GLOBAL LAND USE CHANGE.

A PERSPECTIVE FROM THE COLUMBIAN ENCOUNTER

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CHAPTER 10

LAND-USE HISTORY AND FOUR HUNDRED YEARS OF VEGETATION CHANGE IN NEW ENGLAND

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"The upland climax vegetation of New England? Trees, of course."

H. M. Raup

Introduction

Forests in New England are extraordinarily resilient. Despite centuries of cutting, burning, grazing, deforestation and recent pollution, trees repeatedly return to dominate most upland sites unless substantial energy is expended to exclude them (Raup, 1979; Smith, 1979; Russell, 1980). The agriculturally motivated deforestation and reforestation of New England over the past 250 years comprises a series of ecologically significant landscape transformations that presage the widespread destruction of forested ecosystems in many developing regions of the world today. And yet, despite the return of forest cover to an extent that may rival that of the presettlement landscape, there are many questions concerning the long-term impacts of land-use history on the structure, composition and spatial patterning of modern forests. Equally important are persistent legacies in biotic and functional characteristics of forest ecosystems that have developed as a consequence of human activity and historical changes in forest vegetation.

The New England landscape provides an opportunity to examine the long-lasting impact of extensive land use on forest ecosystems. Lessons learned from such an analysis may be applied towards understanding other parts of the world where forest cover has been substantially altered or removed and eventually recovered. In broad areas of Fennoscandia, eastern North America, and Central America the current cover of forest vegetation effectively obscures the evidence of the landscape transformations that have occurred as a result of intensive agricultural activity. In even larger portions of the developing world deforestation and forest ecosystem modification are presently occurring at a prolific rate. Thus, a major objective of this review of changes in the New England landscape is to provide information relevant to a general understanding of human impacts on forested regions.

A final objective is to focus in more closely on the social causes of the changes that have occurred in New England forests. Information on the economic, technological, and historical factors underlying human activity provides a context for understanding the changing pressures on forests in this region. Ultimately, it is hoped that a broader understanding of the dynamic changes in the landscape will provide a strong basis for guiding decisions on future research, conservation priorities and management activities of this forested area.

In reviewing the natural forest dynamics, human history and landscape transformation of New England this paper focuses on the states of Connecticut, Rhode Island, Massachusetts, Vermont and New Hampshire as they share many similarities in physical features, biological characteristics and human history. It excludes much of Maine, which differs greatly in terms of forest conditions and land-use activity. Most of the discussion deals with the upland heart of the region where most of the forested area occurs. However, the coastal and riverine lowlands were important regions of commercial enterprise and population density; activities in the lowland centers were inextricably interwoven with the transformations in the upland landscape (Cronon, 1991). These connections are commented on in this paper where relevant.

Following a brief review of regional characteristics, insights from paleoecological studies are utilized to highlight the dynamic nature of the precolonial vegetation in response to natural environmental change and disturbance. A detailed review of the history of colonial settlement and development of the New England landscape is then presented to provide the social context for understanding the resulting vegetational changes. Finally, the vegetational, faunal and ecosystem consequences of this human land use are outlined. This background is used to discuss potential future changes and areas for further study.

Regional Characteristics of the New England Landscape

Physical and biological features

The New England states, excluding Maine, form a roughly rectangular area 250 by 450 km in size that extends north and east from the Atlantic Ocean. Physiographically the region consists of seven broad areas, the coastal lowlands, inland uplands, the Connecticut River valley, the Champlain valley and the White Mountains, Green Mountains, and Taconic Mountains (Figure 1). These regions differ in bedrock geology, as well as general elevation and relief; however, with major exceptions in the Connecticut River valley and Taconic range the geological substrate is comprised of acidic, relatively nutrient-poor material. The entire region was glaciated until approximately 10-13 thousand years ago. Variation in the depth and texture of surficial materials is the result of local glacial geomorphology. In general the soils are shallow and bedrock is extensively exposed.

Substantial variability in regional climate results from elevational and coastal-inland gradients. Average annual rainfall exceeds 1000 mm and is evenly distributed through the year. Summer temperatures average 22°C (July) whereas winter averages drop to -4°C (January) in inland locations. Regional differences in growing season length exceed three weeks between southern coastal and northern locations. Within the region the broad valley of the Connecticut River provides a distinct environment due to its low elevation and the predominance of broad, level areas of glacial lake sediment, sandy deltaic material and floodplain deposits.

The regional vegetation changes latitudinally with local variation due to elevation in the Connecticut Valley and northern mountains (Figure 2). Northern hardwoods-conifer forest covers much of Vermont and New Hampshire, extending southward along the White and Green Mountains into northern Massachusetts. Important hardwood species in this forest include sugar maple (*Acer saccharum*), beech (*Fagus grandifolia*), yellow birch (*Betula alleghaniensis*), paper birch (*Betula papyrifera*) and red maple (*Acer rubrum*). Among the conifers, red spruce (*Picea rubens*) and balsam fir (*Abies balsamea*) are common in the north, whereas hemlock (*Tsuga canadensis*) and white pine (*Pinus strobus*) increase to the south. Southern New England forests (Central Hardwoods) include more oak (*Quercus alba, Q. velutina, Q. rubra*), gray birch (*Betula populifolia*) and hickory (*Carya ovata, C. cordiformis*) along with red maple and

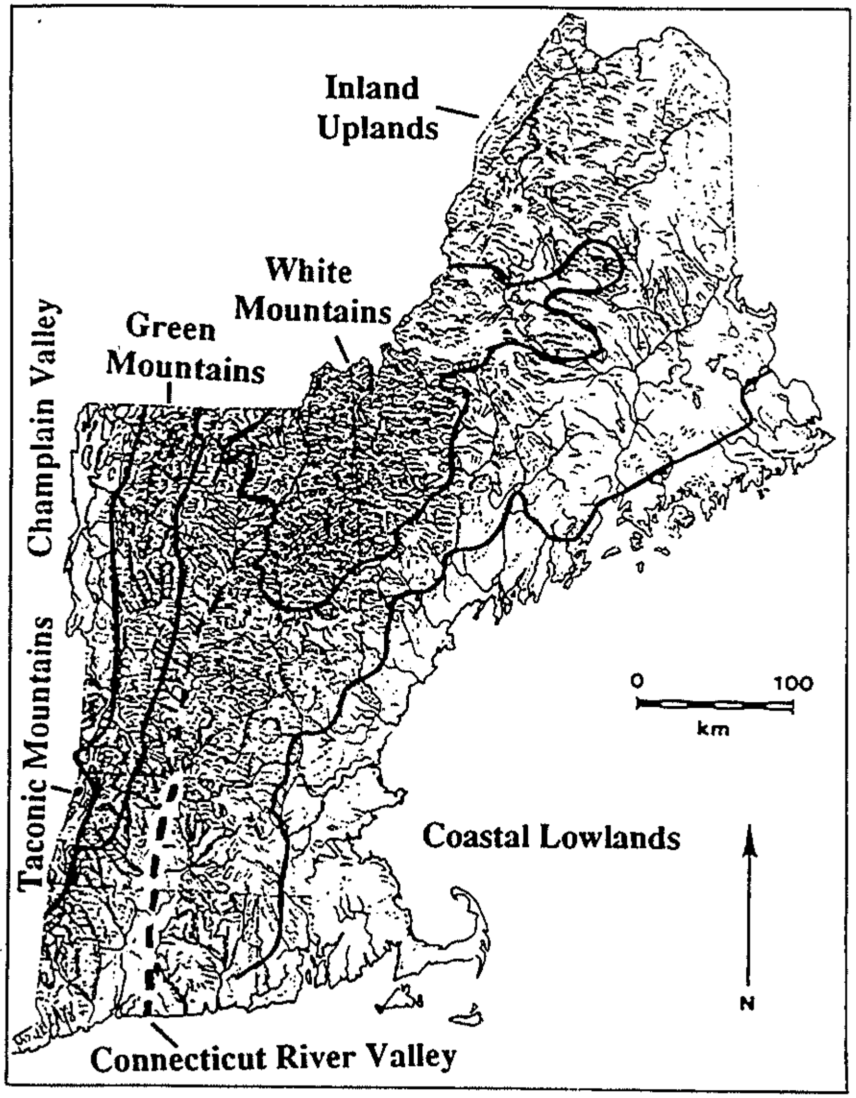


Figure 1. Relief map of New England depicting the major physiographic regions. Modified from Wright (1933) and Jorgensen (1977).

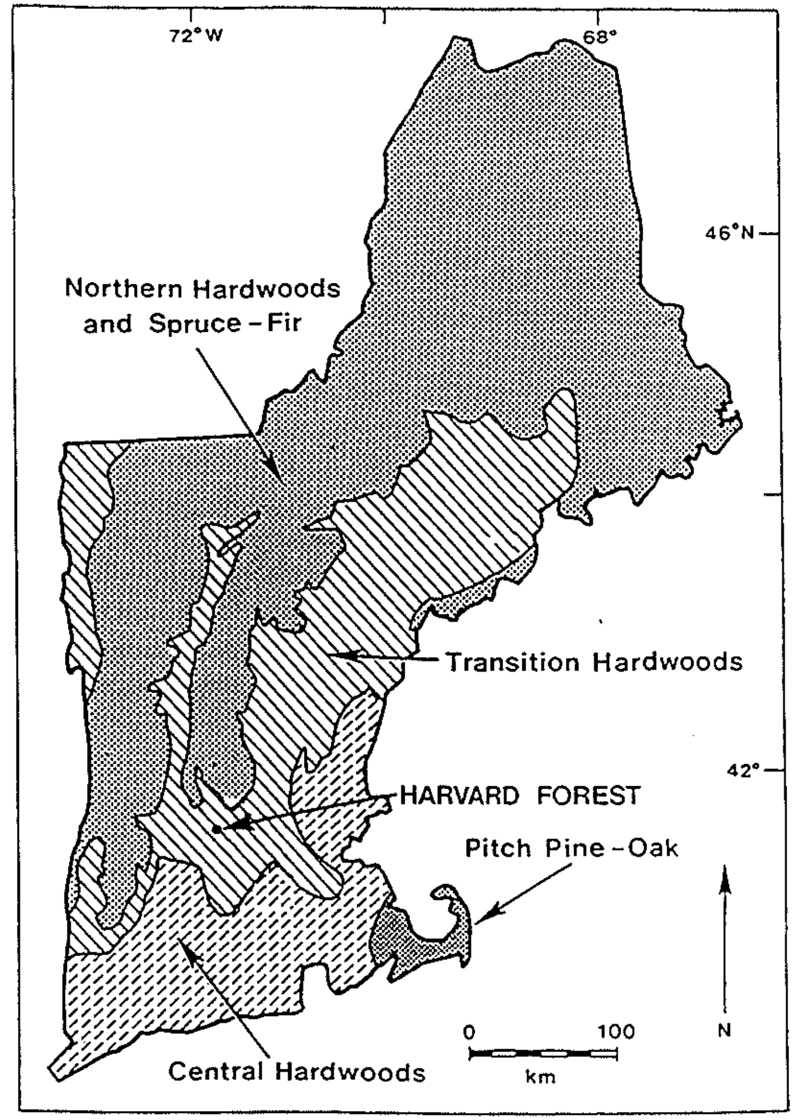


Figure 2. The major forest vegetation zones in New England. The Transition Hardwood forest extends far north along the low Connecticut Valley and in southern Maine. Northern Hardwood forest extends southward along the White and Green Mountains into northern Massachusetts. Glacial sandy deposits forming the area of Cape Cod support a xeric forest of pitch pine and scrub oak species. Modified from Westveld (1956).

community occurs across central Massachusetts, up the Connecticut River valley and through eastern New Hampshire. A distinctive vegetation of pitch pine (*Pinus rigida*) and oak (*Quercus ilicifolia, Q. stellata*) species occurs on sandy soils across Cape Cod and inland on outwash deposits.

Dynamics of the precolonial landscape

Any serious attempt to evaluate the role of European settlers in transforming the landscape of North America must establish the range of environmental conditions and dynamics of the vegetation during "presettlement times," when aboriginal peoples and natural processes shaped the landscape. Although the earliest historical accounts contain some insight on this period, they provide only a snapshot view that may be biased by the background or motivations of the recorder (Russell, 1980; Cronon, 1983; Crosby, 1986). In contrast, paleoecological studies provide a lengthy temporal perspective for evaluating vegetation and environmental conditions in a consistent manner from prehistorical through modern times. Specific topics addressed by the paleoecological record that pertain to the understanding of the impact of European settlement on the region include: the rate of presettlement ecosystem change, the role of non-climatic factors (e.g. natural and aboriginal disturbance processes) in altering terrestrial and aquatic environments, and the evolutionary context for the organization of plant and animal communities.

The paleoecological record from New England supports the viewpoint of environment and vegetation as dynamic on geological and ecological time scales (Watts, 1973; Davis, 1986; Hunter *et al.*, 1988; Huntley and Webb, 1989). Major environmental factors including climate have changed continuously in the recent past, though at variable rates. Coupled with natural disturbance processes, this dynamic environment has generated shifts in the overall ranges of many plants and animals and changes in the composition and structure of forest communities. These observations support the notion of plant and animal communities as aggregations of individualistic species responding to unique combinations of climatic, edaphic, biotic and historical factors (Fisher, 1933; Wright, 1977).

