers of the Old World, and thus Indian history may not have included massive episodes of mortality such as associated with the Black Death of medieval Europe. That picture changed abruptly when Europeans arrived with, as Alfred Crosby has put it, “all of the microscopic parasites of humans, which had been collected from all parts of the known world.” Infectious diseases transported from the Old to the New World include bubonic and pneumonic plagues, chicken pox, cholera, diphtheria, dysentery, influenza, measles, scarlet fever, tuberculosis, typhus, typhoid, whooping cough, and, among the most deadly, smallpox.

Diseases were transmitted so effectively across the ocean and landscape that some of the great epidemics in North America preceded the arrival in 1620 of the Mayflower. Indeed, the tribes that greeted the waves of colonists were only a shadow of the original populations and social organizations. Of note is the fact that the customs and demographic characteristics documented by such early colonists as William Bradford, John Josselyn, and William Wood were consequently affected by European contact and disrupted by widespread mortality. The most famous example of this phenomenon is the story of Squanto, who is known by most Americans as the Indian who taught the colonists the native agricultural practices they needed to survive the harsh New England conditions. In fact, the Squanto who readily greeted the colonists in English had already made a three-year voyage to England and back via Canada. By the time of his return, his entire village had died from disease, and the land was in ruins. Consequently, as we read of the “Indian” practices that he taught the colonists, we must wonder how much of his knowledge was indigenous and if any of it was influenced by his encounters and experience in the Old World.

Early epidemics presumably arose from the initial contact with explorers and fishermen. John Cabot’s voyages to North America began in 1497, and French explorations by Giovanni da Verrazano in 1524 produced the earliest coastal maps, which were subsequently used by Jacques Cartier (1535–41) and Samuel de Champlain (1603 onward) and others. Meanwhile, the Basques established outposts in Labrador and the Maritime Provinces of Canada in 1536. The Indian propensity for using trade as a means of cultural contact and reduction of conflict
and the European desire for furs provided ample opportunity for repeated exposure and the spread of infection.

Epidemics occurred in 1535 in the St. Lawrence Valley and 1564–70 and 1586 in New England. During 1616–19 massive disease outbreaks reduced populations from Rhode Island to southern Maine by as much as 90 percent. The effects were clear to early explorers: as smallpox raged up the Connecticut River Valley to Vermont in the 1630s, it killed “thousands” of Indians but only two Europeans. From then on, history is replete with Indian diseases: influenza in 1647, diphtheria in 1659, smallpox again in 1662–63, a “strange disease” in 1675–76 during King Philip’s War, smallpox reemerging in Vermont in 1684 and 1690, and so on. On the basis of the staggering loss of Native Americans during this time, some historians have come to call sixteenth- and seventeenth-century America the “widowed” rather than the “virgin” land.

This view is poignantly supported by Bradford and Winslow’s description of a 1620s scene in southeastern Massachusetts: “Thousands of men have lived there, which dyed in a great plague not long since; and pitty it was and is to see, so many goodly fieldes, and so well seated, without men to dresse and manure the same.”

In point of fact, however, the empty fields provided what the colonists viewed as a godsend, and Captain Thomas Dermer described (in 1626) as “ancient plantations, not long since populous, now utterly void.” By reducing the number and strength of Indians and disrupting their social structure, disease aided the transformation of the landscape to European dominance. As elegantly documented by Alfred Crosby, disease assisted colonial expansion worldwide.

Perhaps in large part because of the impacts from European contact including disease, early descriptions of Indian settlements are difficult to resolve with archaeological results. Entering northern Vermont in 1604 along the lake now bearing his name, Champlain chronicled that “there is a great deal of land cleared up and planted with Indian corn" and that the open shores support “fertile fields of maize.” In 1524 Verazzano described New England as a populated agricultural landscape and noted fields in Rhode Island, eastern Massachusetts, Block Island, Nantucket, and Martha’s Vineyard. In 1614, Captain John Smith counted forty Indian villages from Cape Cod to Penobscot Bay in southern Maine and wrote that “the sea coast as you pass shewes you all along large Corne fields.” Captain Martin Pring spent six weeks in Plymouth, Massachusetts, where he ate “Pease and Beans” with Indians and noted fields that exceeded an acre in size, filled with vegetables and tobacco. When the Indians on Block Island were finally massacred in 1662 in retaliation for the death of Captain John Oldman, the colonists proudly document that they destroyed more than 200 acres of Indian corn fields and sixty wigwams in the oak-sprout-covered forest.

Clearly, one possible Indian impact on the environment was the local clearing of forests for settlement equipped with only fire and axes. The hearings and chronicles by the early colonists, including smallpox, indicate that unmetabolized, the land being cleared to plant it, set fire to the old uncultivated and abandoned sites to make it habitable.

The initial clearing of millions of trees to kill them, burn them, and even use them for maintenance of villages, left large quantities of firewood. Early on, however, from a nearly deforested New England, include many references to wood. Such observations suggest that deforestation around villages is a fire hazard, although its extent and mechanisms varied from region to region on the landscape.

The Role of Fire

It has long been recognized by which Indians may have used fire to clear land for agriculture. Worldwide, native peoples used the fire to clear land for agriculture. Moreover, the extent of fire-management practices and their broadcasted effects varied from one region to another, although it is clear that fire was used in the Northeast. 

The most often-cited reference to fire management with fire came from Roger Williams, who wrote in his Narrative of a Voyage to New England in 1631:

“...we did behold to burne for a space of five miles in length.
clearing of forests for settlement and planting, a difficult task for people equipped with only fire and tools of wood and stone. Schematic drawings and chronicles by the early explorers suggest a pattern of short-fallow cultivation for maize and a landscape mosaic of gardens, forests picked of firewood, and brushy areas of abandoned old fields. In Boston Bay, Champlain documented that "there were also several fields entirely uncultivated, the land being allowed to remain fallow. When they wish to plant it, they set fire to the weeds, and then work it over with their wooden spades," suggesting that there was some alternation among cultivated and abandoned sites, presumably to allow the restoration of fertility.

The initial clearing of mature forests evidently involved the girdling of trees to kill them, burning and cutting to remove them, planting among the stumps, and eventual removal of stumps. In addition to the maintenance of villages and fields, Indians must have collected large quantities of firewood. Early historical records, by colonists arriving from a nearly deforested European landscape where firewood was scarce, include many references to the Indians’ profligate waste of wood. Such observations suggest widespread wood gathering and clearing of forests around villages. However, the extent of Indian activity must have varied tremendously, and the intensive effects were undoubtedly focused on high-density areas in the major river valleys and coastal sites.

The Role of Fire

It has long been recognized that fire represents the mechanism by which Indians may have had the most pervasive effect on the landscape. Worldwide, native people have used fire to improve wildlife habitat, enhance agriculture, drive game, and open village sites. Nonetheless, the extent of fire-management practices in northeastern landscapes and their broadscale importance in controlling vegetation patterns continue to be widely debated. Conflicting interpretations emerge because of the scanty number of ethnographic sources, most of which are confined to the coastal region, and the potential for intentional or inadvertent bias. A few sources yield an impression of widespread or frequent burning that affected local forest conditions. For example, in Rhode Island Roger Williams indicated that Indians “burnt up all the underwoods in the Countrey, once or twice a yeare.” Captain Martin Pring on Cape Cod, collecting sassafras, noted an Indian ignition “which we did behold to burne for a mile space,” and in the early days of Plymouth the colonists viewed one “place where the savages had burnt the space of five miles in length.”

The most often-cited references to the Indian practice of landscape management with fire come from Thomas Morton and William Wood,
early inhabitants of Massachusetts Bay near present-day Boston. Although extremely limited in geographical scope, these observations provide specific detail on Indian motivations as well as the seasonal timing, behavior, and effect of fires on forests. Intriguingly, Wood explicitly links the precipitous decline of the Indian population from disease with decreased fire and corresponding increase in forest undergrowth.

