CHAPTER 2

The Physical and Biological Setting for Ecological Studies

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In the late 1890s, Nathaniel Shaler, dean of the Lawrence School of Science at Harvard University, and Richard Fisher, professor of forestry, agreed on Harvard's need to establish a research forest in the New England countryside to serve as a laboratory for investigations in forest biology and management and as an outdoor classroom where students could learn the emerging discipline of forest science. After considerable travel and with encouragement and support from local alumni, Fisher selected a series of tracts in the town of Petersham in north-central Massachusetts as the center for the new Harvard Forest. He discovered in this rolling and picturesque upland landscape a large range of the biological and environmental conditions that were characteristic of New England and that fit his criteria for a field laboratory and classroom. The land captured much of New England's considerable variation in soils and vegetation as it stretched from lowlands such as the Tom Swamp valley—where acid spruce and larch bogs, red maple swales, and sedge and shrub marshes prevailed—to mesic forests of hemlock and hardwoods on gentle slopes, and up to dry and rocky oak knolls (Figure 2.1). Equally important for studies of land management, the landscape that Fisher surveyed embraced a wide variety of land-use history, from intensely cultivated agricultural sites on the broad upland ridges, to pasture and woodlots on the rocky slopes, to small pockets of older growth forest on moist, rocky, and less-accessible sites. Thus, with the establishment of the Harvard Forest in central Massachusetts and with subsequent acquisitions like the old-growth Pisgah Forest in southern New Hampshire, the base was created for the intensive and long-term studies that form most of our research.

However, all researchers at the Forest—including Fisher, ecologists and foresters such as Hugh Raup, Steve Spurr, Ernie Gould, and Walter Lyford, and their modern successors—have recognized the need to expand on this modest center of intensive studies and to place the results from Petersham in a broader geographical context. Thus, through time, the research laboratory and classroom grew in size beyond Harvard

Figure 2.1. Diorama from the Fisher Museum of the old-growth hemlock forest adjoining Harvard Pond in Petersham, Massachusetts. Depicted in the foreground are Nathaniel Shaler, Harvard dean, geology professor, and first director of the U.S. Geological Survey, and Richard Fisher, first director of the Harvard Forest. Shaler was instrumental in promoting the concept of a field laboratory and classroom for forest studies at Harvard, and Fisher located the property and then initiated the ecological and historical studies that remain the hallmark of Harvard Forest research. The old forest was subsequently damaged by the 1938 hurricane. Photograph by J. Green, from Foster and O'Keefe 2000.

lands to embrace a range of sites throughout Petersham and north-central Massachusetts, across much of the New England region, and progressively to many distant places around the globe. In the integrated studies that we present in this volume, the hierarchy of geographical scales from site to landscape to subregion to region and ultimately to the globe is embraced as an explicit framework for research. To facilitate discussions in subsequent chapters, much of which crosses scales rather fluidly, we provide a brief overview of the physical environment and biological characteristics of these settings for our studies.

New England Region

Our regional studies focus on most of New England (Maine, New Hampshire, Vermont, Massachusetts, Connecticut, and Rhode Island) because of a broad similarity across this six-state area in vegetation and flora, natural disturbance regimes, and cultural history. Overall, the physiographic divisions, the broad patterns of topography, and regional

variation in soil characteristics in New England are closely tied to geology. Local relief has been strongly modified by some twenty episodes of glaciation over the past 2 million years, and the landscape patterns of soils, stream drainage, and topography are largely a consequence of interactions between the bedrock geology and the erosional and depositional history of the most recent glacial period. New England is a predominantly hilly region of broad highlands ranging from 200 to 500 meters above sea level (a.s.l.), with narrow valleys and a few broad lowlands that extend below an elevation of 200 meters. Six major physiographic areas include the Champlain Valley, Green Mountain Uplands, Connecticut River Valley, Central or Inland Uplands, and the Coastal Lowlands, which grade into a narrow Coastal Plain (Figure 2.2). Additional physiographic variation is found in the Taconic Highlands and Vermont Valley in the west and the New Brunswick Highlands and St. John Lowlands in Maine. At both the broad scale and across local landscapes, much of this variation occurs through alternating valleys and uplands that trend north to south because of the structure of the underlying bedrock.