In New England vegetation and environment have varied continuously in time and space since the last glacial period (Figure 3). Following great changes in precipitation, temperature, and wind conditions in the millenia after deglaciation, temperate climatic conditions broadly similar to the present were established between 8-10 thousand years before present (B.P.). Thus the major modern forest zonations (e.g. conifer forest at

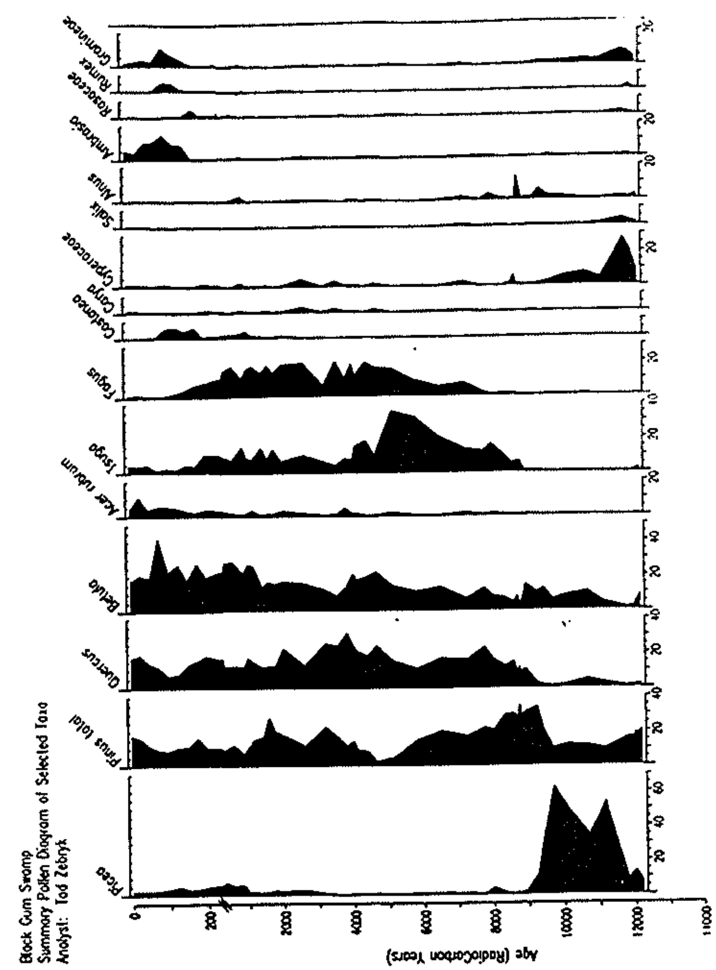


Figure 3. Pollen diagram from the Black Gum Swamp at the Harvard Forest in central Massachusetts depicting the major vegetational changes in the vegetation over the past 12 000 years. Tundra communities were replaced by boreal forest dominated by spruce until approximately 9200 years B.P. when pine and other tree species became important. Changes in relative abundance of species resulted from climate change, species migrations, disease (*Tsuga*) and fire until 250-300 years BP when European settlement resulted in major deforestation and the increase in agricultural weeds, herbs and successional species. Note vertical scale change at 250 years B.P. Modified from Foster and Zebryk (1993).

high elevations and latitude, mixed forest in central New England, and oak hardwood forest in southern New England) have been in place for approximately 8000 years. Since that time, however, climate has fluctuated through a series of long- and short-term trends. From 8000-5000 BP warmer conditions resulted in expanded northern ranges(e.g. white pine across Ontario; Björck, 1985) and increased elevational range of some temperate species (e.g. hemlock and white pine in the White Mountains), and decrease in abundance of boreal species (e.g. spruce; Davis, 1985). Climatic conditions during this 3000-year period include decreasing precipitation and an increase in the mean annual temperature of approximately 2°C, but with warmer summers and cooler winters than today (Davis, 1986). During this warmer, drier period many of our common tree species (*Acer rubrum, Tsuga canadensis, Fagus, Carya* spp.) migrated into southern or central New England, and a number of sites experienced higher fire frequency (Davis, 1985; Patterson and Backman, 1988).

Progressive cooling of the climate over the last 4000 years has been detected throughout the northeastern United States (Davis, 1958, 1985; Gajewski, 1987, 1988; Webb, 1988) with the most significant vegetational changes occurring in the last 2000 years (R. B. Davis *et al.*, 1975). A reduction in the elevational and latitudinal range of many taxa was accompanied by regional increases in spruce 2000 to 1000 years ago (*Picea mariana* and *P. rubens*; Gaudreau and Webb, 1985; Gajewski, 1987; Foster and Zebryk, 1993), and a broad decline in the abundance of hemlock and beech at many sites within the past 400-1000 years (Figure 3; R. B. Davis *et al.*, 1975; Backman, 1984; Bennett, 1985; Gaudreau and Webb, 1985, Whitehead and Jackson, 1990; Foster and Zebryk, 1993). One important though somewhat enigmatic change during the past 3000 years is the migration of chestnut through southern New England to its present range limit in southern Vermont and New Hampshire (Paillet, 1982; Russell, 1983; Bennett, 1988b).

Natural disturbance processes

Throughout the presettlement period disturbance processes including fire, wind, and pathogens have altered the vegetation but with variable frequency and intensity across New England. Collectively these disturbance processes exerted a profound impact on the local distribution of species, the landscape mosaic of vegetation and the regional characteristics of forests (Fisher, 1933; Cline and Spurr, 1942).

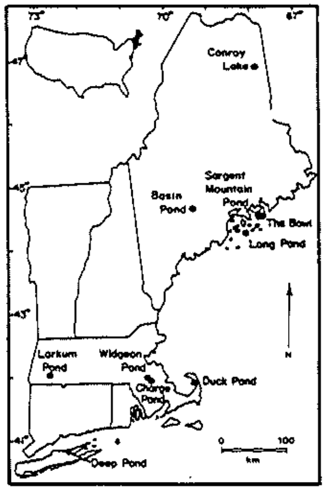
Fire

Fire was the most prevalent disturbance process, with its importance controlled geographically by climatic conditions, fuel abundance, and ignition potential (lightning and aboriginal populations). Analysis of the charcoal and pollen content of lake sediments suggests that the frequency and overall importance of fire in New England decreased inland and northward from coastal areas (Figure 4; Patterson and Sassaman, 1988; Patterson and Backman, 1988). In the sandy and dry environment of Cape Cod, the coastal islands and southeastern Massachusetts, fires were frequent and maintained an open oak and pine forest (Backman, 1984; Winkler, 1985; Dunwiddie, 1989). Lower fire frequencies are recorded in coastal Maine (Backman, 1984), southern Connecticut, and east-central Massachusetts (Davis, 1969; Winkler, 1985) and evidence of fire is nearly absent from the northern hardwood forest in western Massachusetts (Backman, 1984) and the White Mountains (Davis, 1985). A recent study in central Massachusetts, albeit from a low-lying and moist site that should be relatively protected from burning, documents fires approximately every 1000 years (Foster and Zebryk, 1993). Thus a general trend of decreasing fire is apparent along climatic gradients (dry and warm to moist and cool) and vegetational gradients (oak and pitch pine to central hardwoods to northern hardwoods and spruce-fir). However, a comprehensive evaluation of the ecological role of fire in New England is currently precluded by the very low density of sites. For example, there is no basis for examining trends related to higher Indian populations in coastal areas, the major river valleys, or the Champlain Basin in Vermont. Nor is it possible to evaluate local differences in fire regime as controlled by physiography, vegetation pattern, and soil.

Fire undoubtedly exerted an impact on the vegetation at many scales. Regionally, frequent fires in southern coastal areas would favor a greater proportion of fire-adapted sprouting species, including oaks, hickory, birch, chestnut and pitch pine. Indeed palynological and historical evidence indicates a decrease in many of these species with fire control (Whitney and Davis, 1986; Abrams, 1992). Locally, the distribution of individual species may have been determined by their susceptibility to fire. Studies have suggested that hemlock, a highly fire-sensitive species, may have been restricted to mesic, protected sites across southern New England due to frequent surface fires (Bromley, 1935; Cline and Spurr, 1942; Niering and Goodwin, 1974; Davis, 1981a).

Impacts of Indian Land Use

Archaeological evidence indicates a regional gradient of Indian population density and impacts paralleling that of fire frequency: decreasing from coastal and southern



Pond/Lake	Location	Charcoal: Pollen Ratio Average Precolonial	Average Postcolonial	Ratio Post: Pre
Larkum	Massachusetts (central-inland)	27.5	190.5	6.9
Basin[1]	Maine (north-inland)	80.9	385.5	4.8
Conroy[1]	Maine (north-inland)	38.7	291.1	7.5
The Bowl	Maine (north-central)	123.4	390.9	3.2
Sargent Mountain	Maine (north-central)	131.3	161.2	1.2
Long	Maine (north-coastal)	151.9	320.9	2.1
Deep	New York (south-coastal)	650.1	1040.2	1.6
Duck[2]	Massachusetts (central-coastal)	250.7	160.7	0.6
Charge	Massachusetts (central-coastal)	713.9	2895.0	4.1
Widgeon	Massachusetts (central-coastal)	580.7	968.2	1.7

[1] Data from Winkler (1982) as modified from Swain (1981).
[2] Values are approximately 50% low due to problems differentiating small particles from pyrite.

Figure 4. Location and average charcoal abundance of sedimentary fire-history studies in the northeastern United States. There is a general trend of increasing precolonial charcoal abundance from inland and northern sites to coastal and southern sites. Most sites exhibit an increase in charcoal abundance following European settlement. Modified from Patterson and Backman (1988) and Patterson and Sassaman (1988).

regions to the north and from major river basins into highland areas (Figure 5). Along the latitudinal gradient there is a shift from a partial reliance on agriculture to primarily hunting and gathering (Patterson and Sassaman, 1988). The hilly and mountainous regions of interior Vermont and New Hampshire were probably subjected to the least impact by Indian land use.

Agriculture came very late to the eastern woodland Indians and may have involved short fallow or semipermanent cultivation that generated a mosaic pattern of fields, abandoned garden and village sites, and intact forest (Doolittle, 1992). Although early historical accounts abound with descriptions of local forest clearance around Indian villages, there is little evidence that aboriginal activity exerted an impact on the broad-scale pattern of vegetation as would have occurred for example through extensive slash-and-burn agriculture (Burden *et al.*, 1986a/b; McAndrews, 1988; Patterson and Sassaman, 1988). To date there is no conclusive paleoecological record of Indian modification of the New England forest landscape. Even in coastal regions where Indian population densities were presumably highest there is a general absence of the pollen of cultivated plants or fluctuations in weedy and early successional species that would suggest extensive forest clearance and farming (Winkler, 1985; Dunwiddie, 1989).

Wind Damage and Pathogens

Wind damage and pathogens are natural disturbance processes of regional importance in the precolonial landscape. Soil evidence of the uprooting of forest trees extends back nearly 1000 years and documents the ubiquity of wind damage in northeastern forests (Fisher, 1933; Stephens, 1955; Lyford and MacClean, 1966). The relative importance of different types of wind damage apparently varies across New England, with downbursts and northwesterly storms more important in northern New England and tropical storms increasing to the south (Hosier, 1969; Bormann and Likens, 1979; Foster, 1988 a/b). Historical analysis indicates that hurricanes may occur with a frequency of one major storm every 50-100 years and a decreasing gradient of importance across New England from southeast to northwest (Figure 6; Foster and Boose, 1992; Boose *et al.*, 1993). General considerations of the meteorological characteristics of tropical storms suggest that catastrophic storms may be restricted to pathways similar to the hurricanes in 1815 and 1938, which would constrain the strongest winds to those coming from the south and east and going in a northern direction (Foster and Boose, 1992). Thus, there may exist some predictability in landscape-level exposure to tropical winds, with level, south- and east-facing slopes being most exposed and steep northwesterly slopes protected (Boose *et al.*, 1993). The absence of specific stratigraphic markers associated with wind

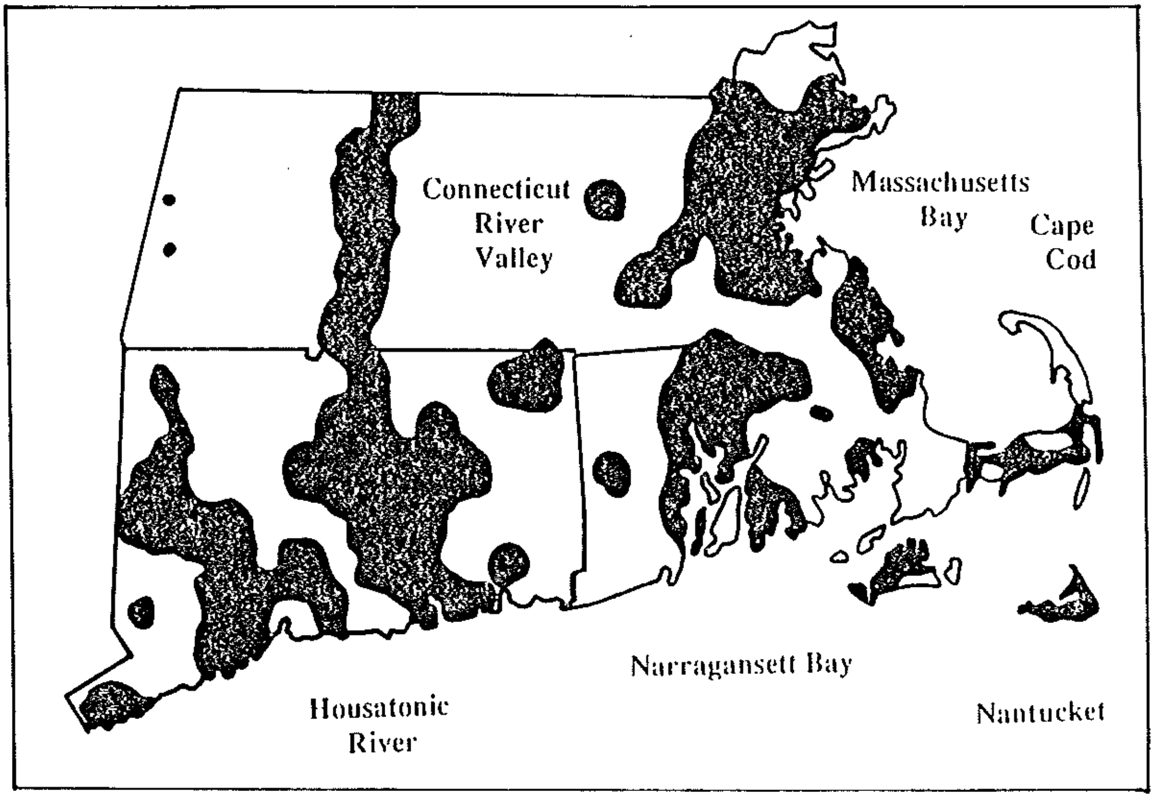


Figure 5. Areas of concentrated aboriginal populations in southern New England during the Late Woodland period (A.D. 1000 - A.D. 1600) preceding European settlement. Populations were concentrated along major river valleys, the coast and the larger islands of Nantucket and Martha's Vineyard and were low across broad upland areas. Modified from Patterson and Sassaman (1988).