The Savages are accustomed, to set fire of the Country in all places where they come; and to burn it, twize a year, vixe at the Springe, and the fall of the leafe. The reason that mooves them to doe so, is that it would other wise be so overgrowne with underweedes, that it would be all a copic peace, and the people would not be able in any wise to passe through the Country out of a beaten path ... for this custome hath bin continued from the beginning. ... For when the fire is once kindled, it dilates and spreads it selfe as well against, as with the winds; burning continually night and day, untill a shower of raine falls to quench it. And this custome of burning the Country is the meanes to make it passable, and by the meanes the trees growe here, and there as in our parks. (Thomas Morton, 1632)

And whereas it is generally conceived, that the woods grow so thicke, that there is no more cleare ground than is hewed out by labour of man; it is nothing so; in many places, divers Acres being cleare, so that one may ride a hunting in most places of the land, if he will venture himselfe for being lost: there is no underwood saving in swamps and low grounds that are wet ... for it being the custom of the Indians to burne the wood in November, when the grasse is withered, and leaves dried, it consumes all the underwood, and rubbish, which otherwise would over grow the Country, making it impassable, and spoil their much affected hunting; so that by this means in those places where the Indians inhabit, there is scarce a bush or bramble, or any cumbersome underwood to bee seene in the more champion ground. ... In some places where the Indians dyed of the Plague some fouretteene yeares agoe, is much underwood as in the mid way betwixt Wesaguscus and Plimouth, because it hath not been burned. (William Wood, 1634)

On the basis of such accounts it appears certain that Indians used fire knowledgeably to manage at least some parts of the forest landscape. The fires were probably low- to moderate-intensity surface fires, burning through the leaf litter and understory. In fact, the descriptions of Wood and others fit well with the current understanding of fuel loadings and fire dynamics that comes from the studies of Bill Patterson and others across the Northeast. Because of the high moisture content of green foliage and the humidity levels and low wind speeds in summer beneath a deciduous canopy, fires spread more easily when the plants are leafless. Consequently, woodland fires were most important during droughts in early spring and fall.

Broadleaf forests in New England will generally support only surface fires. However, with heavy loadings of fine or highly flammable fuels such as grasses, huckleberry, or scrub oak, intense fires and flame heights of 5 to 10 meters or more can occur in open oak forests. Dense pitch pine stands, which are the predominant tree type on Martha’s Vineyard, and inland areas of New York region, can also support crown fires. In these areas, fire can kill smaller and thin-barked trees, clearing a space for new growth of fire-sensitive hemlocks, maple, and white pine. Prescribed burning on Cape Cod, using the available fuel and topography to create fire breaks, is being conducted at any one-forested location to achieve the potential of a twice-annual burning described above as possible.

Likewise, it is highly doubtful that within the fire exclusion area across most of New England, pre-contact Indian activity was insignificant. Even in snow-covered wetlands, low vegetation, which characterizes a regional gradient of fire frequency, decreases from the coast inland to the northern New England and Maine region. This gradient parallels the broad climate and terrain gradients that are apparent in regions with wetter, wind-eroded, sandy, drought-prone soils, or open stands of fire-resistant vegetation. The fire exclusion area is in the region that coincides with regions with greater fire periodicity, as well as environmental and human factors.

Even in fire-prone areas, it is highly probable that fires may have been only once every two or three years in rolling uplands, fire-free periods marking the change. We note, however, the importance and long-lasting effect of these fires on ecosystem function (Figure 4.1). Fire can promote fire-resistant species, increase plant life, and productivity.

Our studies also show considerable variation in fire by local differences within an area. For example, the Cape Cod and the islands are characterized by a well-differentiated moraine landscape, with moraine ridges of sand, gravel, and sandstone, and moraines with finer textured soils and steeper slopes. The lower frequency of fire occurrence than that on the Massachusetts, Vinyard, and Horseneck, with their flanks covered with fire-resistant pine and huckleberry. An extreme example of the successional disturbance is the Martha’s Vineyard. Harlock Island, along its western flank, was subject to a series of widespread, high-intensity fires every 40–70 years. These fires were probably driven by the region’s most recent fire history, and the discovery of archaeological evidence of a late Holocene fire regime that was consistent with the region’s modern fire history.
pitch pine stands, which are abundant on Cape Cod, coastal islands like Martha's Vineyard, and inland outwash plains across the New England—New York region, can also support intense crown fires. Surface fires would clear the forest undergrowth and would selectively damage and kill smaller and thin-barked trees as well as less-fire-resistant species. The result would be an open understory and an increase in fire-tolerant and sprouting species such as oaks, hickories, birches, and pines over fire-sensitive hemlocks, maples, and beeches. Nonetheless, studies of prescribed burning on Cape Cod indicate that repeated fires rapidly consume the available fuel and reduce the frequency that fires can burn in any one-forested location to a few times per decade. The annual or twice-annual burning described by Wood and Morton is physically impossible.

Likewise, it is highly doubtful that fire was frequent or widespread across most of New England, especially in the upland areas where Indian activity was limited. Evidence obtained from charcoal fragments incorporated in wetlands, lake sediments, and small vernal pools indicates a regional gradient of fire with charcoal abundance and inferred fire frequency decreasing from southern coastal sites inland toward northern New England and higher elevations (Figure 4.13). This pattern parallels the broad climate and vegetation gradients, with more charcoal apparent in regions with warmer and longer growing seasons and on sandy, drought-prone soils, especially in coastal areas dominated by flammable vegetation. The fact that high charcoal abundance also coincides with regions with greater Indian populations makes disentangling environmental and human factors a great challenge.

Even in fire-prone areas, historical data suggest that fire frequency may have been only once every 10 to 100 years, whereas in the moist, rolling uplands, fire-free periods of more than 1,000 years clearly occurred. We note, however, that fire need not be frequent to exert important and long-lasting effects on forest structure, composition, and ecosystem function (Figure 4.14). At century-long intervals fire can still promote fire-resistant species and their associated effects on soils, wildlife, and productivity.

Our studies also show considerable landscape-level variation driven by local differences within regions. For example, the coastal area of Cape Cod and the Islands are not homogenous but are physiographically differentiated into morainal and outwash areas that are strikingly different in soil texture, topography, and vegetation. In general, the hilly moraines with finer textured soils and more mesic forests supported lower fire occurrence than the flatter, sandier, and more droughty outwash plains, with their flammable vegetation of oak, scrub oak, and huckleberry. An extreme example of this pattern is seen on the island of Martha's Vineyard. Harlock Pond, which lies in the moraine on the island's western flank, was surrounded by relatively mesic forests of
CHAPTER 4

The Environmental History of Martha’s Vineyard

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Although sketched in broad terms, environmental dynamics, natural and human, provide major ecological insights. The chronicles of Harvard Forest researchers and others suggest that the results from these studies illuminate past climate change, human activity, and the way in which these factors control modern ecological patterns.

Long-Term Climate Change

Interpretations based on pollen and charcoal fossils preserved in the sediments of lakes and peats help us to understand past climate and the environment and vegetation that prevailed. The patterns vary seasonally through time. Although climate conditions since the last Ice Age, particularly during the late Holocene, have been influenced by changes in solar, orbital, and atmospheric factors, the changing environment is not smooth. There have been quite substantial, in the range of 2° to 4°C, changes in both seasonal and annual species and in the composition of ecosystems. The magnitude of these changes, and unusual combinations of species, the effects of past support the notion that climate change has caused changes in vegetation composition and resilient to carry over into the future.

This long-term perspective on environmental change and ecosystem development helps us as we seek to interpret past studies and to use climate models and other environmental reconstructions to understand climate changes in a relative present. Unfortunately, the environment and wet conditions to drier areas and to areas that have been assumed that analogs to past environments exist elsewhere.

Figure 4.13. Historical importance of fire across the New England landscape as indicated by the occurrence of charcoal in lake sediments. Left: The distribution of lakes sampled. Right: The abundance of charcoal in the sediments of each lake during the pre-European (open circles) and European (black circles) periods. Arrows indicate position shift through time. Sites are displayed on axes representing climate (growing degree days, with values indicating northern areas with a short growing season) and the first axis of a multivariate analysis (detrended correspondence analysis; DCA). The importance of fire clearly increases with longer growing season and warmer climate. Highest pre-European charcoal levels occur on Cape Cod and the southeastern island of Martha’s Vineyard. For sites away from the coast, charcoal abundance and the importance of fire increase greatly after European settlement. Modified from Parshall and Foster 2002, with permission from Blackwell Science Ltd.