Physiographic Divisions

The *Champlain Valley* of Vermont is part of the St. Lawrence Lowland that ranges from 15 to 130 kilometers in width and extends 700 kilometers from Newburgh, New York, to Quebec City. Composed of sedimentary rocks (shales, dolomites, and limestones) overlain by sedi-

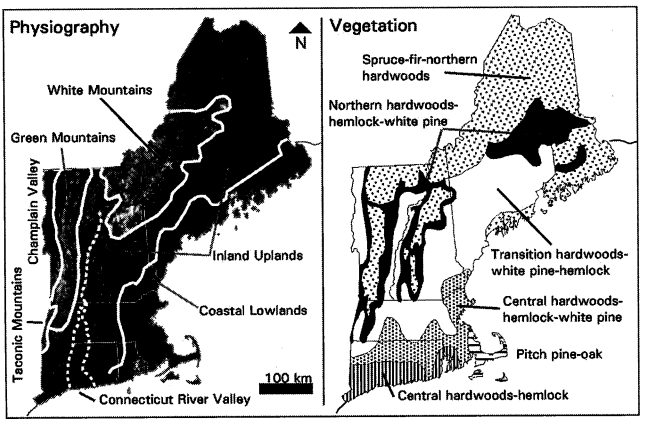


Figure 2.2. Elevation, physiography, and vegetation of New England. The broad lowland and gentle relief of the southern and eastern coasts gives way to more rugged upland terrain to the north and west. The Connecticut River Valley to the south and Champlain Valley to the northwest form prominent lowlands that interrupt this general pattern. Modified from Wright 1933 and Jorgensen 1977. Major vegetation zones are adapted from Westveld 1956.

ments from the Champlain Sea, the lowland has relatively rich soils, gentle relief, and elevations ranging from sea level to 100 meters. To the east, the *Green Mountain Uplands* emerge abruptly from the valley to reach elevations 400 to 1,200 meters a.s.l. and extend the length of New England. Metasedimentary and metavolcanic rocks comprise the bulk of these uplands, which include such familiar landmarks as the Hudson Highlands of New York, the Berkshire Hills of Massachusetts, and the Green Mountains of Vermont. Discontinuous areas of calcareous and alkaline rocks provide locally rich soils, high floristic diversity, and unusual plant assemblages. In general, this region has more productive soils and therefore a more diverse flora than the Central Uplands and the White Mountains.

The *Connecticut River Valley* separates the two large upland regions in New England and ranges from 2 to 35 kilometers in width in its 250-kilometer extent from Long Island Sound on the Connecticut coast to its headwaters beyond northern Vermont and New Hampshire. Underlain primarily by sandstone and shale to the south and metasedimentary and metavolcanic rocks to the north, the gentle relief and low elevation (largely less than 100 meters a.s.l.) is broadly controlled by glacial lake sediments and alluvial deposits interrupted by occasional bedrock ridges and domes. To the east and north, the *Central Uplands* comprise the largest physiographic region and include the White Mountains, with the tallest peaks in New England (Mount Washington at 1,886 meters a.s.l. and other peaks in the Presidential Range), and the intensive study areas of the Harvard Forest LTER program (Figure 2.3). The rocks of this region are variable but tend to be of metasedimentary and metavolcanic origin and produce acidic soils of low nutrient status. Elevations range from 200 meters in the south to 500 meters and higher in the north.

The *Coastal Lowlands* form a 60- to 100-kilometer-wide belt that extends from coastal New Jersey to central Maine. Relief is generally low, the bedrock is highly variable, and the contact with the adjoining highland areas to the north and west is typically abrupt. The extensive Coastal Plain of New England is largely submerged off the Atlantic Coast, where it forms the Continental Shelf that includes Georges Bank and the Gulf of Maine.