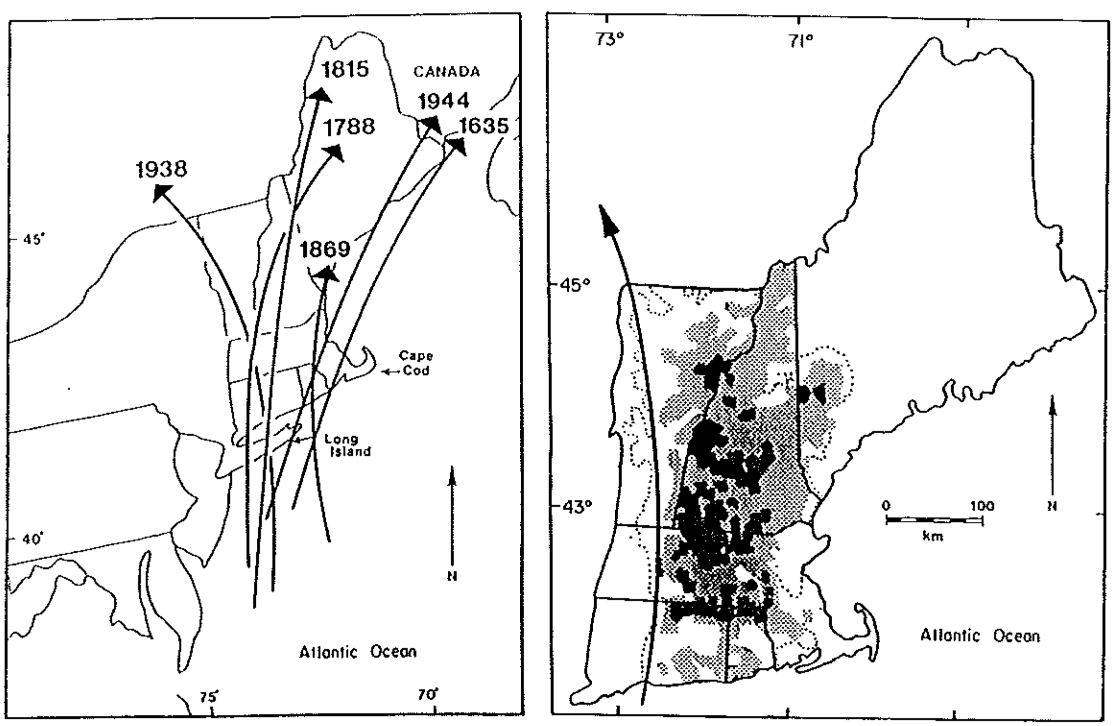


Figure 6. Paths of the major hurricanes that have impacted New England from 1600 to present (a) and the damage inflicted on forests in the region by the 1938 hurricane (b). Damage is indicated in four categories: black -extreme; stippled -moderate; white within enclosed line - slight. Approximately 3 billion board feet of timber were windthrown by the storm, more than 600 lives were lost and damage costs exceeded $100 million. Modified from Smith (1946) and Foster (1988b).

damage will make it difficult to verify these broad conclusions over presettlement times using paleoecological techniques (Foster and Zebryk, 1993).

For pathogens there is but a single putative presettlement event, but it was of broad-scale and long-lasting importance. Starting approximately 4800 BP there occurred a major and apparently synchronous decline of eastern hemlock across its range (see Figure 3; Davis, 1981a; Webb 1988). The rapidity of the decline, its similarity to the impact of the chestnut blight, and its apparent independence from climate change or decline in other species, lead Davis (1981; Allison *et al*,. 1986) to identify it as the result of a pathogen. One possible candidate is an insect like the eastern hemlock looper, which is currently decimating kilometer-wide areas of hemlock across central Massachusetts.

Hemlock persisted during this period in low population levels throughout its range (Davis, 1981b; Allison *et al.*, 1986; Foster and Zebryk, 1993) and recovered to approximately its former abundance in 1000-1500 years, evidently through the evolution of resistance to the pathogen. A number of important observations concerning forest response to pathogens can be drawn from this event: (1) the reorganization of communities after this event differed regionally, and took 400-500 years; (2) hemlock eventually recovered to its original abundance in some locations but in general was reduced somewhat due to the importance of new species that had immmigrated during the interim, or to slight changes in environmental conditions; and (3) significant ecosystem-level changes occurred at many sites, in terms of altered soil characteristics and chemistry, changes in stream water and aquatic processes, and varied forest structure (Whitehead, 1979; Davis, 1985; Ford, 1990; Whitehead and Jackson, 1990).

Insights from the Precolonial Landscape for Understanding Modern Ecosystems

Major lessons from paleoecological studies that pertain to the understanding of the environmental setting encountered by European colonists and their impact upon these ecosystems are manifold: (1) both the environment and the biotic communities arrayed across the New England landscape have a dynamic presettlement history (Fisher, 1933); on an ecological time-scale forest communities never reached a long-term equilibrium; (2) once perturbed by natural disturbance or climate change vegetational adjustment is long-lasting, e.g. on the order of 400-500 years (Foster and Zebryk, 1993); (3) most of the human and natural disturbance processes in pre-colonial times were infrequent and distributed in a geographically uneven pattern controlled by climate, physiography and possibly the distribution of aboriginal populations; and (4) the forest communities

encountered upon European settlement had been established for only approximately 2-3 thousand years and were comprised of species that evolved under rather dynamic edaphic and environmental conditions (Spear, 1989; Whitehead and Jackson, 1990).

European Settlement and Expansion in New England

From well-established coastal settlements, European colonists expanded northward and inland through New England at an uneven pace (Figure 7; Monroe *et al.*, 1980; Donahue, 1983). Due to the absolute reliance of early settlers on agriculture, topography exerted a strong influence on migration and settlement patterns. Initial expansion in Connecticut occurred along Long Island Sound (Atlantic Ocean), and northward along the river valleys of the Thames, Connecticut and Housatonic. This was followed much later by gradual dispersion into the northwestern and northeastern highlands. After the end of Queen Anne's War (1713) settlement progressed west and northward across Massachusetts and in 1725 the General Court of Massachusetts commenced using land grants to pay debts, especially for military service (Clark, 1983); the highlands of Massachusetts were allocated in this manner by 1760 and settlers from southern New England began moving into central and northern Vermont by way of the Champlain and Connecticut River valleys. The more rugged and remote areas of the northeastern highlands and Green Mountains were not settled until the 1820s.

Agricultural Development of Upland New England

In the approximately two to three centuries that have elapsed since European settlement, the interior and non-urban regions (primarily upland, hill country) of New England underwent a series of dramatic changes in population density and distribution, social organization and economic base that have exerted long-lasting impacts on the natural environment. Although time-transgressive across the region, often occurring earlier in the south and near the coast, many of these changes were part of regional and generalizable transformations (Figures 8 and 9; Cronon, 1983). Some of the changes occurred rapidly and were true revolutions, in terms of their alteration of lifestyles and their ecological consequences (Merchant, 1989).

Most towns were carved *de novo* from Indian lands with an initial objective of establishing adequate numbers of settlers and agricultural areas for self-sufficiency. In the seventeenth century, towns were initially based on the European model of a centralized and common field system (Donahue, 1983; Garrison, 1985). However, this

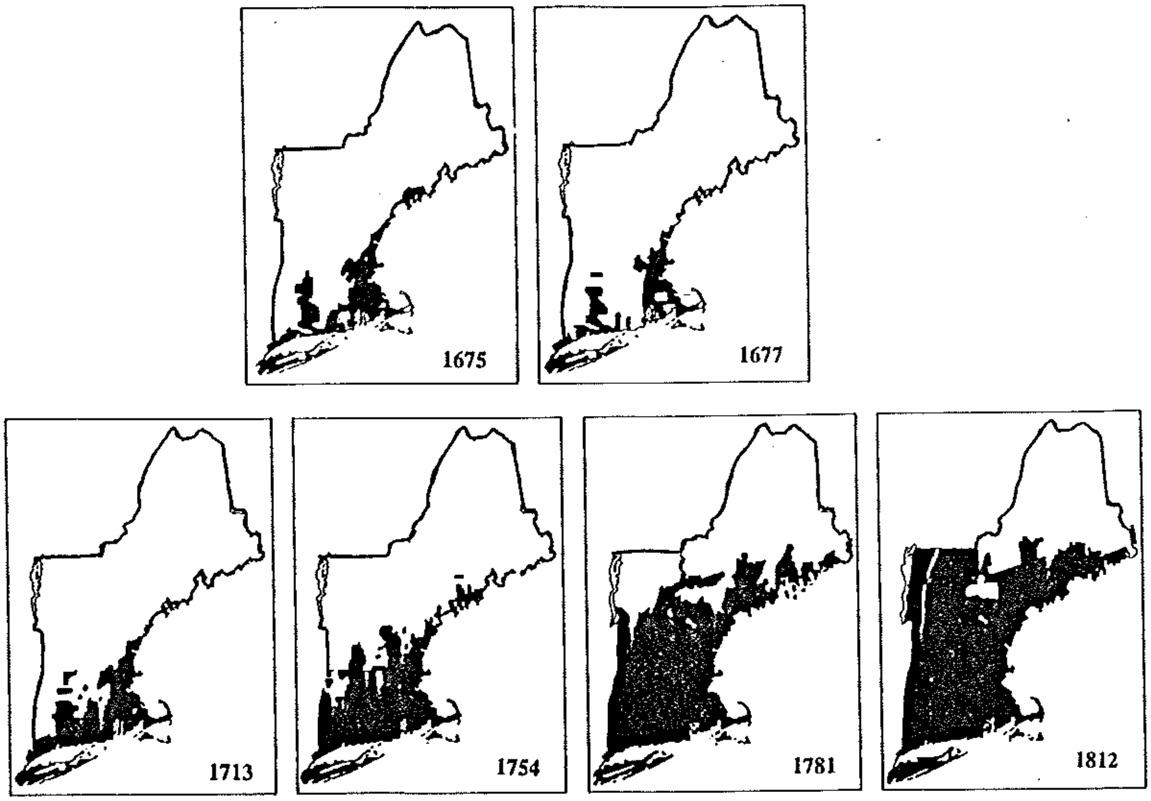


Figure 7. Expansion of the New England frontier from the late 17th century to 1812. Note the initial concentration along the coast and Connecticut River valley during the period of the Indian wars in the 1670s, followed by rapid expansion. From Robinson (1988).

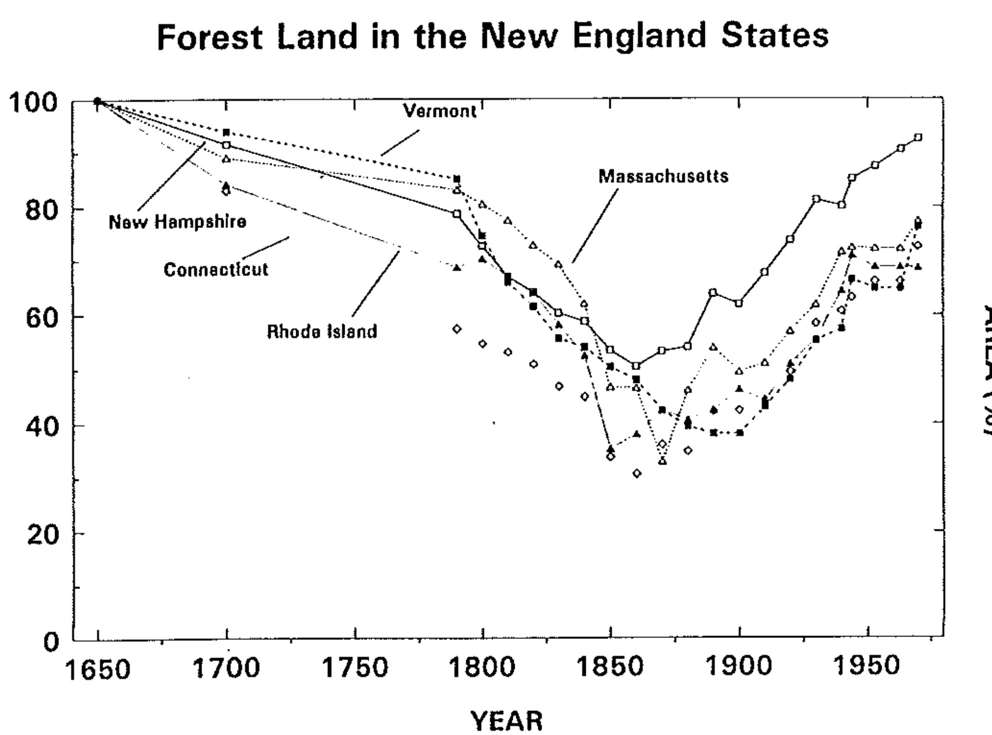


Figure 8. Historical changes in the extent of forest cover in the New England states, excluding Maine. Despite environmental, geological, biotic and social variation across the region, the timing and extent of deforestation and reforestation are remarkably similar. Data were compiled by E. M. Gould, Jr. from the U.S. Census, Baldwin (1942) and unpublished sources.