Figure 4.14. The long-term trajectory of vegetation change in the vicinity of Hemlock Hollow on the Prospect Hill tract (see Figures 2.8, 6.2, 6.8). Top panel shows vegetation changes over the past 11,000 years. Each dot represents one sediment sample, and its relative position indicates the vegetation composition. Through time the original forest of spruce changed to pine (approximately 9,350 years B.P.), then hemlock and hemlock–northern hardwood (approximately 8,350 years B.P.), and finally to hemlock–hardwood–spruce and chestnut (approximately 1,750 years B.P.), which persisted for the 1,500 years before European settlement. After colonization the forests were cut and burned, and the vegetation changed dramatically.

The four bottom panels provide details of the past 8,000 years from the top diagram and illustrate that within the general pattern of forest change driven by climate, there were periods of sudden compositional change resulting from fire (7,650; 6,650; 6,150; 4,700; 1,900 years B.P.), the hemlock decline (approximately 4,700 years B.P.), and European land-use activity. Modified from Foster and Zebryk 1993, with permission from the Ecological Society of America.
beech, maple, oak, and black gum. With the ocean upwind and vegetation of low flammability, the site had a fire frequency as low as that found in the mesic uplands of northern Massachusetts. In sharp contrast, Duarte Pond on the Great Plain, an oak- and scrub oak-dominated outwash plain just 8 kilometers to the east in the center of the island, had among the highest charcoal values of any site in New England and may have burned every few decades. Quite clearly, site and vegetation factors, as well as long-term feedbacks among these, can generate major spatial variation in fire regime on both landscape and regional scales.

In consideration of these results, as well as recent archaeological studies that downplay the role of maize agriculture and larger sedentary populations, Indian impacts may be best understood as locally important but highly variable across New England. These impacts included the creation of fine-grained local patchworks of vegetation of different age, successional status, and composition around encampments and seasonal villages, and modification of wildlife populations through hunting. Indian activities did alter the landscape that the early European explorers and colonists encountered and clearly influenced the pattern and practice of European settlement. However, no solid evidence remains that Native Americans influenced the broad patterns of vegetation or created sizable areas of open or early successional habitat. This scale of impact would await European arrival.

During the first century of European settlement, the colonists from the Old World were moving into a landscape shaped by depopulation. This land represented many things to the different observers and was described in a wide range of ways. It was, however, clearly diverse, striking in its beauty and resources, and already influenced by humans. Verrazano wrote in 1524, on the east coast toward New England, "We could see a stretch of country much higher than the sandy shore, with many beautiful fields and plains full of great forests, some sparse and some dense; and the trees have so many colors, and are so beautiful that they defy description. And these trees emit a sweet fragrance over a large area."

### Historical Land Use and Landscape Transformations in New England

Through the long-term perspective of postglacial change and prehistoric human activity, the few centuries since European arrival to New England emerge as distinct. In a remarkably short period, much of the region was transformed from extensively forested to open and agrarian, with interspersed and cut-over woodlands. Equally rapidly, this pattern was substantially reversed as the land reforested naturally following widespread abandonment of farmland beginning in the mid-nineteenth century. The rapid rate and extent of change in land cover and vegetation; the local extirpation and immigration of animal and plant species; and the major biosphere-atmosphere exchange period the tumultuous years ago.

In exploring the ecological consequences of these activities as well as the major changes in the range of land-use, from agricultural and residential occupation on abandoned farmland, direct human effects such as subsistence and changes in wildlife composition and other dimensions of human activity may be shaped by the landscape, shaped extending far-reaching hand of humans.

#### Establishment and Exploitation

With the establishment and landscape transformation of the rest of New England at different rates, coastal settlements were established in Maine, and farther inland to the Connecticut River Valley to Massachusetts. Small populations, growing hostilities with native groups and the expansion to coastal and local activity increased. As the immigration increased in the rapidly inland and northwestern part, people, settled in established towns and villages. The Green and Wachusett, road systems connecting trading partners. Consequently, New England extends back to Wabanakia, including the region around the Wabanakia for centuries or more.

#### Forest Area and Habitat

Population growth initiatives a sequence of new habitats that continue to shape their importance among these in terms of...
plant species; and the major shifts in biogeochemical, hydrologic, and biosphere-atmosphere exchange processes all make this brief historical period the most tumultuous since the glacial ice sheets retreated 13,000 years ago.

In exploring the ecological changes wrought since European colonization, our studies seek to assess the direct consequences of human activity as well as the major social underpinnings of these dynamics. Of course, the range of land-use effects extend far beyond land conversion to agricultural, residential, or commercial land cover, or forest succession on abandoned farmland. Therefore, we also explore subtle and indirect human effects such as the introduction of pests and pathogens, changes in wildlife composition, and altered chemistry of Earth’s atmosphere. One inevitable conclusion from consideration of these diverse dimensions of human activity is that modern New England is a cultural landscape, shaped extensively in pattern, structure, and process by the far-reaching hand of human history.

Establishment and Expansion of the New England Colonies

With the establishment of Plymouth in 1620, European expansion and landscape transformation proceeded across Massachusetts and the rest of New England at an uneven pace (Figure 4.15). By 1675, small coastal settlements were established from Long Island to southern Maine, and farther inland towns extended from New Haven north up the Connecticut River Valley to the frontier town of Deerfield in western Massachusetts. Small population size, limited transportation, and ongoing hostilities with native groups over the next half century constrained expansion to coastal and lowland regions as populations and commercial activity increased. As the Indian wars drew to a close and European immigration increased in the mid-eighteenth century, colonists pushed rapidly inland and northward. By the early 1800s, New England was settled in established townships, save for northern Maine and the rugged elevations of the Green and White Mountains. An effective, albeit rudimentary, road system connected villages with the coast and distant trading partners. Consequently, although European knowledge of New England extends back to Verrazano’s sightings in 1524, vast areas, including the region around Petersham, were not settled for another two centuries or more.

Forest Area and Human Population Dynamics

Population growth, social change, and economic transformation initiated a sequence of novel disturbances on New England ecosystems that continue to shape their structure and function today. The most important of these in terms of understanding the modern forest landscape
is land-cover change. Although agricultural practices, woodland use, and local industry varied in detail from Connecticut to southern Maine, the overall similarities in land-use history and patterns of land-cover change are striking. These similarities, which are highlighted by the parallel trajectories in forest and open land among the six states are remarkable given the regional variation in physical and biological characteristics (Figure 1.6). Across New England, forest conversion to agriculture progressed rapidly through the mid-1800s, a time when open land peaked at 50 to 75 percent and exceeded 90 percent in individual townships. After a brief period of fairly stable landscape pattern, farmland was abandoned from active use and allowed to reforest naturally and haphazardly. Currently, forests cover from 60 percent to more than 90 percent of the New England upland, making it one of the most heavily forested regions in the United States. Similarity in this history across a heterogeneous region suggests that change was driven largely by broad social, demographic, and economic factors rather than by local changes in the quality of the land. This congruency in human history was particularly strong for the extensive uplands that support the major forest areas that are the focus of our interest.

Township Settlement, Forest Clearance, and Early Agriculture (1650–1790)

Early on, a unique form of land ownership and political organization emerged in New England based on dispersed settlement, private ownership, and a political hierarchy of town, county, and state. Towns

Figure 4.15. European settlement pattern across Massachusetts showing a general pattern of spread from the eastern coast and the Connecticut River Valley into interior upland areas. Dates indicate the actual timing of initial settlement and land clearance for each town, as opposed to the official date of town incorporation, which is oftentimes much later. Modified from O’Keefe and Foster 1998b.