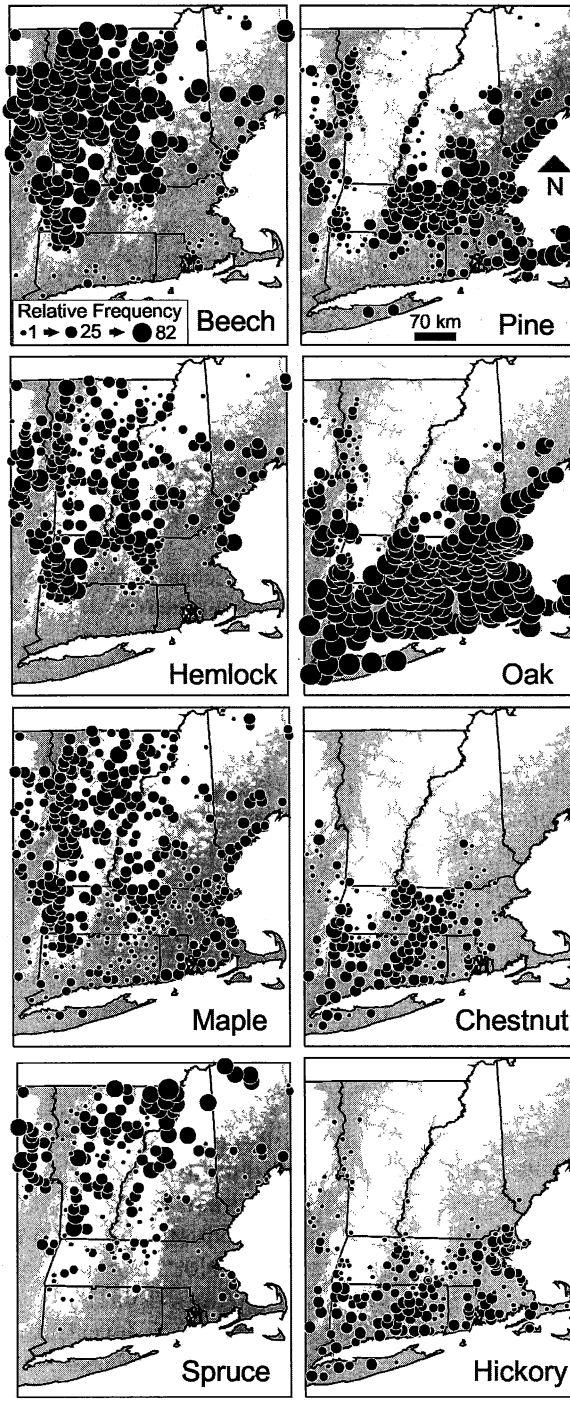
Morainal and outwash deposits that have been modified by coastal processes since the last glaciation comprise the areas from Cape Cod southward through the islands of Nantucket and Martha's Vineyard in Massachusetts, Block Island in Rhode Island, and Long Island in New York state. These coastal areas are dominated by sandy soils, low elevation, and varied relief.

Across New England, strong gradients in precipitation, temperature, and length of growing season are driven largely by elevation and latitude and to a lesser extent by a moderating coastal influence that extends inland 5 to 20 kilometers. Mean annual temperature ranges from

Figure 2.3. View looking east across the margin of the Connecticut River Valley toward the Central Uplands of northern Massachusetts where the Harvard Forest is located. Photograph by D. R. Foster.

11°C in southern Connecticut to 4°C in the northern highlands of Vermont, New Hampshire, and Maine, whereas precipitation ranges from 88 to 125 centimeters and is distributed fairly evenly through the year. Gradual environmental gradients are restricted to areas of gentle relief such as the sloping uplands from southern Connecticut through the Harvard Forest and northward into the southern White Mountains. Elsewhere, relatively sharp transitions occur from lowland areas such as the Champlain and Connecticut valleys to the adjoining hills. These abrupt physiographic changes produce a tight juxtaposition of climate zones, geology, vegetation, and land-use history.