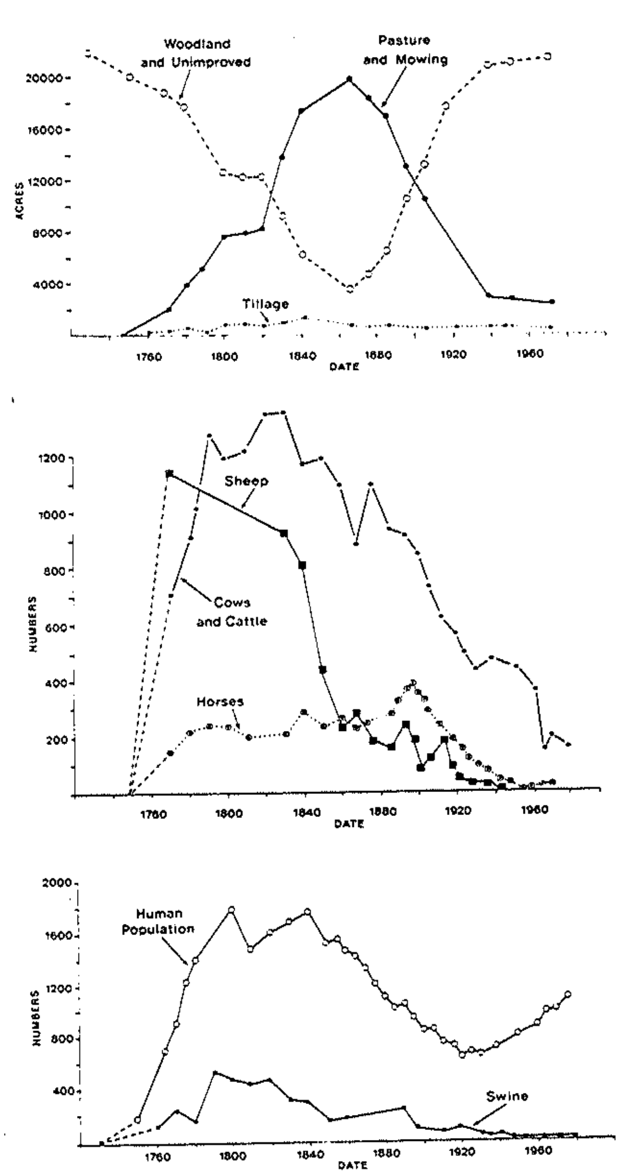


Figure 9. Historical changes in land-use, domestic and human population for the town of Petersham in central Massachusetts. Data are from Petersham tax records and the U.S. Census.

organizational pattern was abandoned in the early eighteenth century in favor of a uniquely New England model of dispersed settlement and individual ownership of private land. Towns (the entire area of a township) were approximately 6 x 6 miles, which represented a practical size in an era of foot transportation, such that all inhabitants were easily within one hour of the village center, the meetinghouse, and church (Gould, 1978). With the General Court providing land, the first years in a town's history were usually marked by land speculation and trading, with few of the original proprietors actually settling on their land (Willson, 1855; Gates, 1978).

In the hilly uplands, hilltops were often selected for the village center and initial clearing as they supported the best agricultural soils characterized by good drainage and relatively few stones (Botts, 1934; Bogart, 1948; Black and Wescott, 1959). In contrast, settlers in broad valley areas took advantage of the level and easily tilled plains for much of their agricultural activity. Land was cleared through girdling and cutting of trees, followed by the burning of slash and wood and the planting of successive grain crops and then corn (Preston, 1822). Land use was determined by a careful reading of the land based on topography, moisture and forest vegetation and frequently assisted by extensive trial and error (Belknap, 1792). In highland area of New England, individuals were documented as initially clearing 0.5-2.0 ha of forest per year for agriculture (Raup and Carlson, 1941; Bogart, 1948).

Through much of the eighteenth century dispersed, low-intensity agriculture and home- and village-based artisanship were the dominant employment, family occupation and economic base of rural New England (Gates, 1978; Garrison, 1985). Populations were dispersed and low (e.g. 20-35 per km^2). Farmers developed their holdings of 10-40 ha into a mixture of woodland (10-25%), woodland-pasture (10-25%), open pasture (50%) and a limited extent of arable land (< 10%) for grain and diverse crops (Figure 9; Garrison, 1987; Raup and Carlson, 1941). Few individuals maintained the livestock, land base or equipment necessary for all of their own needs; however, in the aggregate and through cooperation and exchange, townships were largely self-sufficient (Pruitt, 1981). All towns supported diverse artisans, shops, mills (for grain, wood and linen) and tanneries (Pewson, 1895). Roadnets were developed primarily for internal circulation and provided relatively poor access to distant markets (Raup and Carlson, 1941). Despite these drawbacks, the amount of trade and travel noted in farm journals of the day was remarkable (Stabler, 1986). Beef (self-transportable; Gates, 1978) and potash provided the major exports from hill towns (Bogart, 1948; Multhauf, 1981), timber was a more important commodity along watercourses, and diverse agricultural products originated from the large river valleys (Gates, 1978; Rothenberg, 1981; Garrison, 1985). Regional markets included Boston, New York, Montreal, Hartford and Providence and international trade was substantial (Pabst, 1941; Pruitt, 1981; Baker and Patterson, 1986).

Commercial Farming and Industrialization

From the late 1700s through the mid-to-late 1800s the economy, social organization and landscape of New England underwent a complete transformation (Pabst, 1941; Merchant, 1989; Baker and Izard, 1987). This period embraced a shift from home production and local consumption to a market farm economy leading to commercial and intensive agriculture (Bidwell, 1916; Bogart, 1948; Kimenker, 1983; Garrison, 1985). During this period an extensive transportation infrastructure developed through road construction and improvement and the building of canals and railroads (Rothenberg, 1981). New village centers were established and urban areas were developed based on water power and industrial activity. In response to the availability of new markets for agricultural goods, New England farmers responded with increased production. This was accomplished through accelerated clearing of forest land, including marginal sites, and through land improvement by drainage (Torbert, 1935; Barraclough, 1940).

Beef and wool production remained preeminent until canal and rail connections with the west and the relaxation of wool tariffs in the 1830s-1840s reduced profit margins on these commodities (Pabst, 1941). Farming was a productive enterprise for full-time employment or in combination with small-scale production of manufactured goods. Most farm families (e.g. > 50% in central Massachusetts; Raup and Carlson, 1941; Gould, 1950) also engaged in home production of shoes, hats, or clothes and many farmers derived additional income running tanneries, sawmills or gristmills (Mann, 1889; Baker and Patterson, 1986). Local industry thrived. For example, in the mid-1840s Petersham, Massachusetts, a town of approximately 1800 individuals, supported two wheelwrights, a button factory, four shoemakers, a laddershop, carriageshop, two stores, ten sawmills, two gristmills, three tanneries, six blacksmiths, a cidermill and a cooper: a diversity of enterprise matched throughout the region (Brown, 1895; Fiske, 1979). This was a period of maximum agricultural activity, population density, and commerce in the hill towns (Willson, 1855; Raup and Carlson, 1941), as well as the beginning of industrial concentration. Many towns literally moved downhill, either relocating their village center along river banks or establishing separate village sites in order to utilize water power (Botts, 1934; Torbert, 1935; Gould, 1950; Robinson,

1988). The factories, which started small and employed local residents and new immigrants, progressively grew to become a major source of northern textiles and wooden products (Botts, 1934; Meeks, 1986).

The 1830s and 1840s oversaw a revolution in transportation as railroads and canals provided regional and interregional movement for people and goods. It has been estimated that prior to 1820 the cost of shipment for one ton of material 20 miles by road in New England was equivalent to the fare for movement of the same material from Boston to London (Pred, 1966). Efforts to provide inexpensive railroad connections began in Massachusetts in 1835 with the construction of the Boston-Worcester Railroad and the subsequent Boston-Albany line across the Berkshire Mountains into New York State. At the end of the 1830s the United States railroad system consisted of a mere 2800 miles of disjointed line; by 1860 it comprised a well-articulated network of 30 600 miles (Pred, 1966). Canals linked the midwest through Lake Erie (1824), Lake Champlain to the Hudson River (1822), Providence, Rhode Island to Worcester, Massachusetts (1828), and provided flat boat access up the Connecticut River to central Vermont (Meeks, 1986). The mania for canal construction prompted efforts to connect regions across extreme obstacles; for example serious but never realized plans were laid to connect the Connecticut and Champlain Lowlands via the 800 m divide across the Green Mountains in Vermont. When successful, such projects provided access to new markets and encouraged the exponential growth of the valley towns that they reached; however, reverse flow of new products and alternative sources of goods from distant areas provided competition for New England farmers. Through the period 1850-70, much of New England was eventually integrated into the national economy and distribution network (Meeks, 1986; Merchant, 1989).

Agricultural Decline and Specialization

Transportation, technological improvements and social changes tied to the Industial Revolution produced major transformations in agricultural and industrial areas of New England (Black and Wescott, 1959). The availability of inexpensive western grain (e.g. corn imported from the midwest in 1840 cost $.10 per bushel in Peacham, Vermont, versus an estimated cost of $.75 for local grown; Bogart, 1948), beef, and other agricultural goods resulted in a decline in diversified farming and specialization on bulky or perishable crops including dairy products, fruit, vegetables, poultry, hay and firewood for the growing urban markets (Chase, 1890; Currier, 1891; Davis, 1933; Donahue, 1984; Baker and Izard, 1987). Crop specialization was determined by distance and transportation to markets: urban towns and their adjacent areas concentrated on cordwood, market crops and milk, more distant towns shipped butter, cheese and hay (Pabst, 1941; Baker and Patterson, 1986).

Growing industrial activity in valley towns and large mill towns (e.g. Worcester and Lowell, Massachusetts, the Naugatuck Valley, Connecticut and Providence, Rhode Island), coupled with a good distribution system eliminated much of the need for local production and artisanship. The result was the closure of many village shops and small factories and a decline in the home-production system, beginning as early as 1850 in central Massachusetts and 1870 in northern Vermont (Raup and Carlson, 1941; Bogart, 1948; Thorbahn and Mrozowski, 1979). A major demographic shift began as especially the young left farm villages for the cities and the midwestern states (Pabst, 1941; Gates, 1978; Barron 1984). In Vermont, between 1840 and 1900, 42% of the towns experienced greater than a 25% decline in population (Robinson, 1988). In this period 40% of the natives emigrated from the state and the urban population increased over 80% (Barron, 1984). Throughout New England this period of agricultural and industrial specialization was accompanied by a concentration of population, energy, and human activity (Figure 10). Paralleling the demographic shift, there occurred widespread abandonment of farmland; between 1850 and 1900 approximately nine million acres of new forest established naturally on former farmland in New England (Barraclough and Gould, 1955). In Vermont, New Hampshire and Maine two million acres of cleared land were reforested from 1880-1900 and more than 11 000 farms were abandoned (Robinson, 1988).

There were many causes for the decline in rural agriculture, small industry and population; however, changes in the fertility of the land was not prominent among them (Black and Wescott, 1959; Raup, 1966; but see Donahue, 1983). New England farms were productive, farmers were prosperous (Raup and Carlson, 1941), and even at the peak of agricultural abandonment the productivity of New England farmland compared favorably with other parts of the country (U. S. Census, 1880; Bell, 1989). In fact, there is evidence that the quality of tilled land improved through the eighteenth and nineteenth centuries in hill towns (Jones, 1991).

There were disadvantages to New England land; for example, the soil is stony and small field sizes were not conducive to the scaled-up agricultural practices accompanying increased mechanization. However, the major factors operating in the agricultural decline appear to have been largely external to the land. These primarily social factors included a growing attraction to the life, jobs and financial benefits of cities and industrial activity, a declining interest in agricultural lifestyle, a decrease in economic opportunities in small

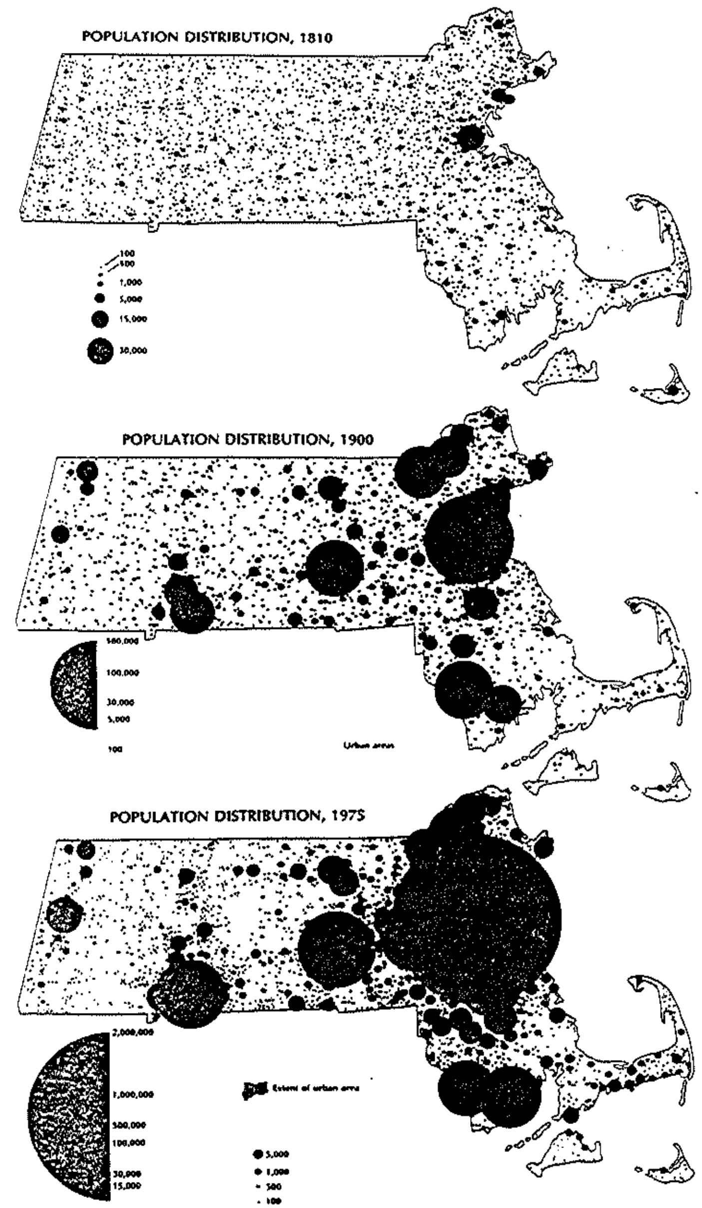


Figure 10. Historical changes in population distribution in Massachusetts. In the agricultural period (1810) density was low (412 000 inhabitans) and remarkably evenly distributed (79% in rural areas), with the exception of Boston, Salem and a few other coastal communities. With industrialization into the 20th century there has occurred a tremendous increase and concentration of population into urban and suburban centers. In 1975, 85% of the population of 5.8 million individuals were located in urban areas. Many of the rural communities have actually undergone a great decline in population during the past 100 years. Data from the U.S. Census with maps modified from Wilkie and Tager (1991).

towns, and the opening of new lands in the midwest and far west (Gould, 1978; Garrison, 1985). The young left the farms but many of the prosperous farm families also relocated (Mann, 1889; Barron, 1984).