Figure 4.16. Changes in forest area at the Harvard Forest and state population in the mid-nineteenth century as people and cities. Information about land ownership from MacConnell 1975, Rane 1908, and Bald MacConnell and Niedzwiedz 1974, 1992 and Spurr 1960 for Harvard Forest.
(often approximately 100 square kilometers; see Figure 4.15) were
granted to groups of individuals, and subsequent property divisions
were made until most of the town area was privately owned. Initial land
clearance proceeded slowly, land speculation was widespread, and
agriculture served a small, reasonably self-sufficient population (Figure
4.16). Forest clearance ranged from less than 1 to more than 3 acres per
year as farmers undertook the laborious process of cutting and burning
the forest (Figures 4.17a and 4.17b). However, with continued immigra-
tion, improved transportation, and the emergence of markets across the
region, throughout the Colonies, and abroad to the West Indies and Eu-
rope, commercial agriculture flourished and deforestation accelerated.
In inland areas agriculture was based on commodities such as beef cattle
driven to coastal and river ports, potash from the ashes of the forests,
and timber floated to mills. All towns supported mixed agriculture,
small industry, and commerce, and most individuals balanced farm
work with household manufacture of such items as boots, shoes, hats,
and brooms. Throughout New England’s interior abundant wood re-
sources provided fuel, building materials, household and farm prod-
ucts, and essential material for local sawmills, tanneries, coopers and
other industries.

Figure 4.16. Changes in forest area in Massachusetts, Petersham, and the Prospect Hill tract of
the Harvard Forest and state population. Population growth increased with industrialization in
the mid-nineteenth century as people abandoned rural farms and concentrated in mill villages
and cities. Information about land cover is derived from Dickson and McAfee 1988, Mac-
Connell 1975, Rane 1908, and Baldwin 1942 for Massachusetts; from Raup and Carlson 1941,
MacConnell and Niedzwiecki 1974, Cook 1917, and Rane 1908 for Petersham; and from Foster
Figure 4.17. Changes in the New England landscape depicted in the Harvard Forest dioramas and modeled after the landscape history of Petersham, Massachusetts. The same site and scene are shown through various stages, from the presettlement forest (a) to initial clearing (b), the height of agriculture (c), farm abandonment and establishment of white pine (d), logging of white pine (e), growth of hardwoods after logging (f), and finally the modern forest (g). Photographs (a through f) by J. Green, from Foster and O'Keefe 2000. The final scene (g) shows a stream and stone wall running through a modern forest in Petersham that developed through the same general history depicted in the dioramas. Photograph by D. R. Foster.

Commercial Agriculture

Under intensive agrarian land use, the New England landscape was transformed from a pastoral splendor, with many stately manors and village greens ("commons"), to a network of farms. A well-developed system of intrasectoral and regional travel and trade routes, such as Salem and Boston, Gloucester, New Bedford, and...
Figure 4.17. Continued

Commercial Agriculture and Local Industry (1790–1860)

Under intensive agriculture and expanded local industry, the landscape was transformed into the quintessential image of agrarian splendor, with many stately homes, white steepled churches, broad village greens ("commons"), and extensive fields and farms (Figure 4.17c). A well-developed system of local roads connected to regional turnpikes and regional travel and trade were surprisingly active. Coastal ports such as Salem and Boston and fishing and whaling centers such as Gloucester, New Bedford, and Nantucket were engaged in wide-ranging
international trade. This was an era of a relatively homogenous population distribution and agricultural landscape pattern that represents the extreme point in the physical transformation of the New England landscape (Figure 4.18). People lived close to the land and used it and its products actively.

Understanding the landscape and land-use patterns of this period is essential for interpreting modern landscapes. For example, areas that persisted as woodland in the mid-nineteenth century make up the majority of our primary forests: areas that may have been cut over or grazed but were never cleared of their native plant species. As a consequence of
this history, primary forests support many of their original species and are in general the least altered forest ecosystems. In parallel fashion, the practices of land clearance, plowing, pasturing, or manuring each exerted a distinct influence on the native plants, soil environment, and local hydrology. As we will see, these historical impacts persist, even on sites that were abandoned for agriculture and have been reforested for more than a century. In many ways, the present landscape is still recovering from the period of agricultural prosperity and intense impact that occurred 150 years ago. Therein lies one of the essential uses of history to the ecologist.

An analysis of farm census data for the mid-nineteenth century indicates three dominant land uses that we can arrange in order of increasing intensity of disturbance to the native vegetation and land: woodlot, pasture, and tilled land. Pastureland predominated across the region, as befits a generally hilly landscape of rocky, poor soils where the transportable crops were cattle, sheep, and other livestock that could be driven to market. Pastures were diverse in appearance and ecology, from sedge and tussock-dominated swales, to rocky hill slopes that retained some native species, to improved grasslands where the removal of larger stones, shallow plowing, and seeding provided good fodder. Plowed land occupied only about 5 percent of cleared area and produced grains for animal and human consumption such as corn, wheat, oats, rye, and barley and English hay, which was rotated with other crops or pasture. Limited transportation made local production of grain and hay critical.
Figure 4.18. Changes in population size and distribution in Massachusetts over the past two centuries. The homogeneous distribution of people in small agricultural villages of 500 to 2,000 inhabitants changed abruptly with industrialization in the mid-nineteenth century as the population concentrated into urban centers and large mill towns. Data compiled from U.S. censuses, with maps modified from Wilkie and Tager 1991.
In order to develop a regional understanding of the broad patterns and variation in primary woodlands and farmland, we compiled statewide maps from 1830 that depict forest and open land cover. Across the state a general picture of deforestation, agricultural dominance, and fragmented woodlots emerges (Figure 4.19). Important variation is also notable: across the north-central region around the Harvard Forest, open areas were expansive and woodlots were small, numerous, and isolated;
to the west, woodlot size and total area increased on larger, rougher hills, and, quite strikingly, the largest block of forest occurs in southeastern Massachusetts on extensive sand plains at the base of Cape Cod. It is important to recognize that these nineteenth-century woodlands were seldom the tall and maturing forests of today but were primarily young, sprout woodlands of oak, chestnut, maple, and birch, disturbed by cutting, grazing, and fire. Woodlots were preferentially restricted to the poorer agricultural sites like wetlands, steep slopes, or remote rocky areas. Consequently, across the region, the shape, distribution, and composition of these woodland areas varied considerably with local physiography and soils.

Specific land-use patterns varied with soils and land ownership. On the Prospect Hill tract of the Harvard Forest, tilled land made up 15 percent of the area and occupied small fields bounded by massive stone walls, on well-drained loamy soils, and in close proximity to barns and farmhouses. Using hand tools, oxen, and horses farmers could work small areas, fitting agriculture very closely to slight variations in soil drainage, moisture, or rockiness. Depressions, swales, and drainage- ways became pastures, as did extensive areas at great distance from the buildings. On the Sanderson Farm on Prospect Hill, the one remaining woodlot occupied wetlands and poorly drained soils toward the back of the property. However, even swamp forest on deep peat can be logged in winter when the frozen ground and snow ease transportation. Historical reconstructions indicate that most of these stands were cut repeatedly from the late 1700s onward.

As documented in Hugh Raup’s delightful article “The View from John Sanderson’s Farm,” the mid-1800s represented a time of prosperity and apparent stability in the New England countryside. Census data confirm that farmland productivity rose throughout this period. The development of rural town centers and the construction of expansive colonial homes through mid-century suggest that the inhabitants anticipated a long future working the land. Contrary to historical interpretation and popular assumption, the New England farmers did not scrape a hard-scrabble existence from stony land. Nor did they exhaust the nutrient capital of the soils or their ability to produce crops. Instead, cultural changes quite external to the land brought the period of agricultural prosperity to an unanticipated close.

**Industrialization and Reforestation (1860–1940)**

Social and economic change across the eastern United States in the mid-nineteenth century was generated by at least four factors: the opening of the West following the Louisiana Purchase, improved transportation from the midwestern farmlands to the East and abroad, industrial development, and the discovery of gold on the West Coast. These forces brought competition for labor and goods, and the lure of jobs and new lifestyles to the industrial areas. The added effects of the Civil War and the massive influx of soldiers and developing industrial centers brought new immigrants with grants (Figure 4.18). In upland New England, many moved downhill as the conditions shifted the focus from the agriculture to the valleys, where waterways were near. Transportation provided by trains, roads, and canals. In northeastern New England the growing population focused on industrialization and reliance on the land declined in production and consumption with agriculture and natural resources from the land, forests gradually restored.