The forests of this environmentally complex region are described fairly well by a classification and map developed in 1956 by a group headed by Marinius Westveld for the Society of American Foresters. Vegetation was described in terms of its natural "undisturbed" composition, as well as the important successional taxa in each region that had increased in abundance because of land-use activities or other disturbances. A simplified version of this Westveld classification includes five forest vegetation zones: Spruce–Fir–Northern Hardwoods, Northern Hardwoods–Hemlock–White Pine, Transition Hardwoods, Central Hardwoods, and Pitch Pine–Oak (Figure 2.2). Interestingly, Westveld's map agrees quite well with recent reconstructions based on witness tree data and led by ecologist Charlie Cogbill as a collaborative effort of the Hubbard Brook and Harvard Forest research groups (Figure 2.4).


Relative Frequency
1 25 82
Beech
N
70 km
Pine
Hemlock
Oak
Maple
Chestnut
Spruce
Hickory

The *Spruce-Fir* and *Northern Hardwoods* zones cover northern and eastern Maine, extending south and west through the higher elevations of the Green and White Mountains of Vermont and New Hampshire and the Berkshires of Massachusetts. Characteristic hardwood species are beech, yellow birch, and sugar maple, with paper birch, white ash, red maple, and aspen on cut-over, wet, or high-elevation sites. Red and white spruce and balsam fir predominate at higher elevations, in old fields, and along the Maine coast, whereas black spruce occupies poorly drained sites. In southern and lower areas, hemlock and white pine are more common than spruce and fir.

Transition Hardwood forest covers low elevations in New Hampshire and Vermont, southern Maine, central Massachusetts, and northwestern Connecticut where Northern Hardwood species overlap with the oaks and hickories of the Central Hardwood region. White pine and hemlock are common conifers, and indeed in earlier classifications this area was called the "white pine region" because of the extensive white pine on old abandoned farm fields. However, when this first generation of pines is cut or otherwise removed, it is generally succeeded by a mixture of hardwood species. This zone includes Petersham, which helps to explain the relatively diverse vegetation across the Harvard Forest. Transition Hardwoods grade into the *Central Hardwood forest* of Connecticut, Rhode Island, eastern Massachusetts, and the Connecticut River Valley of southern New England. Typical tree species include black, red, and white oaks; red maple; black birch; and pignut and shagbark hickory.

On the sandy soils of Cape Cod and the Islands, along with scattered sand plains elsewhere in southern New England, *Pitch Pine–Oak forests* occur. Dry site conditions, long and intensive human land use, and relatively frequent fires control the composition and growth of these forests. In addition to pitch pine, typical trees include white oak, scarlet oak, black oak, and sassafras, with scrub oak and heath species in the understory.

Central Massachusetts Subregion

The central Massachusetts area constitutes portions of four counties in the north-central part of the state and encompasses physical, biological, and cultural gradients that vary across three major physio-

Figure 2.4. Distribution and abundance of major tree taxa across New England at the time of European settlement. The witness tree data that were used to compile these maps were derived from property surveys conducted for individual towns at the time of their settlement. Massachusetts was the location of abundant white pine and a relatively sharp shift from southern taxa (hickory, chestnut, oaks) to northern taxa (beech, maple, hemlock, and spruce). White areas are uplands higher than 225 meters in elevation. Based on data from Cogbill et al. 2002.