Rural Transformations During the Last Century

As the populations of rural towns declined there was a parallel reduction in the local tax base (Willson, 1855; Gates, 1978). Land could be purchased at auctions or bank sales on speculation, for consolidation into adjoining farms, and for second homes by urban dwellers (Brown, 1895; Gates, 1978). Attempts were made to revitalize the towns through agricultural societies, the promotion of tourism (Robinson, 1988) and local efforts like the establishment of Old Home Days seeking to draw former residents and departed children back to their native towns. However, many hill towns were gradually reduced to a residual group of permanent residents and an expanded seasonal population (Black and Brinser, 1952). Miles of stone walls, old cellar holes and abandoned roads in a forested landscape testified to the old agrarian past. This decline contrasted markedly with the phenomenal growth of nearby mill towns.

The newly formed forests gave rise to new activity based on a wide variety of forest products, including timber, furniture and especially shipping containers. Fields seeded into white pine, which provided excellent material for boxes, crates and barrels. The old road system provided access for logging operations throughout the backwoods, the advent of the portable sawmill enabled work on remote forest stands and the rural landscape provided an underemployed population for woods work (Gould, 1978). The result was an unprecedented level of cutting activity; by the peak in 1909-1910, approximately 2.5 billion board feet of timber were being cut annually (Figure 11; Hawes, 1953). The timber boom generated increased land trading and speculation (Gates, 1978; Behre, 1932), but also resulted in the cutting of the last virgin stands in southern New England and the production of a largely even-aged forest of low quality. As the better forests were all cut, and alternate forms of packaging were developed, the intensity of cutting decreased.

Since World War II the urbanization of New England has continued (Meeks 1986). Villages and towns within an hour of expanding urban and industrial areas have been strongly affected by suburbanization. Small towns elsewhere have been influenced by the secondary house market and a rising interest in country living (Fiske, 1979). Tremendous expansion of the interstate highway system has greatly reduced travel time throughout the region and furthered the influence of suburbs on the rural landscape.

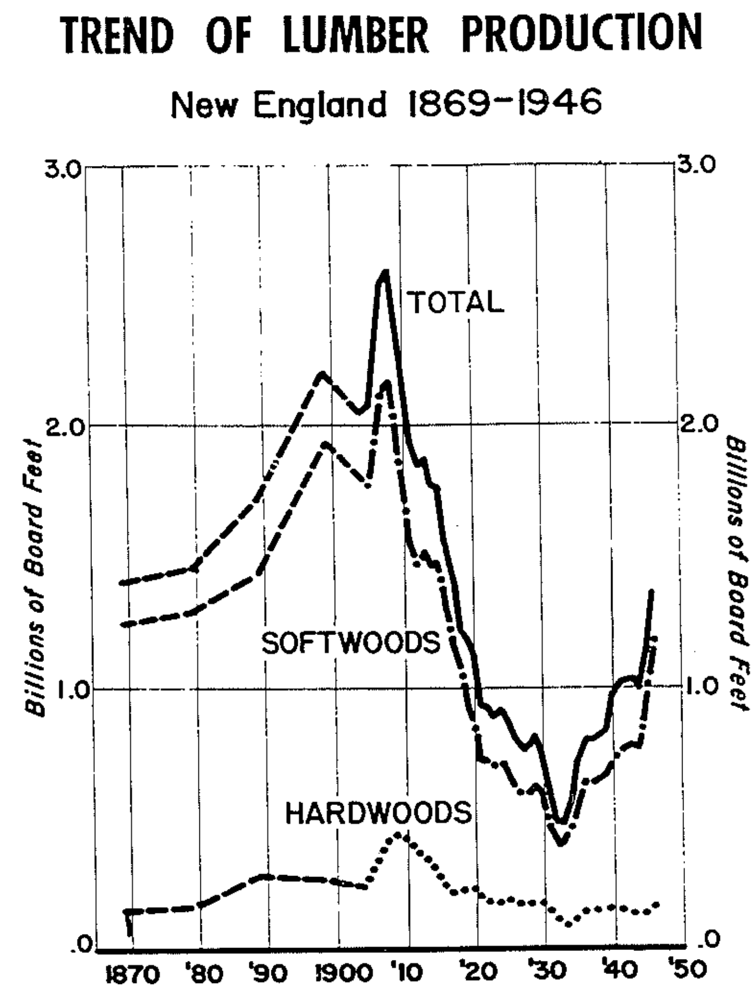


Figure 11. Changes in lumber production in New England through the period of farm abandonment and industrialization. The increase in softwood harvesting during the late 19th and early 20th centuries included substantial quantities of white pine growing on abandoned farm fields. Data from Baldwin (1949).

Many of the mill and valley towns and even leading cities of the industrial revolution have been drastically changed by international competition and resulting high levels of unemployment. The forest landscape, however, continues to receive less intensive use. The scattered farming that does occur is largely monoculture (e.g. dairy cows), limited in geographical scope, and yet generally more productive than ever (Rozman and Sherburne, 1959). Concentration on the best lands, high quality imported feed, and better breeding have resulted in decreased numbers of farms, farmland and even cows with little reduction in production (Meeks, 1986). Although the modern demand for lumber is the greatest in history, production is near the lowest in the past century (Dunwoody, 1974). Meanwhile, New England's wood products are being provided substantially from outside sources while the local timber base continues to increase (Gould, 1966).

Forest and Ecosystem Response to Land-use History

An assessment of historical changes in the forest conditions of New England faces numerous challenges: (1) the precolonial ecosystems were dynamic and thus there are no baseline or pristine conditions with which to compare; it is a continual problem to separate out effects of human activity from those of natural disturbance, climate change, and forest growth (Spurr, 1950; Raup, 1979; Hunter *et al.*, 1988; Sprugel, 1991); (2) no good examples of unaltered forests exist for comparison due to the long and pervasive impact of altered disturbance regimes, introduced pathogens, modified animal populations, and changed atmospheric conditions; and (3) there is an absence of consistent historical documentation.

Nevertheless, it is clear that European settlers introduced novel disturbances of a magnitude, frequency and intensity unlike processes operating in the presettlement landscape. Thus it is valuable to evaluate the available evidence concerning the role and nature of changes in forest communities over the past 200-300 years and to compare them to evidence from the time of settlement or the paleoecological literature.

Changing extent of forest land

Considerable regional variation exists in the timing and extent of changes in the forest area across New England. For example, large portions of the Connecticut River Valley were settled and cleared by the late seventeenth century and remain open today whereas the adjoining uplands, settled later, have gone through a complete cycle of deforestation

and reforestation (Garrison, 1987). In contrast, suburban areas around Boston, Providence and Hartford are undergoing a secondary deforestation and fragmentation as second-growth forests are being cleared for housing developments and commercial activity (MacConnell, 1975).

Despite this variability the regional pattern of deforestation and reforestation is remarkably consistent (Figure 8). With the exception of Maine, where large northern tracts have never been cleared, each of the New England states shows a major decrease in forest area through the late 1700s, a peak of open, agricultural land from 1830-1890 when only 20-40% of the uplands remained forested, and rapid reforestation through the late nineteenth and early twentieth centuries. The northern states (Vermont and New Hampshire) lag somewhat behind those to the south in terms of the timing of these trends. At present, the New England states range from 65-85% forested. Within this regional setting the upland hill towns, like Petersham, Massachusetts, present an extreme. Settled late relatively to much of eastern Massachusetts, Petersham was cleared rapidly for agriculture (Figure 9). The maximum extent of cleared land (approximately 85%) greatly exceeded that of the state on the whole and the process of reforestation on abandoned land proceeded much more rapdily.. Today Petersham is 95% forested, compared to the state average of 70%.

Changes in the pattern of forest land

Very little is known about the detailed pattern of deforestation and reforestation within any region of New England and thus we have a very incomplete understanding of what the landscape distribution of forests was at different periods of time. Historical information and a consideration of agricultural activity indicates that local clearing occurred outward from established homesteads and roads towards the back of individual properties (Averill *et al.*, 1923; Foster, 1992). In many hill towns this would have resulted in the initial opening of land along major hill tops and ridges and progressive clearing of forest into valleys, rocky slopes and more inaccessible locations (Bogart, 1948).

At the height of agriculture the forest remnants comprised a highly fragmented system of discontinuous woodlands (Figures 12 and 13; Hawes, 1933). Historical studies suggest that most farmers maintained small woodlots as a source of fuelwood, poles and small materials, often on rocky or wet sites (Averill *et al.*, 1923; Cline *et al.*, 1938). Larger forest areas were scattered throughout the countryside on relatively remote locations or on shallow and poorly drained soils (Fisher, 1921). Preliminary analysis from central Massachusetts indicates that the major factor associated with the distribution of these larger wooded areas was accessibility: there is a positive relationship between forest area and distance from roads, houses and village center (Foster 1992).

Slightly more information is available concerning the process of reforestation, due to the existence of maps from the 1830s, late 1800s and twentieth century (Figure 14). Reforestation appears to be essentially a reversal of the suggested pattern of deforestation, driven by the progressive abandonment of agriculturally marginal and remote sites. The result is the continual expansion and eventual coalescence of individual wooded areas and the gradual shrinkage and subsequent fragmentation of the remaining open areas (Fisher, 1921; Spurr, 1956; Foster, 1992). In the modern upland landscape of New England non-forested sites are primarily town or urban centers, residential areas and agricultural fields (MacConnell, 1975). The latter are restricted to the better agricultural soils, either in broad valleys or at the crest of major ridges (Black and Westcott, 1959).

Structural changes in the forests

Paleoecological records indicate that the last 300 years have witnessed the greatest and most rapid change in upland vegetation since deglaciation 14 000 years ago (Figure 3; Jacobson and Grimm, 1986; Jacobson *et al.*, 1987; Foster and Zebryk, 1993). The major cause of this change, an acceleration in the rate and intensity of disturbance, has generated a striking structural pattern in forest communities. On a stand basis the modern forests are largely even-aged, comprised of trees that initiated through sprouting, seedling establishment or release after an intensive, large-scale disturbance such as logging, fire or field abandonment (Frothingham, 1912; Winer, 1955; Smith, 1979). These human activities have also imposed an oftentimes abrupt patterning of communities in the landscape in terms of age, height and composition (Figure 14d; McKinnon *et al.*, 1935; MacConnell, 1975). Across subtle environmental gradients contrasting land-use histories on adjacent parcels have resulted in sharp changes determined by arbitrary political boundaries, ownership boundaries, or management decisions (Barraclough, 1940). The result is a patchy mosaic of forest and non-forest communities.

The forest mosaic in the modern landscape of New England is determined by a number of human and natural factors: clear-cutting for fuelwood and timber products, especially through the 1930s, fires, particularly until the early 1900s, grazing field abandonment, and the impact of the 1938 hurricane and associated salvage cutting (Merrill and Hawley, 1924; Baldwin, 1949; Winer, 1955; Brown, 1960). Based on

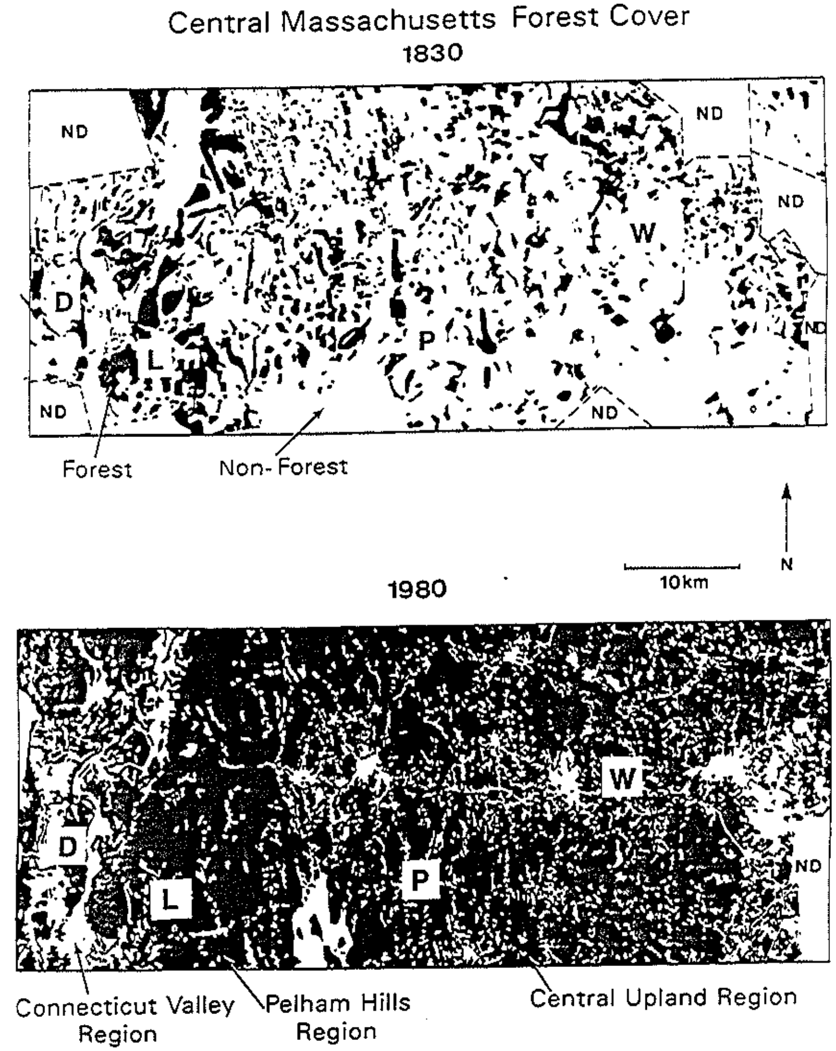


Figure 12. Forest cover (black) for north-central Massachusetts in 1830 at the approximate peak of agricultural clearance, and in 1980. Major physiographic regions include the Connecticut Valley, the rough Pelham Hills, and the undulating Central Upland regions. Four townships are indicated: D - Deerfield in the Connecticut Valley Lowland, L - Leverett in the Pelham Hills; P - Petersham in the rural Upland, and W - Westminster in the more urbanized Upland. ND indicates no data.