The timing, rate, and pattern of reforestation varied somewhat across New England and urban markets and regional patterns. Western New England reforested gradually by Vermont, with its woodlots abandoned early and returned to forest. The major valleys and areas in northwestern New England forested. Farming narrowed from self-sufficiency to products that were grown outside the region, including potatoes, vegetables, and bulk materials. As a consequence, New England agriculture expanded to orchards, truck crops, or specialty growing.

Reforestation largely reversed the clearing. In upland towns like Greenfield, woodlots on wetlands and steep slopes in the broader river valleys perished to forest first. In both cases, and often abutting restricted to the productive coastal areas, this process led to the extent and shape (Figure 4.19). The forest currently makes up approximately 80 percent of land use. Agricultural land is largely converted south on hillslopes and ridges. In the eastern lowlands toward Boston, the...
forces brought competition to New England farmers and provided the lure of jobs and new lifestyles to rural families. In combination and with the added effects of the Civil War, they promoted regional exodus and massive redistribution of the eastern population from rural villages to developing industrial centers where they were joined by foreign immigrants (Figure 4.18). In upland regions, many town centers literally moved downhill as the construction of industries, shops, and houses shifted the focus from the agriculturally productive soils of the ridges to the valleys, where waterpower for industrialization coincided with transportation provided by the expanding railroad network (Figure 4.20). On larger rivers, planned industrial cities such as Lowell and Holyoke in Massachusetts, Manchester in New Hampshire, and Willimantic in Connecticut were developed to exploit water around a system of factories and canals. In a wholesale landscape reorganization the growing population focused into urban and eventually suburban areas, and reliance on the land declined. Increasingly, materials for local production and consumption were imported, and the need for local agriculture and natural resources declined. As the population moved away from the land, forests gradually returned (Figure 4.17d).

The timing, rate, and pattern of land abandonment and reforestation varied somewhat across New England, often controlled by distance from urban markets and regional patterns of soils and physiography. Southern New England reforested first, followed by New Hampshire, and gradually by Vermont, with its richer soils. Rough pastures were abandoned early and returned to forest most rapidly. Productive croplands in the major valleys and areas in reach of urban markets retained more agriculture. Farming narrowed from a diverse base that enabled regional self-sufficiency to products that could not be transported easily from outside the region, including perishable items such as milk, fruits, and vegetables and bulky materials such as hay and fuelwood. As a consequence, New England agriculture became identified with dairy farms, orchards, truck crops, or specialty items like shade tobacco for cigar wrappers.

Reforestation largely reversed patterns that were followed in initial clearing. In upland towns like Petersham, coarse pastures adjacent to woodlots on wetlands and steep slopes were abandoned earliest, whereas in the broader river valleys pastures on nearby hills were allowed to revert to forest first. In both cases, remaining farmland became increasingly restricted to the productive soils and areas closest to the farms. Regionally, this process led to the development of striking patterns of forest extent and shape (Figure 4.19). In the central Massachusetts uplands, forest currently makes up approximately 90 percent of the land area. Agricultural land is largely confined to narrow strips running north-south on hilltops and ridges. In the Connecticut River Valley or the Eastern Lowlands toward Boston, the productive soils continue to support
extensive farmland, along with the bedrock ridges and larger streams. Forests of the late nineteenth century continue to be dominated by outwash formerly dominated by deciduous hardwoods, which have been largely converted to agricultural use.

Modern forest patterns present a very different picture (Figure 4.21). As fields were abandoned, they were recolonized by species such as white pine, gray birch, and small coniferous species such as red cedar. The forest edge was characterized by fencerows and surrounding grasslands which were more palatable than the hardwood forest floor, allowing grasses to compete with grasses and weeds. As grasses and weeds were cleared, deciduous hardwood forest was replaced by a mosaic of trees and shrubs, creating multiple layers of vegetation to develop on abandoned farmland. In some areas of Vermont, forests of “old-field hardwoods” have developed.
extensive farmland, along with suburban and urban development. The bedrock ridges and larger swamps that were forested in the mid-nineteenth century continue to be so today, and the extensive areas of sandy outwash formerly dominated by pitch pine and scrub oak communities have been largely converted to urban uses, airfields, or industry.

Modern forest patterns provide many clues to landscape history (Figure 4.21). As fields were abandoned, opportunistic, light-seeded species such as white pine, gray and paper birch, and red maple and bird-dispersed species such as red cedar and black cherry were established from fencerows and surrounding woodlands. Pine and cedar, which are less palatable than the hardwoods, were also favored by cattle grazing, which frequently continued as lands were abandoned, and by their ability to compete with grasses in many fields. By far the most important vegetation to develop on abandoned fields from Connecticut to northern Vermont were forests of “old-field white pine.” The extent of white pine

![Figure 4.21. A typical landscape and topographical arrangement of vegetation corresponding to land-use history in central New England: open fields (valley bottom), white pine (lower to mid-slopes), hardwood forest (mid- to upper slopes), and hemlock (upper slopes). Forest was cleared for agriculture in the nineteenth century up to the lower boundary of the hemlock forest, which remained forested, though was cut. Abandonment of pastures on the upper slope gave rise to white pine stands that were subsequently logged and then regrew to hardwoods (see Figure 4.17). Later abandonment of the lower slope pastures and hayfields gave rise to the existing band of white pine forest. Current farming activities concentrate on the most productive and accessible lands in the valley bottom. Photograph from Winchester, New Hampshire, by D. R. Foster.](image-url)
forest in the early twentieth century was sufficient to earn central New England the designation of “White Pine region” on forest maps.

As noted by Henry Thoreau in *Succession of Forest Trees* and as eventually relearned by foresters and ecologists across the region, the cutting of white or pitch pine on upland sites (Figure 4.17e) frequently gives rise to an ensuing forest of hardwoods such as maple, oak, birch, chestnut, and ash that previously grew alongside or beneath the pines (Figure 4.17f). The ability of the hardwoods to sprout and their greater tolerance of shade provide them with a competitive advantage over the pines. Consequently, we often see a landscape pattern in which primary woodlands support hardwood-hemlock forest, sites abandoned in the nineteenth century support hardwoods that succeeded cut pines, and white pines remain on the more recently abandoned sites and are rejoined by open fields.

Overall, the rate of reforestation in New England slowed through the twentieth century, and new development for housing, commercial activity, and highways initiated a decline in forest area in suburban areas. Despite the ongoing utilization of forests for a range of products, forest growth continues to exceed logging harvests. Having expanded greatly in extent over more than the past century, the forests of New England are continuing to grow and mature (Figures 4.17g and 4.22).

**Historical Changes in Forest Use**

Through history the remaining woodlands were subjected to a range of changing uses. Early on, wood availability exceeded need, and thus most cut trees were piled and burned in the process of land conversion. Transportation limited the region’s commercial base although major streams were cut along major streams in New England. Only potash was useful as fertilizers and indigo and valuable wood products were widely produced across the state, especially in New Hampshire and Maine.

As forest area declined in demand, most of the homes consumed 10 or more cords of wood. After 75 percent of wood consumed was fuel created regional patterns around the brass, lime, and hardwoods of the Valley of Connecticut, throughout Massachusetts, and, more particularly for charcoal. As technology evolved, the wood fiber as opposed to raw wood was transported across remaining forestland to industrial centers along major waterways and in river cities such as Holyoke, Massachusetts, and paper industry, far-flung mills in New England consumed small-diameter trees. By 1900, the transportation network for logging cutters consumed 54,000 cords of wood fuel for the state; by the early 1900s trackless logging was common.

The effect of rapacious lumbering was noted by Thoreau in his *Journal*. We feel the chopping of this winter has been as if all the choppers feel it as such. There is here no forest left. The chopper’s axe has been here as noted in 1846 (Trees of Massachusetts), the most unbroken forest cover are everywhere falling. The axe has spread havoc. . . . The new woods they cannot cultivate in ten, and descend in fuel, which would better be...)

Two critical concerns regarding the effect of frequent logging were apparent: the limited availability of woodlots and frightful mistreatment, and livestock grazing. . . .

Our studies of census data regarding the effect of frequent logging (Figure 4.23). Across central...
sion. Transportation limited the contribution of wood products to the region's commercial base although oak and especially pine were selectively cut along major streams and were important exports from parts of New England. Only potash and pearl ash, derived from wood ash and useful as fertilizers and industrial chemicals, represented concentrated and valuable wood products that warranted transportation. These were widely produced across the region. Remote forests distant from waterways or farmland escaped initial impacts.