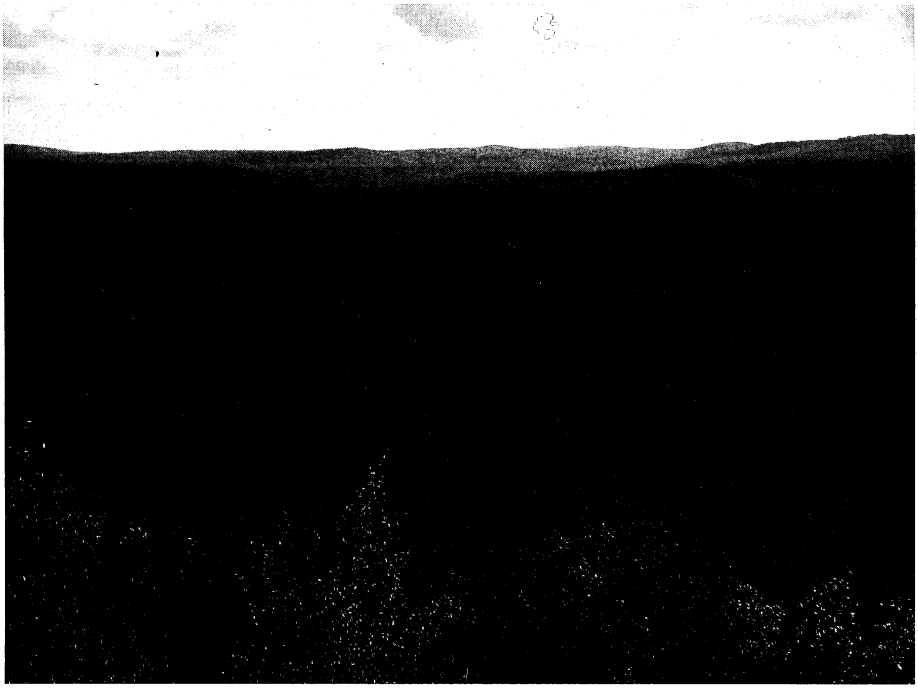


Figure 2.5. Nearly unbroken forest fills the view of the Central Uplands region, including the northern part of the Harvard Forest and town of Petersham on the distant ridge. Photograph by D. R. Foster.

graphic regions that differ in relief, geology, soils, land-use history, and climate. The broadest physiographic area is the Central Uplands (Figure 2.5), which in north-central Massachusetts is characterized by north-south trending hills and narrow valleys from 150 to 430 meters a.s.l. The bedrock of gneisses, schists, and granites is overlain by thin glacial till on the uplands and deeper and more level outwash, alluvial deposits, and peats in the narrow valleys. Soils are acid sandy loams of low nutrient status.

With the exception of developed areas, lakes, and marshes, the Central Uplands are predominantly forested, with few remaining farms. Upland villages with low population density are scattered across the forested hills, whereas larger industrial towns and small cities border some of the major streams. The Quabbin Reservoir, which was created in the 1930s to provide drinking water for more than one-quarter of the Massachusetts population living in the Boston metropolitan area, forms a 10,000-hectare water body surrounded by approximately 23,000 hectares of land owned and managed by the Metropolitan District Commission, a state agency. The reservoir occupies the historic Swift River

Valley and portions of the former towns of Dana, Prescott, Greenwich, and Enfield. The tops of bedrock hills that emerged through the old valley floor now persist as parallel north-south islands in the reservoir. The Quabbin Reservation forms the largest piece of an extensive, though loosely affiliated, conservation partnership, the North Quabbin Regional Land Partnership (NQRLP). Lands in the North Quabbin Region are protected from commercial and residential development and are managed by federal and state agencies, nonprofit conservation organizations, and educational institutions including the Harvard Forest. Most of the land in the area and, indeed, in New England is in small private ownership. Much of the forested land is actively managed for wood products and other values.

To the west, the Massachusetts portion of the Connecticut River Valley is easily distinguished by topography, vegetation, and land use. The level to rolling plains at 30 to 75 meters a.s.l. are underlain by sedimentary sandstone and shale and support level deposits of outwash, alluvium, and glacial lake sediments. Soils range from excessively well-drained, sandy outwash to poorly drained, silty, flood-plain sediments. A series of bedrock ridges composed mainly of volcanic basalt ("traprock") emerge through the valley bottom and reach a maximum height of 400 meters a.s.l. in the Pocumtuck Range. The rich and fertile soils, level terrain, ease of river navigation, and long settlement history by Native Americans and Europeans have led to a modern cover of extensive farmland; concentrated urban, industrial, and residential areas; and discontinuous forests. In contrast, the traprock ridges remain wooded. The diverse environments offered by the flood plain, rich alluvial soils, sandy outwash, and basaltic and sedimentary outcrops support a remarkable array of unusual plant assemblages. These threatened communities and the great cultural heritage make the Connecticut River Valley a priority area for state and national conservation.

To the east, the Central Uplands grade gradually into the Eastern Lowland, which is part of the extensive Coastal Lowland. This area of hills, gentle relief, and meandering rivers set in broad valleys ranges from 40 to 200 meters a.s.l. Acid bedrock is overlain by till, broad glacial-lake sediments, alluvium, and marine deposits. The region grades eastward from rural, agricultural, and forested areas into the densely populated suburban and high-technology region adjoining Boston.