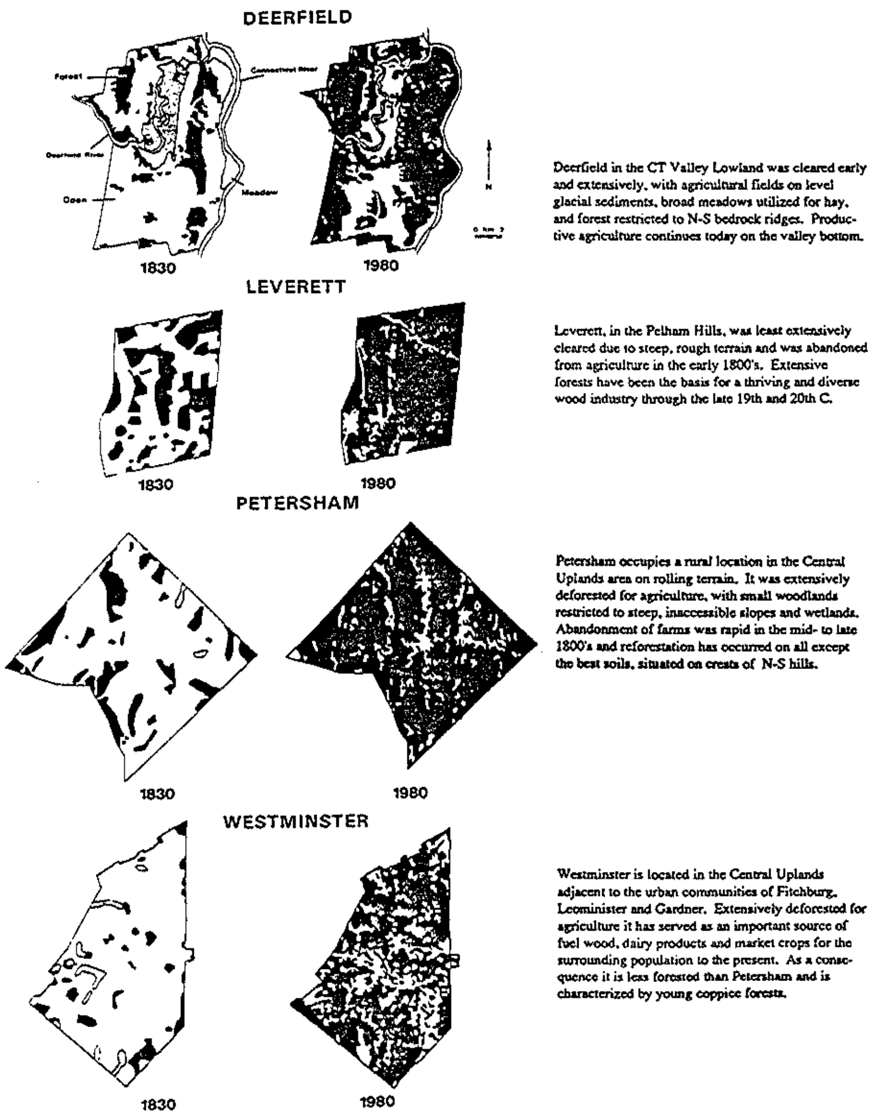


Figure 13. Maps of four townships characteristic of different physiographic regions in central Massachusetts depicting distinctive amounts and patterns of forest, open land and meadow in 1830 and 1980. See Figure 12 for the location of the townships.

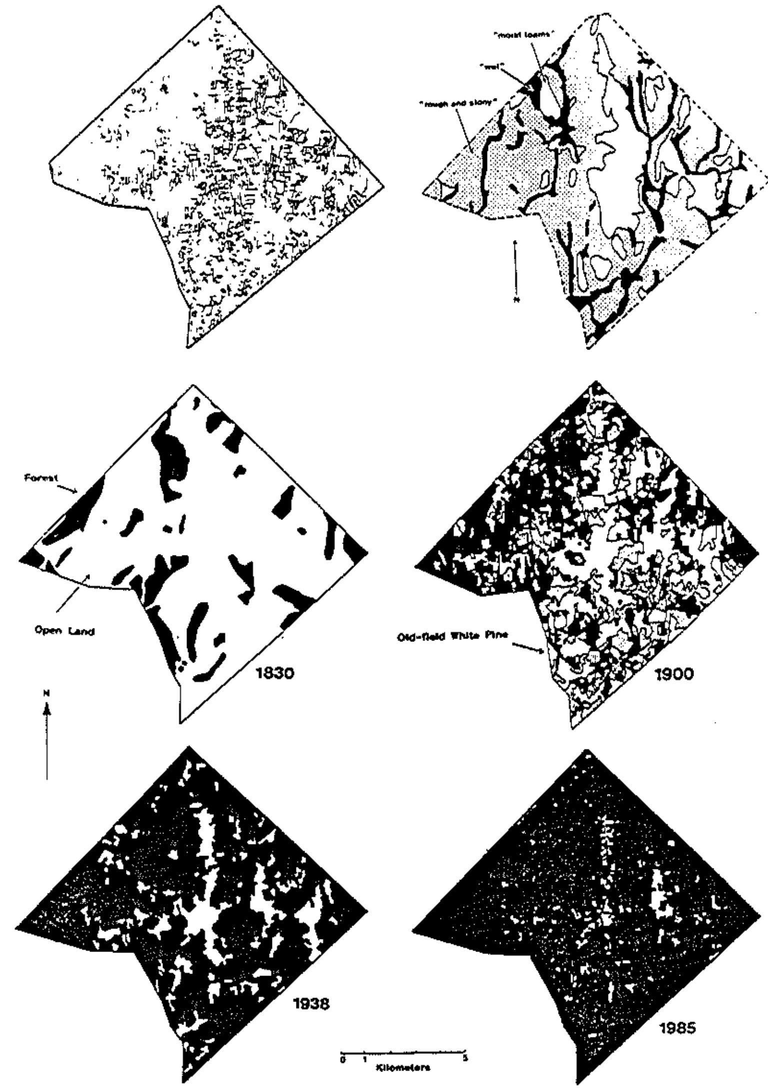


Figure 14. The town of Petersham, Massachusetts depicting (a) the distribution of stone walls, (b) broad soil characteristics and (c-f) the pattern of reforestation from the approximate height of agricultural activity in 1830 to the modern period. In the map of 1900 stippled areas depict areas of old field white pine established on fields abandoned in the previous 30 years.

historical characteristics there are two major classes of forest land in New England: (1) primary forests on sites that have never been cleared, and (2) secondary forests on former agricultural land that has reverted back to woodland (Cline and Lockard, 1925; Stephens and Waggoner, 1980; see Peterken, 1977). Both forest types generally have been clearcut often followed by fire, so that cutting history is a major determinant of modern structure.

Across New England, fuelwood cutting was the major use of wood products into the 1880's (Frothingham, 1912; Reynolds and Pierson, 1942), so much so that the potential for depleting supplies for home, railroad and industrial use was a major concern in the middle part of the nineteenth century (Emerson, 1846; Cook, 1961). Many woodlots were cut on a 20-40 year rotation in order to provide domestic heating and industrial sources of charcoal and chemicals (Cook, 1961). As much as three-quarters of the fuelwood cut in the early 1800s went to domestic needs, as the average farm could consume more than 20 cords per year (Reynolds and Pierson, 1942). In particular regions, such as the Naugatuck Valley and adjoining uplands in northwestern Connecticut, hundreds to thousands of hectares were clearcut annually to fuel the brass, lime and iron industries (Frothingham, 1912; Winer, 1955). Elsewhere, growing town centers and cities provided a constant demand on the surrounding countryside (Cline *et al.*, 1938). After the 1830s the railroad industry required extensive material for ties and fuel; in Massachusetts alone more than 54 000 cords of wood were used as fuel on 560 miles of railroad during the period 1844-45 (Cook, 1961).

With the development of efficient stoves, access to coal supplies, and concentration on logging of old-field white pine in the late 1800s and early 1900s, timber and related forest products finally surpassed heating as the major use of wood. The development of the portable sawmill enabled logging to proceed in even the most remote stands (Smith, 1970). The resulting cutting through the 1920s reached essentially all old-growth timber and most second growth stands of merchantable age (Nichols, 1913). Cutting peaked in most New England states between 1905 and 1910 (Kneeland, 1918), with approximately 2.5 billion board feet of pine cut annually, in contrast to the 1870s when the annual cut was less than one million board feet (Barraclough, 1940). Then, in 1938 the hurricane destroyed forests across a 100-mile path from southern Connecticut into central Vermont, prompting an unequaled salvage operation in which more than 3.5 billion board feet of timber were harvested and stored in ponds and lakes to deter decay until the logs could be milled (NETSA, 1943).

Throughout the settlement period and with increasing logging activity, fire became an important cause of stand regeneration and landscape patchiness (Graves and Fisher,

1903; Patterson and Backman, 1988; Fahey and Reiners, 1981). Fire was used extensively following logging to reduce residual slash; frequently these fires as well as those set by railroads escaped into surrounding areas. By the early 1900s fire was seen as one of the major deterents to forest improvements and extensive efforts were made to evaluate its extent and effect and to limit its occurrence (Hawes, 1923; Gould, 1942; Merrill, 1974).

As early as 1840 warnings were being sounded concerning forest destruction and the poor quality of New England's woods (Emerson, 1846). By the early 1900s this message had become a common theme (Massachusetts State Foresters' Office, 1906). It was recognized that current tax laws, the absence of forest management, and the onslaught of fire, clear-cutting, grazing and disease had led to a condition of young, even-aged stands dominated by inferior hardwood species (Cline *et al.*, 1938). The legacy of the period from 1880-1920, the so-called "Period of Forest Devastation" (Hawes, 1923), is the even-aged patchwork of stands in the modern landscape (Fisher, 1921).

The even-aged and mosaic quality of the forests pertains as well to New England's public lands in State and National forests. These forests comprise the bulk of the preserved land in the region and are often erroneously conceived by the public to represent examples of natural and undisturbed ecosystems. To the contrary, the majority of public forest land was purchased at extremely low prices due to the young and poor quality of its timber and its low suitability for immediate productive use (Gould, 1986a). For example, in the White Mountain National Forest (WMNF), the largest continuous forest preserve in New England, over 70% of the area was cut-over (often clear-cut) or burned between 1870 and 1930 (Gould 1986b). In 1936 it was estimated that few forests in the WMNF exceeded 40 years of age; the average was less than 20 years. Haul roads totalling more than 4000 km and over 100 km of railroad track provided access throughout the area. Today more than 17 000 ha of this forest has been designated as Wilderness despite the omnipresent evidence of roads and railroad track and an average stand age less than 80 years old. To the west in Vermont, a similar story holds; the largest state-owned forest preserve (Groton State Forest) was established on land extensively clear-cut and then burned by fires at the turn of the century.

Changes in species composition

Recognition of the physical structuring of forests in the New England landscape does not address the question of whether human activity has altered substantially the composition of forest communities and the relative abundance of species in this region. The answer appears to depend on the scale of analysis (Siccama, 1971; Foster, 1992). Studies based on early forest descriptions, land surveys, and pollen records suggest that on a regional basis the broad distribution of species and forest types has altered little across New England (Raup, 1957). In central Massachusetts, for example, an analysis of vegetation descriptions on a township basis reveals an elevational and latitudinal zonation of central hardwoods, transition hardwood and northern hardwood forest that broadly parallels the modern map (Westveld, 1956; Foster, 1992).

On a stand and landscape scale, however, studies of old-growth forest, fine-scale pollen analysis, and forest reconstruction indicate that considerable change has occurred in the relative abundance and distribution of species and in the relative importance of particular forest types (Figure 15; Winer, 1955; Siccama, 1971; Whitney and Davis, 1986; Glitzenstein *et al.*, 1990; Foster and Zebryk, 1993). In fact, the inability of many early studies to explain forest composition on the basis of site properties alone has led to a widespread conclusion that land-use history closely regulates local vegetation type (Merrill and Hawley, 1924; Stout, 1952; Goodlett, 1960).

An increase in pioneer or early forest species has been widely cited as the major cumulative impact of historical land-use activity (Lutz, 1928; Spurr and Cline, 1942; Smith, 1979). Including such trees as gray birch, aspen, pin cherry, black cherry and red cedar, these pioneers increased as a result of the widespread disturbance and the early successional habitats created by cutting, clearing, and burning. Repeated cutting, grazing and fire also selected for hardwood species that sprouted prolifically, including chestnut, oak, red maple, birch and hickory (Graves and Fisher, 1903; Frothingham, 1912; Fisher, 1931). Consequently, sprouters increased, especially in forests utilized for fuelwood and charcoal around cities and in mining areas (Winer, 1955; Whitney, 1993).

Chestnut is the preeminent example of a sprout-hardwood species that benefitted greatly from repeated human disturbance to forests (Paillet, 1982; Russell, 1987). Producing extensive basal dormant buds and capable of phenomenal rates of height extension and diameter increment when reproducing vegetatively (Zon, 1904; Paillet and Rutter, 1989), chestnut responded to cutting or fire by massive proliferation and rapid stand dominance (Murdoch, 1912; Foster *et al.*, 1992). Paleoecological studies indicate that the abundance of chestnut increased substantially from presettlement time through the early twentieth century when the chestnut blight was introduced on trees imported from Asia. By the turn of the twentieth century chestnut accounted for approximately 50% of the standing timber in Connecticut (Frothingham, 1912).