As forest area declined in the late eighteenth century and wood demands increased, the extent and intensity of cutting increased. Individual homes consumed 10 or more cords per year and accounted for up to 75 percent of wood consumption. Industrial demand for charcoal and fuel created regional patterns of concentrated activity. For instance, around the brass, lime, and iron industries focused on the Naugatuck Valley of Connecticut, thousands of acres of forest were clear-cut annually for charcoal. As technology enabled the production of paper from wood fiber as opposed to rag in the 1870s, pulpwood cutting spread across remaining forestlands. Wood-demanding industries were concentrated along major waterways such as the Connecticut River, and as river cities such as Holyoke, Massachusetts, became centers of the pulp and paper industry, far-flung regions in Vermont and New Hampshire became the source of fiber. The railroads augmented demand as they consumed small-diameter trees for fuel and ties and provided a regional transportation network for logs and wood products. In 1845, more than 54,000 cords of wood fueled trains on 560 miles of track in Massachusetts; by the early 1900s track length had increased fivefold.

The effect of rapacious cutting did not go unnoticed. In 1855 Thoreau wrote in his Journals: "Our woods are now so reduced that the chopping of this winter has been a cutting to the quick. At least we walkers feel it as such. There is hardly a woodlot of any consequence left but the chopper's axe has been heard in it this season." And George Emerson noted in 1846 (Trees of Massachusetts): "A few generations ago, an almost unbroken forest covered the continent... Now, these old woods are every where falling. The axe has made, and is making, wanton and terrible havoc... The new settler clears in a year more acres than he can cultivate in ten, and destroys at a single burning many a winter's fuel, which would better be kept in reserve for his grandchildren."

Two critical concerns regarding the forest resources of New England were apparent: the limited size and timber volume of the remaining woodlots and frightful mismanagement consisting of overcutting, burning, and livestock grazing. Both authors warned of impending wood shortages.

Our studies of census data from 1885 substantiate this concern regarding the effect of frequent cutting on forest structure and condition (Figure 4.23). Across central Massachusetts, more than half of the log-
ging focused on stands twen
ty-five years old and a
dearth of older forests and
to establish fence posts, fuel, railroad ties,
woodlots were especially
to one-inch-thick woodlots fewer than twenty-
scattered, young sproutland
white pine provided an abun-
dance of small, short lengths of wood
tainers such as barrels, bu-
ucts of an era before cardboard
century and early development of the portable saws
these widespread pine forests
been previously inaccessible.

The result has been called
1920, with a peak in 1909-
timber were harvested across
boom times was due to a
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ningly, the rural land was
ployment, and the old farms
But loggers also reached out
the last stands in Connecticut
southern New Hampshire the
of immense 300-year-old pines
by the efforts of Richard Fisher.

Figure 4.23. The age of forests cut in 1885 in central Massachusetts (top panel) and the relative amount of wood cut by tree species (lower panels). In the late nineteenth century average forest age was young, with many forests cut at less than twenty years old. The species harvested varied with regional abundance and wood value. Modified with permission from Foster, Motzkin, and Slater 1998, 107: fig. 9, copyright Springer-Verlag.

Figure 4.24. Historical changes in timber harvesting in Massachusetts and Vermont. Modified with permission from Berlik et al. 2002a, 2002b, with permission.
ging focused on stands twenty-five to forty years in age, suggesting both a dearth of older forests and heavy reliance on small-sized wood for fence posts, fuel, railroad ties, and containers. In the uplands, where woodlots were especially small, nearly half of the cutting occurred in woodlots fewer than twenty years in age. The result was a landscape of scattered, young sproutlands. At the same time, new stands of old-field white pine provided an abundant source of wood for timber as well as containers such as barrels, boxes, and crates. Since these essential products of an era before cardboard and plastics could be manufactured from small, short lengths of wood, stands could be harvested at a young age (thirty years and older) and with little regard for timber quality. The development of the portable sawmill in the late 1800s enabled logging in these widespread pine forest stands as well as remote forests that had been previously inaccessible.

The result has been called a “period of forest devastation” from 1880 to 1920, with a peak in 1909–10 when more than 2.5 billion board feet of timber were harvested across New England (Figure 4.24). In contrast to booms based on old-growth and pristine forest, this activity was rooted in agricultural decline and second growth. The fields had become white pine forests, the rural landscape provided a population in need of employment, and the old farmland paths provided efficient forest access. But loggers also reached out to remaining old-growth forest, including the last stands in Connecticut and important sites across the north. In southern New Hampshire they came within feet of one magnificent stand of immense 300-year-old pines and hemlock. This forest was saved only by the efforts of Richard Fisher (director of the Harvard Forest), head-

![Figure 4.24. Historical changes in timber harvesting in Massachusetts. Figure modified from Berlak et al. 2002a, 2002b, with permission from Blackwell Science Ltd.](image-url)
lines in the New York Times, and donations from across the country. Today it forms the Harvard Forest's Pisgah tract, a virgin forest centered in a 5,000-acre state park. Across the larger region, however, after 200 years of clearing, widespread old-field succession, grazing, burning, and repeated cutting, the forests could be characterized as "only a pitiful remnant of the once extensive forests of the colonists."

Although the current intensity of logging may have declined to less than half of peak values in the early 1900s, harvesting still exerts a pronounced impact on forest structure and function. Detailed and spatially explicit information on logging for the eastern United States is difficult to obtain because much of the land is owned by thousands of private landowners and the predominant form of logging—selection cutting of individual or groups of trees—is difficult to quantify from aerial photographs or satellite imagery. To overcome this problem we used a unique Massachusetts database—Forest Cutting Plans, which are required for all commercial logging activities—and documented a surprising pattern (Figure 4.25). Over the eighteen years of data collection, harvesting occurred at an annual rate of 1.5 percent of the land area and was selective for larger and higher quality material and species (for instance, red oak and white pine). Remarkably, the pattern of logging was...
spatially random with regards to topography, distance from roads, land-use history, and broad cover type. In conjunction with other information, these results suggest that logging is probably acting to homogenize forest composition and to selectively promote lower quality trees and less valuable species. Thus, despite the fact that regional forest growth greatly exceeds removals, the pattern of cutting is undoubtedly exerting a profound, albeit easily overlooked, effect.

**Ongoing Land Conversion, Modification, and Protection**

Although the broad forest history is one of recovery and decreasing human use over the past century, other activities have substantially altered the physical setting of the region. These effects range from land conversion and hydrologic changes to the introduction of exotic pests, species, and chemicals (Figure 4.26). Many natural areas have been converted to permanent or semipermanent human uses. The selective distribution of highly modified lands, for example, varying with soil type, physiographic unit, or distance from the coast, results in a long-term loss of particular habitats. For example, despite the general decline in agriculture across New England, broad expanses do remain in open fields and farm use, preferentially concentrated on rich lowlands such as the Connecticut River and Champlain Valleys. Industrial and urban areas are situated preferentially on areas viewed as “wastelands” such as sandy outwash plains, wetlands, and coastal marshes. As a consequence, exemplary floodplain forests, sand plain ecosystems, and unaltered wetlands are uncommon.

Modification of many areas has resulted in seminatural ecosystems, substantially different from those that existed at the time of European settlement. Changes in local hydrology and watershed conditions have transformed the composition of freshwater and coastal wetlands. Similarly, dam construction and stream channelization have altered sediment loads, the hydrologic regime, and migrational pathways for fish and other organisms in many waterways. Alteration of hydrologic function occurs throughout many watersheds from high in the headwaters where remnant dams and road crossings trap sediment, to middle reaches where flood-control structures and reservoirs occur, to coastal areas where tide flows are regulated and marshes are ditched.