The physiographic variation across the central Massachusetts subregion yields subtle gradients in environment, history, and vegetation. The Connecticut River Valley and Eastern Lowland have low elevations, gentle relief, and mild climates, with summer and winter temperatures that average 2° to 3°C warmer than the intervening Central Uplands. In response to this climatic variation, southern plant species decline on the Uplands, and the Northern Hardwoods-Hemlock forest extends

southward from New Hampshire onto this area of higher elevation. Broadly, the Connecticut River Valley is lower, has more nutrient-rich soils, and is more agricultural than the Eastern Lowlands.

Petersham and the Harvard Forest

The township of Petersham, Massachusetts, contains most of the Harvard Forest and is typical of many rural hill towns in the Central Uplands (Figure 2.6). Embracing an original area of approximately 10,000 hectares, Petersham was nearly doubled in extent in 1938 upon dissolution of four towns in the Swift River Valley to form the Quabbin Reservoir and its forest reservation. The town lies in an undulating part of northern Worcester County where broad north-south trending hills of schists and gabbros overlain by a thin mantle of glacial till are separated by narrow valleys with rocky slopes and small streams, wetlands, and mill ponds. Elevations range from 150 to 300 meters a.s.l, but even this minor variation can lead to substantial differences in local environment (Figure 2.7).

Like much of central New England, Petersham supports extensive

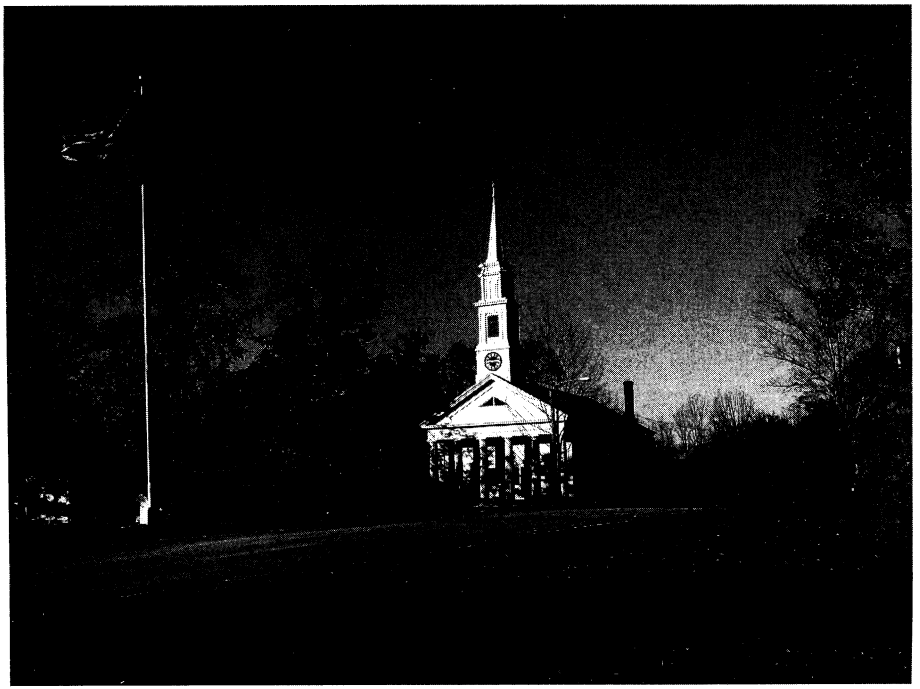


Figure 2.6. The town common (village green) and Unitarian Church in the center of Petersham, Massachusetts. Photograph by D. R. Foster.