White pine is another species that has undergone major changes in abundance and

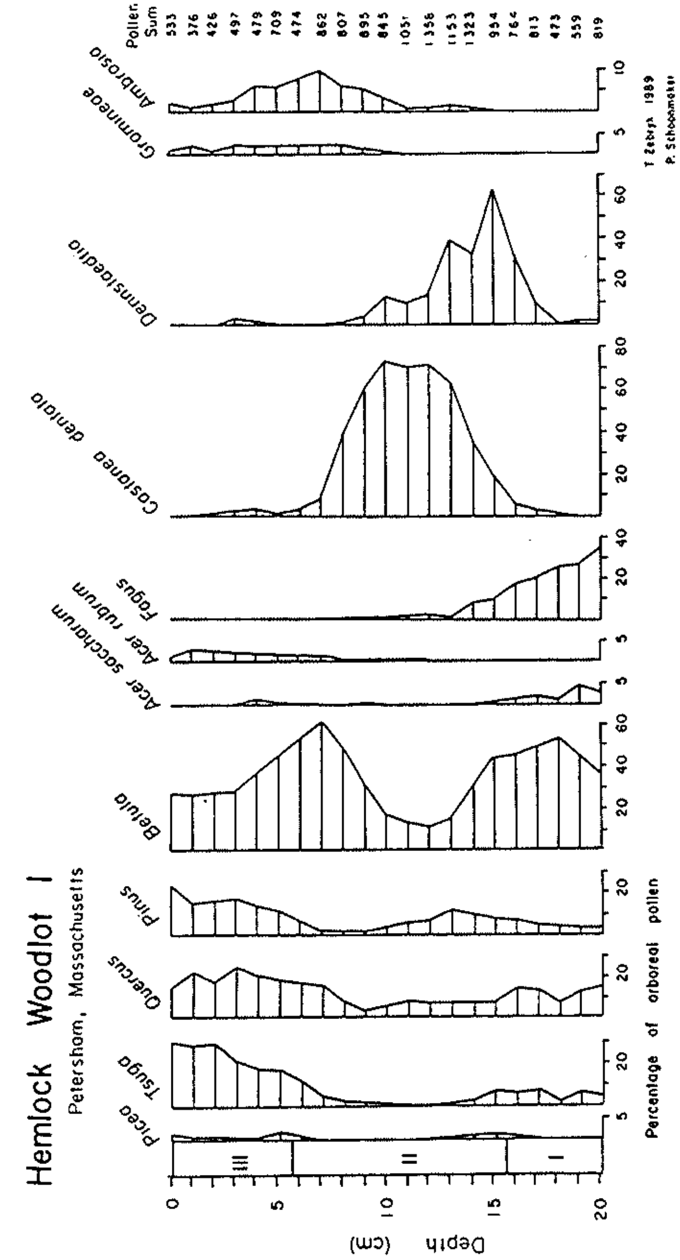


Figure 15. Pollen diagram from the humus soil in a hemlock forest at the Harvard Forest, Petersham, Massachusetts. The site is a primary forest that was never cleared for agriculture but was clear-cut early in the settlement period (at about 18 cm depth) and then cut repeatedly for fire wood. Tree species respond quite individualistically to the series of human impacts. Chestnut (*Castanea*) benefitted greatly from the cutting activity until it was decimated by blight in 1913. Beech (*Fagus*) and sugar maple (*Acer saccharum*) nevr recovered to presettlement levels of abundance whereas hemlock (*Tsuga*), pine (*Pinus*) and red maple (*Acer rubrum*) have gradually increased to the present. From Foster *et al.* (1992).

distribution through the historical period. In the pre-settlement landscape white pine presumably had a patchy distribution, scattered throughout old-growth stands and dominant only on dry, sandy soils and on fire-prone sites. However, the circumstances associated with farm abandonment provided a unique opportunity for the widespread establishment of white pine (Spring, 1905; Egler, 1940). Fence-row trees and scattered pines in woodlots represented an abundant seed source in the agricultural landscape. Grass, thin sod, and litter provide an excellent seed bed for white pine, which was able to thrive in the absence of competition on neglected pastures, particularly if grazing reduced competition with the hardwood species. The gradual abandonment of pastures and fields in the mid- to late 1800s provided ideal conditions for the development of massive pine stands (Figure 14). By the turn of the century the volume of white pine timber exceeded 7 billion board feet and led to the designation of the northeast as the white pine region (Nichols, 1913). Subsequently, intensive cutting and selective removal of pine by the 1938 hurricane greatly reduced this abundance (Foster, 1988b; Gould, 1966). The pine forests provided an excellent site for hardwood (red oak, red maple, white ash, birch) establishment (Cline and Lockard, 1925) and thus a gradual succession has occurred through time.

Many studies have shown that conditions prevailing at the time of field abandonment, especially seed bed, seed source and the extent of grazing, strongly determine the composition of the initial pioneers and of the subsequent vegetation. Thus, red cedar in the south, white pine in the central region and red spruce to the north are favored by grazing and a pasture seed bed, whereas gray birch, red maple, aspen and paper birch became established more readily in the absence of grazing and on mineral soil in former tilled fields (Lutz, 1928; Raup, 1937; Spurr, 1956).

Concomitant with the increase in pioneer and sprouting species through the early 1900s there occurred a decline in some tolerant, mature forest species, notably hemlock, beech and red spruce, but also including sugar maple and yellow birch in some areas (Chittenden, 1905; Egler, 1940; Winer, 1955; Spurr, 1956; Siccama, 1971; Hamburg and Cogbill, 1988). For beech and hemlock this reduction involved a great acceleration of a decline beginning before settlement (Brugam, 1978a/b; Gajewski *et al.*, 1987; Foster and Zebryk, 1993). Hemlock in particular, is highly susceptible to fire and largely has been eliminated from upland areas that have burned in the past two hundred years (Winer, 1955). Hemlock is seldom eliminated by cutting alone, due to the abundance of advanced regeneration (Lutz, 1928; Merrill and Hawley, 1924); however, once it is removed from an area by fire or land conversion for agriculture, hemlock is very slow to reinvade (Kelty, 1984). Thus, the presence of older hemlock trees in the landscape has

been interpreted as an indication of primary forest conditions (i.e. never cleared; see Figure 15) and a long-term absence of fire (Marshall, 1927; Winer, 1955; Smith 1950; Kelty, 1984).

With the decrease in fire and the elimination of chestnut by blight the major trend in forest composition throughout New England during the twentieth century has been a steady increase in long-lived shade tolerant trees especially hemlock and sugar maple (Spurr, 1956) but also including beech and red spruce in some areas (Egler, 1940). Effective fire control has enabled the widespread establishment of these species as an understory component in many stands dominated by less tolerant sprouting species such as oaks, birch, chestnut (Graves and Fisher, 1903; Smith, 1950; Abrams, 1992). Sugar maple and hemlock are capable of persisting as advanced regeneration that ascends into the canopy through openings caused by mortality or larger disturbance (McIntosh, 1972). Thus processes such as the demise of the overstory chestnut, the 1938 hurricane, and logging activity serve to release these shade-tolerant species and effectively accelerate a successional process possibly towards a more self-reproducing canopy (Spurr, 1950; Kelty, 1984; Paillet, 1982; Abrams and Nowacki, 1992).

Grazing, by cattle, horses, sheep and pigs is a final critical, though elusive, factor shaping forest composition. During the height of agriculture in the mid-nineteenth century most extant forest areas and woodlots were probably grazed (Graves and Fisher, 1903). As late as the 1930s, Guise (1939) estimated that 48% of New England woodland was currently pastured, with grazing often accompanied by light burning to increase the cover of grass. Grazing maintains an open understory, tends to cause a retention of weedy species and decreases the component of hardwood species. The prevalence of this practice 50 years ago must be a strong determinant of the existing composition of our forests.

Despite intense modern interest in forest fragmentation and species diversity, essentially no quantitative information is available concerning the loss of species other than game birds and mammals resulting from the massive destruction of forest habitat in the northeastern United States over the past 300 years (Figure 16; Bickford and Dyman, 1990). Few studies have critically addressed the changes in floristic composition or have successfully examined the relative contributions of land use versus environmental factors in controlling this composition (Whitney and Davis, 1986; Marks and Smith, 1989; Foster, 1992). In fact, most efforts to examine impacts of modern fragmentation fail to even mention the severe deforestation of the temperate forest region that occurred a century and a half ago (see DeGraaf and Healy, 1990). Thus, there has been little serious attempt in this effort to learn from history.

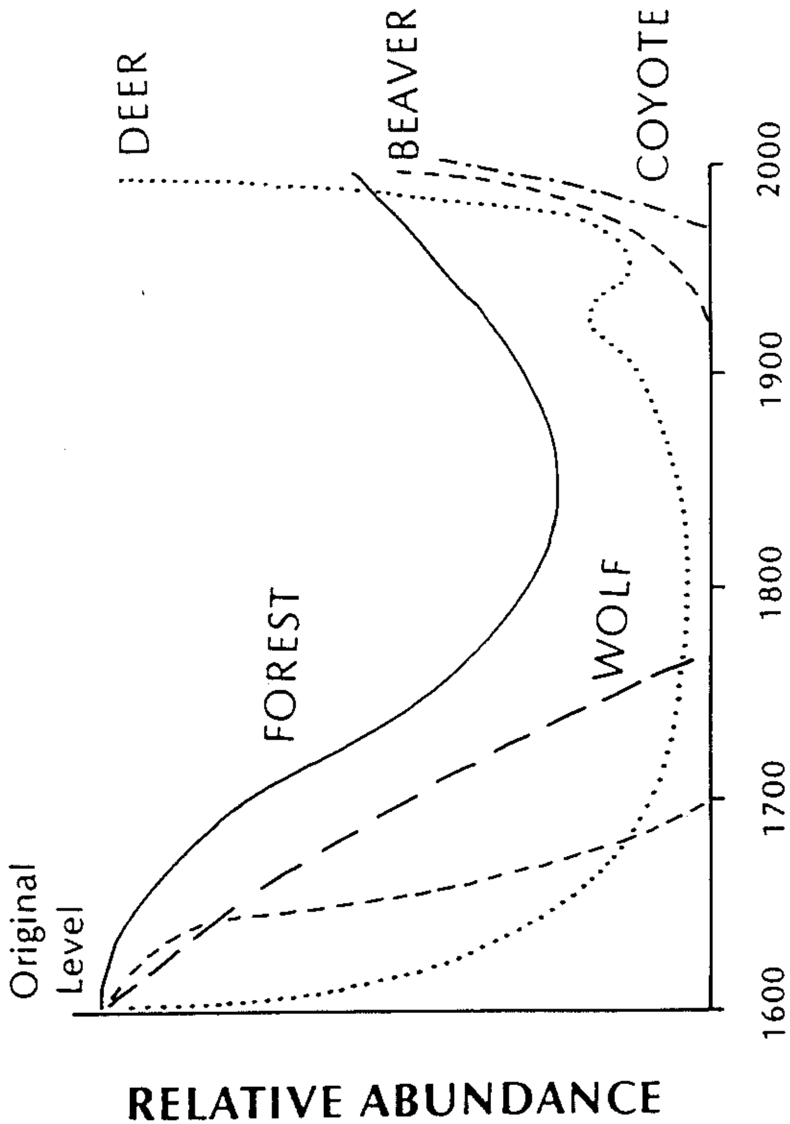


Figure 16. Changes in the relative abundance of selected mammal species in Massachusetts over the past 400 years. Whereas the wolf has been eliminated, beaver have been reintroduced and the coyote represents a new species in the landscape. From Bickford and Dyman (1990).

Occasional studies have identified species thought to be restricted to or more abundant in primary woods (e.g. Niering and Egler, 1966). In Connecticut, Nichols (1913) suggested that *Hamamelis virginiana, Kalmia latifolia, Cornus alternifolia, Acer pennsylvanica, Viburnum alnifolium* and *Taxus canadensis* occur predominantly in forest areas never cleared. This list was largely corroborated by Whitney and Foster (1988) in a study focussed on northern Massachusetts and southern New Hampshire. Following on more extensive research in Great Britain (see Peterken, 1977; Peterken and Game, 1981, 1984) it has been argued that the major factors restricting colonization of this group of species into secondary forest included (1) low seed production and dispersal, (2) possible changes in soils through agricultural use, and (3) competition by established plants (Whitney and Foster, 1988; Gerhardt, 1993). Peterken's studies in England indicate that as much as one-third of the flora has not effectively colonized secondary forests from primary forest refuges (Peterken and Game, 1984). However, this work also suggests that survival for plant species in the primary forests is largely unaffected by forest area or degree of isolation (Peterken and Game, 1981). Rather, the major loss in species diversity has come about because the remaining primary forests cover only a subset of the original forest sites and woodland species.

One study that has attempted to examine floristic relationships with historical and environmental factors was reported by Foster (1992) from central Massachusetts. Using Canonical Correspondence Analysis it was shown that a combination of edaphic factors (soil moisture and slope position) and land-use history (primary/secondary woodland, cutting history, abandonment date and the distinction between pasture and cultivated lands) provided a significant and informative model of stand and species variation. In this study of the Harvard Forest, primary forests were concentrated on intermediate to poorly drained sites and were characterized by many of the species listed by Nichols (1913) and Whitney and Foster (1988).

Altered seed pools are one critical legacy of land-use activity that will continue to influence the future dynamics of the vegetation. The extreme longevity of seeds of the weedy species that are characteristic of old field and early successional habitats results in a long-term imprint of past vegetation. The seed pools in second-growth forests are often compositionally distinct from the existing vegetation and are dominated by field and shrubland taxa, such as Gramineae, Polygonaceae, *Comptonia*, etc. (Livingston and Allessio, 1968; del Tredici, 1977; Ellison, 1992) that were growing on the site 50-100 years earlier. When such second-growth forest extensively disturbed, the resulting vegetation response is often unexpectedly dominated by agricultural weeds, rather than forest species. For example when the more than 200-year-old Cathedral Pines forest, a stand of old growth white pine and hemlock was uprooted by tornado in 1989, one of the most abundant species on the disturbed soil was pokeweed (*Phytolacca americana*), a weedy plant characteristic of abandoned areas and road sides. Whether the seeds were carried in from surrounding agricultural areas by birds or represent long-term storage from an extremely ancient field, this weedy species came to dominate in a forest protected for its national natural significance (Patterson and Foster, 1990).