Dam construction for reservoirs and industrial power has also greatly increased the extent of surface water in lakes and reservoirs. Across many upland areas, natural water bodies are uncommon and historic water bodies were created, to the detriment of wetlands and valley communities. One extreme example of this process lies adjacent to the Harvard Forest in the Quabbin Reservoir, which provides drinking water for the greater Boston metropolitan area. Created in 1938, this 10,000-hectare reservoir is one of the largest water bodies in New En-
Introduced Pests and Natural Disasters

The region's forests have been affected by a number of introduced organisms. Chestnut blight, blister rust, gypsy moth, Dutch elm disease, hemlock woolly adelgid—the list goes on. The composition and structure of many forest stands have been altered. From 1910 to 1920 the chestnut blight affected chestnut trees across the region, killing up to 90% of the trees by the 1930s. Once the canopy of many forest stands had opened up, and the understory had been killed, the role of this species has been taken over by other forest species. The loss of large numbers of trees has allowed other species to become dominant. In many forests, many wildlife species have been affected.

Gypsy moths, introduced to New England by trading ships and introduced to the Midwest and the West through trade and the transportation of goods, have had a significant impact on forests. The defoliation by lepidopteran gypsy moth larvae has resulted in the decline of many forest stands. The establishment of the hemlock woolly adelgid in the 1950s and 1960s has had a significant impact on the health of American hemlock stands. The life cycle of the adelgid, which feeds on the sap of hemlock trees, can be over a decade, and the infestation can result in the death of the host tree. The disease has spread rapidly, particularly in New England, where the hemlock is a major component of the forest understory.

A number of introduced pathogens have had a significant impact on the health of forests. Dutch elm disease, for example, was first detected in the United States in the early 20th century and has caused the loss of millions of elm trees. The disease is caused by the fungus Ophiostoma ulmi, which is vectorized by the elm bark beetle. The disease spreads through the vascular system of the tree, eventually killing it. The disease has had a significant impact on many areas with large populations of elms, including much of New England.

Figure 4.26. The suburbanization and development of Massachusetts. Over the past five decades, areas of dense population have expanded outward from Boston and other metropolitan areas and are contributing to a gradual decline in and perforation of extensive forest areas. Modified from Hall et al. 2002, with permission from Blackwell Science Ltd.; data from MacConnell 1973 and MassGIS 2002.
gland. Inadvertently, this artificial water body and its surrounding protected lands also provide the largest conservation property in southern New England and a focal point for wildlife conservation and natural area management.

**Introduced Pests and Pathogens**

The region’s forests have been inadvertently exposed to a number of introduced organisms—including the chestnut blight, white pine blister rust, gypsy moth, Dutch elm disease, beech bark disease, and the hemlock woolly adelgid—that have had a dramatic effect on their composition and structure. All but the gypsy moths have specific hosts. From 1910 to 1920 the chestnut blight killed the aboveground stems of all chestnut trees across the region, removing a dominant species from the canopy of many forests. Although millions of chestnuts survive across the region, they become reinfected with the fungus and die by the time they reach a large sapling size. As a consequence, the ecological role of this species has been transformed from canopy dominant to understory tree. The loss of large chestnuts with their rapid growth, strong, decay-resistant wood, and edible nuts has significantly affected the forests, many wildlife species, and human activity.

Gypsy moths, introduced to Massachusetts in 1869 as potential silk-producing worms, have subsequently spread throughout the Northeast and into the Midwest, where they periodically defoliate hundreds of thousands of hectares and cause significant mortality among oaks and other favored species. White pine blister rust, a fungus with an alternate host on the shrub genus *Ribes*, and beech bark disease, a complex pathogen consisting of a fungus and a scale insect, have altered forest composition and caused significant mortality in these important tree species. Beech bark disease has exerted an uneven effect regionally but has converted broad areas of northern forest from open, older growth stands to dense thickets of beech sprouts. In many maturing forests, beech is exhibiting a striking contrast to the general trend of major tree species by undergoing a decrease in basal area and an increase in density of small stems. Mast from beech nuts is an important food source for bears and smaller mammals in northern forests, and so the disease is affecting the entire ecosystem.

Dutch elm disease, a wilt fungus transported by a bark beetle, transformed the appearance of most towns in the Northeast during the 1950s and 1960s by killing the spreading elms that lined and shaded the main streets, commons, and parks. Devastation of the elms was greatly facilitated by the creation of virtual monocultures in our urban forests. However, elm played a minor role in the natural landscape of the Northeast, and so this loss was less significant than those caused by the other pathogens.
Today, the hemlock woolly adelgid is poised to exert a major impact on our forests as it slowly kills large areas of hemlock in southern New England and elsewhere in the Northeast (Figure 4.27). The loss of hemlocks is especially disturbing because this species is one of our longest-lived trees and is abundant in the least disturbed habitats, such as steep slopes, swamp forests, and stream banks, where it creates a unique cool, dark microhabitat. The unfortunate arrival of hemlock woolly adelgid provides us with an unusual opportunity to develop a comprehensive study at the ecosystem, landscape, and regional scales of an important process in New England's history and increasingly in forests globally: the spread and effect of an introduced pest.

The Unfolding Effect of an Exotic Pest: The Hemlock Woolly Adelgid

For many reasons the spread of the hemlock woolly adelgid (HWA) across the eastern United States warrants concern and study by ecologists, conservationists, and landowners. Hemlock holds a unique position among temperate forest trees, and its loss or decline will affect forests, wildlife, and landscape appearance profoundly and irreversibly. Hemlock is among the longest-lived and most shade-tolerant temperate trees, matched most closely only by beech and sugar maple, two of its hardwood associates. It grows in soils that are acidic, which means it tends to stay among our last tree species that have burned intensively. As a result, it is likely to be restricted to primary and secondary forests with less intense human activity. Its presence is long term. It is a sad irony that more heavily forested and crown dense forests, which are dominated by hemlock, are less likely to host the hemlock woolly adelgid lady bug, this quintessential old-growth forest insect.

Hemlock's predilection for streams and watercourses, and on lake shores, which often excludes other plant species, sequences that a rapid hemlock die back and deterioration of water quality. Hemlock woolly adelgid attacks the hemlock during winter months. However, to most New Englanders, the impact of the HWA will be near impossible to see. The adelgid is an ideal tree for hedgerows and backyards lose their hemlock woolly adelgid tolerance or ecological replacement of hemlock.

Despite growing interest in hemlock woolly adelgid, there is little about the dynamics of its spread and persistence. Unanswered questions remain about the role of abiotic and biotic factors in determining the rate and extent of hemlock woolly adelgid infestations. Once infested, how rapidly and at what density do hemlocks become infested? How do physiological mechanisms that cause mortality of hemlock affect the future health of hemlock? And how will these forests respond to changes in climate, streams, and ponds?

To address such questions, we need to further examine forest response to hemlock woolly adelgid. The research focuses on a 100 km transect across the Connecticut coast northward to the Piscataqua River, which encompasses a gradient of forest types affected by hemlock woolly adelgid. The study examines the impact of the insect, and embraces a wide range of forest conditions. Although the HWA...
hardwood associates. It grows slowly and has limited ability to disperse, which means it tends to spread slowly across the landscape and is among our last tree species to recolonize sites like old fields or areas that have burned intensively. As a consequence, large old hemlock trees tend to be restricted to primary forest sites that have received comparably less intense human activity and where hemlock has been present for a long time. It is a sad irony that as the general landscape is becoming more heavily forested and wilder and as old-growth forests, many of which are dominated by hemlock, are emerging as a conservation priority, this quintessential old-growth species is being threatened by an exotic insect.

Hemlock’s predilection for growing in forested wetlands, along stream courses, and on lake shores and its habit of casting dense shade that often excludes other plants raise many questions regarding the consequences that a rapid hemlock decline will have for aquatic ecosystems and water quality. Hemlock canopies intercept snow and shelter wildlife during winter months. Meanwhile, the shady, acidic, and relatively cool and stable environments in hemlock forests provide unusual terrestrial and aquatic habitats in a landscape dominated by hardwoods. However, to most New Yorkers, the immediate and perhaps greatest effect of the HWA will be aesthetic. Hemlock’s evergreen and shade-tolerant nature makes it a distinctive background in nature reserves and an ideal tree for hedgerows and property boundaries. As our forests and backyards lose their hemlocks, we will discover that there is no substitute or ecological replacement for this unusual species.