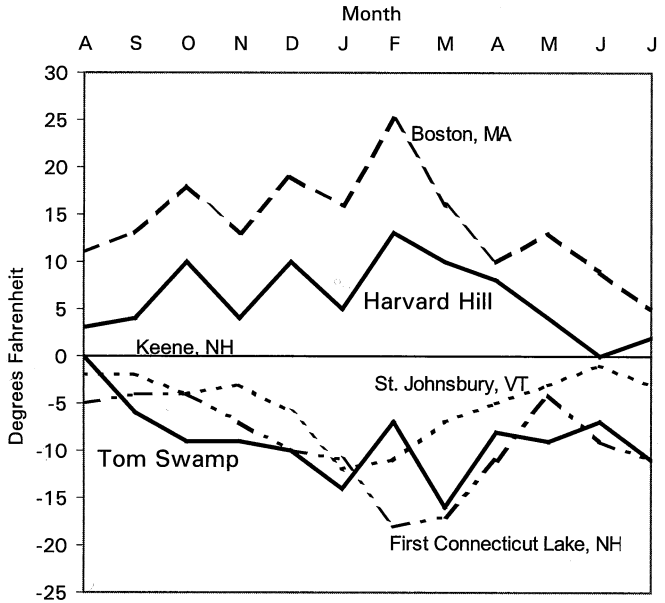


Figure 2.7. Variation in topographic position and vegetation in New England can lead to extreme differences in temperature between sites less than 5 kilometers apart. The figure shows deviations in monthly minimum temperature from that at Keene, New Hampshire (zero line), for two sites at the Harvard Forest (Harvard Hill—an upland site above Tom Swamp; Tom Swamp—a valley bottom site; see Figure 2.8), and areas in southern (Boston), northern (St. Johnsbury, VT), and extreme northern (First Connecticut Lake, NH) New England. Because of cold air drainage and radiative cooling caused by a thin canopy, the wetland site is markedly cooler than the adjoining upland forest. The differences between the local sites at the Harvard Forest are of the same magnitude as regional differences among sites separated latitudinally by more than 200 kilometers. Modified from Rasche 1958.

forests that are 50 to 100 years in age and that arose following succession on old abandoned agricultural fields in the late nineteenth or early twentieth century, logging, or blowdown and salvage logging due to the 1938 hurricane (see Figures 1.3, 1.4). Forest composition varies with history and site conditions with mixed hardwood stands of red oak, black oak, white oak, red maple, white ash, black birch, and paper birch on sites that were cut or blown down; white pine on old-field sites that were not cut or blown down; red maple on poorly drained lowland swales; and hemlock, often with white pine and hardwoods, in older forests that were cut historically as woodlots but never cleared for agriculture. Shrub-dominated and forested wetlands occupy muck and peat soils. A limited amount of agricultural land remains on the broad ridges in the central and eastern part of town that support the most productive soils in this landscape.