Despite growing information on HWA biology, we know relatively little about the dynamics of HWA infestation and its effect on forest patterns and processes. Unanswered questions include the following: What factors determine the rate and pattern of spread of this wingless insect within a stand, from forest to forest, and across the region? Are there climatic or biological factors that may eventually limit the insect’s spread? Once infested, how rapidly do trees decline and die and what are the physiological mechanisms involved? How does the decline and mortality of hemlock affect the forest environment and the availability and cycling of important nutrients? What species and forests will replace hemlock? And how will these major forest changes influence wildlife, streams, and ponds?

To address such questions, we developed a major research effort to examine forest response to HWA outbreaks in southern New England. The research focuses on a 100-kilometer-wide region that stretches from the Connecticut coast northward to southern Vermont. This transect encompasses a gradient of HWA infestation, ranging from the most heavily affected forests in New England to areas beyond the current extent of the insect, and embraces a wide range of different landscapes and forest conditions. Although the HWA has only just reached the Harvard For-
est, it looms as a major ecological factor that we need to anticipate, study intensively, and understand comprehensively.

**Forest Dynamics in Response to the Hemlock Woolly Adelgid**

The HWA is a small, aphidlike insect introduced into a number of East and West Coast locations on nursery stock from Japan. It damages the trees by inserting a long stylet into the parenchyma tissue of the needle and inner twig, removing carbohydrates and nutrients and potentially injecting toxins and damaging cellular function. Since the HWA entered Connecticut across Long Island Sound around 1985, it has spread especially northward across southern New England, to reach more than half of the towns in Massachusetts (Figure 4.27). Across Connecticut we estimate that the abundance of hemlock has decreased by one-third because of mortality from the HWA and salvage or preemptive logging. The long-term prognosis for the species is bleak (Figure 4.28). In

![Hemlock Mortality](image)

![Hemlock Crown Vigor](image)

**Figure 4.28.** Effect of the hemlock woolly adelgid on forest vigor and mortality in a broad transect extending from Long Island Sound (south) to the Connecticut-Massachusetts border (north). The gradient in damage relates to the northward expansion of the insect and the duration of infestation.

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**Figure 5.5.** Pollen diagram from Aino Pond, Ashburnham, MA. A 1300-year record shows a continuous increase in hemlock pollen, with modern hemlock values surpassing those of oak, beech, and most other hardwoods. The sharp decline in oak pollen reflected in the diagram has occurred continuously but was not always as pronounced as shown here. The long-term decline in oak pollen (with concomitant increases in hemlock) extends at least 400 years and has been postulated as the result of a long-term deterioration in climate. The rapid decline in oak pollen and associated increase in hemlock around 1000 years ago are quite apparent. Pollen data from Michael et al. (1989, fig. 2a, with permission from Springer).

extremely resilient to intensive management practices and is widely throughout the region of New England and adjacent areas. The effects of HWA on hemlock, however, are much more severe. The long-term effects of HWA on hemlock and other tree species in New England are likely to be significant, as the pest continues to spread and impact the region. The hemlock and associated forest ecosystem are integral to the ecological and cultural landscape of New England.
the 150 forests that we have examined, mortality exceeds 60 percent in half of the stands, and trees are dying at a rate of 5 to 15 percent per year. The remaining trees are deteriorating in all infested stands; most remain as thin and graying shadowy ghosts that retain less than 25 percent of their original foliage. Absolutely no sign of tree or forest recovery can be observed after heavy infestation, and we anticipate that the remaining trees will die within five to ten years of infestation.

As the dense hemlock canopies thin and begin to break up, light levels near the ground increase dramatically, and the forests are rapidly colonized with seedlings of black birch, red maple, and oak as well as weedy herbs and shrubs including pokeweed, fireweed, raspberry, and ferns. Seedling densities increase in proportion to the increasing light as hemlocks continue to decline and die. As a result, vegetation cover remains high, erosion is minimal even on steep slopes, and succession proceeds rapidly (Figure 4.29). In stands with less hemlock cover and correspondingly more hardwood canopy and residual shade, seedling
establishment is slower, and hemlock replacement occurs gradually through in-growth from adjacent trees and up-growth of existing seedlings or new seedlings.

To interpret broadscale patterns of HWA spread, we mapped all hemlock forests in the Connecticut portion of our transect from aerial photographs and then visited and sampled 120 stands in detail. The HWA occurred in nearly 90 percent of stands, but hemlock mortality varied regionally, from 20 to 100 percent in the south compared with 0 to 15 percent in the north. Trees exhibited no apparent resistance although there is considerable within-stand variation in infestation rate and decline. The broadscale south-to-north trend in decline parallels the migration path of the adelgid and the duration of infestation. Birds and other animals, including people; wind; and transportation of nursery stock and forest products are the main facilitators of HWA movement. The rapid spread to the north may be a consequence of the migratory route of many bird species.

Across southern New England and increasingly to the north and beyond the current range of the adelgid, landowners and public agencies are logging hemlock forests at an unprecedented rate. In southern Connecticut alone more than 25 percent of hemlock forests have been logged, and many more will be cut before they die from HWA. The decision to harvest these forests is largely driven by economic, safety, and aesthetic concerns, and therefore, many of the major impacts of the HWA may be indirect: widespread salvage or preemptive logging, road construction, and associated effects. Initial studies suggest that these land-use side effects of the HWA initiate more pronounced ecosystem responses than the HWA itself. In logged stands, canopy removal is more complete and immediate, soil disturbance and changes in light and soil microenvironments are greater, and the transition to hardwood forest occurs much more rapidly than in intact forests where the trees decline gradually from HWA. Recognition of these differences between logging and HWA impacts should figure into landowner decisions and land policy development regarding responses to the arrival of this exotic pest.

Outlook for Hemlock Forests

The future of hemlock and hemlock forests in New England is dim. The adelgid continues to migrate northward, and its progress seems unimpeded by climate or other factors. Although severe winters initiate heavy mortality, they only check the insect’s population growth temporarily because of its parthenogenetic (self-fertilizing) reproduction and the occurrence of two generations per year. In Japan, where the HWA is native, it grows under winter regimes that are as severe as any in
the eastern hemlock's range. The complete absence of recovery in any infested trees or stands suggests that although trees may linger for long periods after initial infestation, they continue a progressive decline. Biological controls based on native predators on the HWA have been tested but appear unable to prevent or control the spread of the insect. The same is also true of chemical insecticide. Consequently, hemlock may be drastically reduced or eliminated across broad portions of New England and the East in a few decades. Our ongoing studies will evaluate the many dimensions and consequences of this new ecological force in our landscape. They will provide new perspectives to the history of earlier pathogens, a better understanding of where our forests are heading, broader insights into the important effects of introduced organisms on natural forest ecosystems, and information that landowners, managers, and planners can use as they seek to shape our landscape into the future.

The Future and Remnants of the Past

As human population increases and disperses from urban centers, suburbanization is increasingly affecting our forests and open spaces (see Figure 4.26). Over the past fifty years both the average duration of ownership, now less than ten years, and the average size of forest properties, now less than 10 hectares, have decreased significantly as our population has become less agrarian and more mobile and as our suburbs encroach on rural areas. These social and geographical trends will strongly influence our perception and use of the forests in the coming century.

Despite the long history of agriculture, clearing, and intensive harvesting in the New England landscape, recent environmental interest has led to the discovery of remnant patches of old-growth forest, once assumed to be entirely eliminated. Although definitions of "old-growth" vary considerably, these forests typically show minimal evidence of human disturbance and include dominant trees well over 200 years old. At present, more than 400 hectares of old-growth forest are recognized in Massachusetts, and the number continues to rise slowly as additional areas are investigated by scientists with a constantly improving understanding of what these ancient trees look like. The largest stand, more than 50 hectares in extent, was recently identified on steep slopes below the summit of Wachusett Mountain in an area heavily used for recreation for 150 years, and less than 40 kilometers from Boston. Although these old-growth stands are among our most natural forests, even these sites are not protected from subtle but pervasive human disturbances such as atmospheric pollution, rising CO₂ levels, and associated climate change. Nonetheless, the ability to identify and protect old-
growth stands within an extensive matrix of forest cover across the modern New England landscape is a remarkable outcome of 400 years of landscape change. The extent to which these modern forests resemble their pre-European predecessors is a major question with important ecological and conservation ramifications.