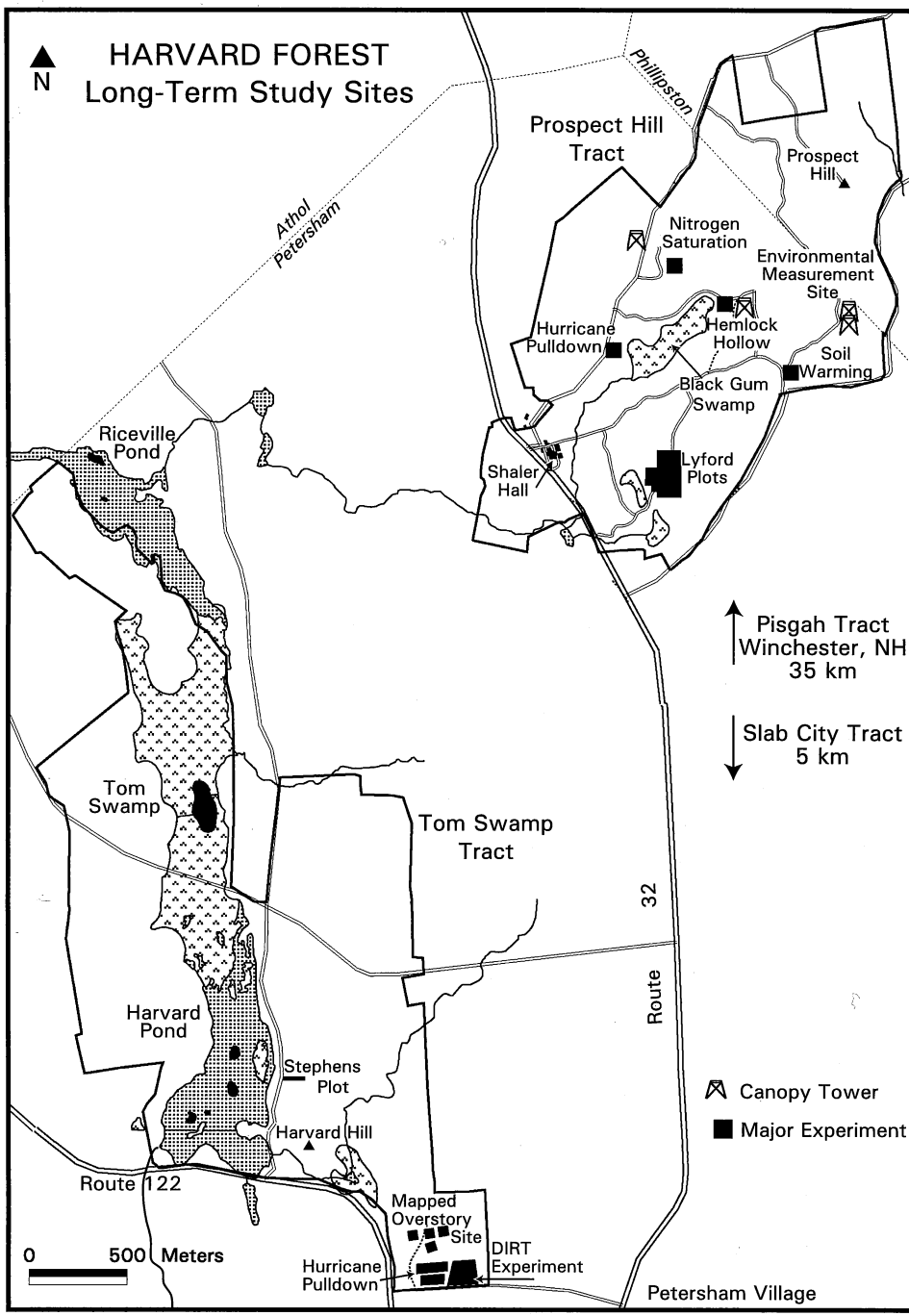


Figure 2.8. The northern part of Petersham showing the location of major research sites and experiments on the Prospect Hill and Tom Swamp tracts of the Harvard Forest.

The Harvard Forest has maintained a research and educational program focused on forest ecology, biology, and management since its establishment in 1907. The continuity of mission and data collection provides a unique long-term record on the more than 1,200 hectares of land that compose the three main parcels of land. These areas—the Prospect Hill, Tom Swamp, and Slab City tracts—encompass the broad range of site conditions, vegetation, and land-use history that characterize the Central Uplands (Figure 2.8). The Prospect Hill tract occupies a predominantly upland location in the northern part of Petersham and the adjacent town of Phillipston and includes the highest elevation in the area (Prospect Hill, 417 meters a.s.l.) as well as the headquarters and main research facilities at the Forest. As described so well in Hugh Raup's "The View from John Sanderson's Farm," the gentle, upland topography was extensively cleared and farmed through the early 1900s except for the large Black Gum Swamp, an adjoining hemlock woodlot, and smaller wetlands in the center of the tract.

The Tom Swamp tract extends downslope and westward from Prospect Hill and the center of Petersham to include Harvard Pond and large areas of sedge, shrub, and black spruce swamp in the bottom of the valley. The wetland areas and steep and rocky hill slopes were never cleared for agriculture, which was largely confined to the gentler terrain toward the hill crests on either side of the valley. The Slab City tract extends in a narrow series of properties south from the center of Petersham and down a steep and narrow tributary to the East Branch of the Swift River, which is the largest stream feeding the Quabbin Reservoir. Oldfield forests on the gentle hills give way to large second-growth hardwood forests on the valley slopes and extensive areas of older-growth hemlock, white pine, and hardwoods on the protected slopes and valley bottoms adjacent to the river. This large, older-growth area, along with an old mixed-hardwood and hemlock forest on the slopes above Tom Swamp, make up the major research natural areas in the Forest.