Even on primary forest sites that appear to provide analogues for the original natural vegetation due to the dominance of shade-tolerant species and old canopy trees, the composition has changed markedly through the settlement period. In two separate stands on the Harvard Forest dominated by mature hemlock (exceeding 100 years in age), a history of cutting, windstorm damage and chestnut blight have triggered major structural and compositional changes (Figure 15; Oliver and Stephens, 1977; Foster *et al.*, 1992). In both cases clear-cutting of hemlock, pine and hardwoods in the 1700s resulted in a dominance of chestnut, birch, oak and other sprout hardwoods. Repeated cutting altered the relative abundance of these species somewhat; however, the major change occurred through the demise of chestnut and cessation of cutting that allowed hemlock to become gradually dominant (see Merrill and Hawley, 1924; Winer, 1955).

The review of available studies provides ample evidence of major transformations in the composition of individual stands and extent of individual species. Postsettlement land use has involved new landscape processes that have driven these changes, including: altered natural disturbance regimes and novel disturbance processes; introduction of exotic species including pathogens; modified roles of grazers, dispersers and pollinators; and long-term changes in soils and their seed pool constituents. The vegetation at any point in time or space is a result of underlying environmental conditions and the selective action of these various processes interacting with the available flora. Across the landscape this intersection of historical and environmental factors creates a highly complex mosaic (Smith, 1979). The intensity and frequency of disturbance during the modern period has resulted in a mosaic that changes more dynamically than that of the pre-colonial landscape.

Ecosystem Impacts of Land Use and Forest Change

The structural and especially the compositional changes of forest communities resulting from past land use represent long-lasting impacts. Equally important are the less obvious modifications of terrestrial and aquatic ecosystem processes. These would include changes in soil conditions, alterations in hydrology, and modifications of animal

populations. All of these factors have important direct effects on forest conditions and many may continue to affect the productivity of terrestrial ecosystems and feedbacks between the biosphere and atmopshere.

There is long-standing debate concerning the impact of land use on soil properties and subsequent feedback with regard to modern forest conditions. Much of this discussion has been shaped by the strongly held belief that agricultural abandonment in nineteenth century New England was propelled in large part by the exhaustion of the nutrient capital of the land through destructive farming practices (Donahue, 1983). Decreased nutrient availability is thought to affect the modern vegetation through reduced productivity, slower rates of succession and altered competitive interactions among species of contrasting nutrient demand. However, with the recognition of the many social factors driving the changes in agricultural practices in the nineteenth and twentieth centuries, much of this reasoning has been called into question (Raup, 1966; Bell, 1989).

Direct impacts of modern forest harvesting, land clearance and agriculture have been used to infer past effects. Forest clearance initiates a series of microclimatic effects that alter the radiation and moisture balance of forested areas and influence soil properties. Reduced transpiration increases soil moisture, which combined with increased temperatures, generally leads to accelerated soil biological activity, a reduction in soil organic matter, and a release of nutrients. Increased mobilization of nutrients can lead to loss through leaching and subsurface runoff. Direct modification of the upper soil layers through plowing or heavy trampling by grazing animals may leave long-lasting physical changes in terms of soil homogenization and a decrease in microtopography. In addition, the reduction in ground cover and disturbance of the soil surface may lead to accelerated erosion. Evidence of increased inorganic inputs and nutrients to aquatic systems and the deposition of fine soil material in depressions and at slope bottoms indicate that erosion and the transport of nutrients from the uplands has occurred extensively (Brugam, 1978a/b).

Removal of the forest canopy alters wind movement, increasing the velocity across open areas. One consequence is decreased snow depth, a factor that strongly regulates soil temperatures and frost depth through insulation. Whereas many northern forests experience essentially no soil frost due to the depth of snow and organic matter, adjoining cleared areas may freeze to a depth exceeding one meter (Bormann and Likens, 1979). Enhanced frost action disturbs the soil surface, moves stones towards the surface and reduces soil biological activity by both large and microscopic organisms.

The long-lasting impacts of these soil changes would be expected to be distributed differentially across the landscape due to the selective nature of human activities on different sites and soils, the differential susceptibility of different physiographic units and soils to these effects, and the subsequent history of vegetation on the various sites.

In addition to direct effects on soils there is the potential for indirect removal of nutrients from sites through the harvesting of timber and agricultural products. For example, the extensive production of potash from New England clearly represented a literal export of nutrient capital from the uplands. Some authors have argued that many of these nutrients were extensively redistributed across the landscape. For example, nutrients from pastures may have been removed as forage by grazing animals and added to tilled fields in the form of manure supplements (Jones, 1991). On a broader scale hay produced on the uplands of Massachusetts in the summer was consumed by cattle in the Connecticut River lowland in the winter and then added to lowland fields as fertilizer (Garrison, 1987). The resulting movement of nutrients may have accentuated differences in fertility that already occurred naturally in the landscape.

Attempts to address these nutrient movement questions using historical sources provide equivocal results. A study by Jones (1991) of agriculture in Deerfield and Petersham, Massachusetts, indicated that crop yields on tilled fields increased continually in both towns from 1780 to 1850. Although it was argued that the source of the apparent nutrient inputs (i.e. manure) to the crop fields came at the expense of inputs to hay fields, hay production held fairly constant through the same period. Recent studies by J. Aber and J. Melillo at the Harvard Forest provide indirect evidence for nutrient re-allocations within the colonial landscape (Aber *et al.*, 1991). In experiments designed to test the response of forest communities to nitrogen inputs these researchers discovered that, contrary to their expectations, conifer stands were more nutrient-rich than nearby hardwood stands. This finding runs counter to the general observation that conifer species dominate on less fertile and more acidic sites but can be explained on the basis of land-use history. In central New England many old-field white pine and conifer plantations occur on the most recently abandoned sites such as former tilled fields, whereas many hardwood forests are second-growth stands on old pastures. The tilled sites, probably initially more fertile, received manure supplements for years. Thus, the soil characteristics of the conifer stands reflect history rather than an equilibrium setting.

Terrestrial and aquatic linkages

Lake sediments provide a continuous record not only of the changes that occur in the terrestrial vegetation but also dynamics of the lake system itself. Because the nature of the recording medium does not change through time lake sediments provide a consistent

record of changes in water quality, organic and inorganic inputs, biota and productivity.

Most lake ecosystems in the northeastern United States exhibit profound changes during the historical period despite a lengthy Holocene record of relatively little change. Sedimentation rates increase, often markedly, and the inorganic fraction of the sediment increases, reflecting soil instability and erosion across the watershed. Associated with mineral inputs is generally an increase in nutrient loading, which often triggers increased primary productivity (Brugam, 1978a). In severe cases, the enhanced productivity can lead to increased decomposition in the lake water, which can consume available oxygen resulting in anoxic conditions and fish mortality.

Detailed studies of these changes indicate that lake and upland ecosystems are tightly coupled and that lakes respond rapidly to alterations in land use. As lake sediments integrate the activity in the larger watershed the history of changes may be complex. Two studies that show the detail of these changes and their linkage to land-use activities include research by Brugam (1978a/b) in Connecticut and Engstrom *et al.* (1985) in Vermont (Figure 17). Brugam's study of Linsley Pond in southern Connecticut illustrates a sequence of progressively more intensive changes in the upland ecosystem. Following deforestation a subtle increase in primary production accompanies changes in pollen frequencies. Farming in the watershed in the early 1800s led to increased organic erosion, input of nutrients from manure and household refuse and a noticeable change in the algal composition. A fundamental alteration of organic and inorganic matter fluxes to the lake and enhanced nutrient inputs parallel expansion of dairy farming in the watershed in the early 1900s. Suburban development in the 1960s resulted in hypereutrophic conditions.

Engstrom's study on Harvey's Lake, Vermont evaluated the feasibility of restoration efforts of the eutrophic lake based on the extent to which modern conditions might reflect a departure from the presettlement situation (Figure 17). Examining the inorganic geochemistry, pigments and diatoms as well as pollen, the researchers showed two major increases in primary productivity (1780 and 1945) associated with extensive logging activity and a major increase in the input of dairy wastes into the lake. Construction of a sawmill on the primary inlet in 1820 coincided with the onset of anoxia and the incorporation of woodchips into the sediments. Anoxic conditions, presumably resulting from the decomposition of sawmill debris, lasted until 1920 when the mill was closed. Dairy waste enrichment of the inflowing stream, accompanied by an expansion of summer homes, produced a dramatic shift in the algal populations to blue-green algae and a new development of anoxic conditions. Thus, modern limnological conditions are markedly different from those that prevailed for over a thousand years before settlement

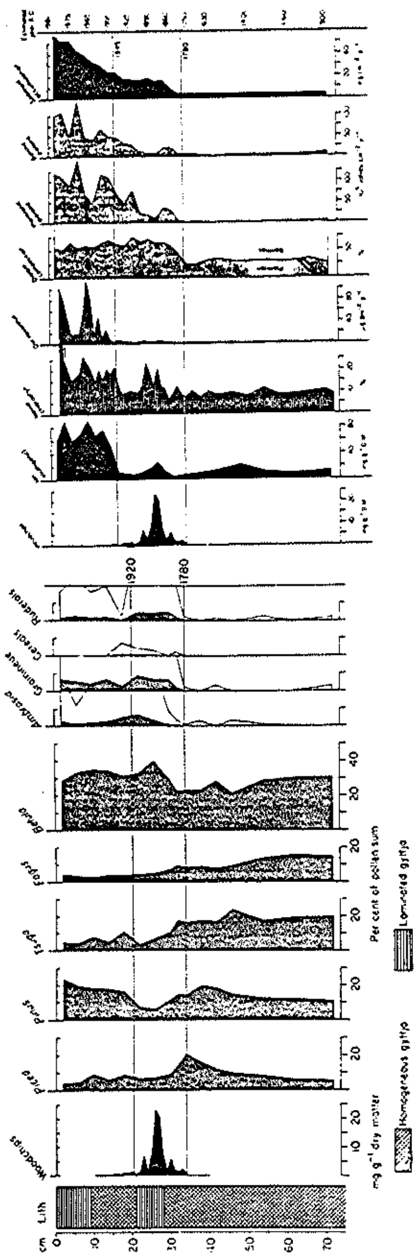


Figure 17. Pollen and sediment stratigraphy from Harvey's Lake, northeastern Vermont, depicting major changes in the regional vegetation, lake chemistry and aquatic biology occurring after colonial settlement in the area (about 1780 A.D.). Forest cutting, land clearance and agricultural activity are indicated by the general decline in all tree species except birch, and increase in herbs and weed species, whereas the concentration of woodchips are derived from a period of lumbermill operation near the mouth of an inflowing stream. Increased nutrient inputs in the period 1780 to 1945 from erosion and agricultural activity resulted in increased sediment accumulation and algal production (see chlorophyll and diatoms stratigraphies). Following extensive construction of summer homes in the 1940s and substantial nutrient additions from sewage run-off, those trends were enhanced, blue-green algae became important (indicated by oscillaxanthin) and the bottom waters became oxygen-depleted (indicated by the dramatic increase in manganese). Adapted from Engstrom *et al.* (1985).

and represent the cumulative impact of changes in the watershed during the intervening period.

Animals and pathogens

Humans and their impact on the landscape have been tied to major changes in the abundance and distribution of animal species and major plant pathogens (Figure 16, Table 1). These, in turn, have affected the forest landscape in innumerable ways. Information is primarily available for major game animals and economically important plant pests, although even here much of the data is anecdotal or from indirect sources (Bickford and Dymon, 1990).

Evidence suggests that most of the large, broad ranging species were largely eliminated from New England or the northeastern United States during the first episode of forest clearance. This group would include elk, caribou, wolf, mountain lion, lynx, wolverine and marten. From Massachusetts these species plus moose and Indiana bat have been extirpated to the present and an additional 75 animal species are listed as endangered or threatened. A number of species have been introduced or have extended their range northward, especially after 1900. These include coyote, possum, turkey, vulture, cardinal, mocking bird and the rainbow and brook trout. The vast majority of species, however, have undergone major changes in abundance even to the extent of being locally eliminated and subsequently reestablished. The recent expansion of turkey across New England and the southward spread of moose are major examples. The early species to increase include many edge species such as deer, which was nearly eliminated in the mid-1800s and has reached densities detrimental to the vegetation in many areas today. Many of the species increasing today, such as moose and turkey are forest species that benefit from the great expansion of woodland.

Future Changes in New England's Forests

The major lesson derived from the retrospective view of the forests of New England is that they are dynamic on geological and historical time scales. Thus, with certainty we can face the future and expect additional change. Ironically, in an age of global concern with deforestation and forest fragmentation, one of the major trends observed in the recent past and anticipated in the near future for New England is a continual aging and growth of the forests and a net increase in the carbon that they store (Figure 18, Table 2). With active harvesting proceeding much more slowly than growth there will be continued

Table 1. Current status and tally of wildlife and plant species in Massachusetts showing native, introduced extinct and extirpated species listed in the state since 1620. Adapted from Bickford and Dymon (1990).

	Total	Native: Inland	Native: Marine or Coastal	Introduced by man	Natural Range Expansion	Extinct	Extirpated	Rare: End *	Rare: Th *	Rare: SC *	Rare %	Federally Listed End & Threat *
Mammals	94	58	28	8	2 coyote opossum	2 eastern elk sea mink	8	7		5	14	7 6whales 1 bat
Birds	434	188 nest annually 40 year round 93 predictable migrants 19 nest irregularly 129 vagrants		5 pigeon starling ring-necked pheasant house sparrow mute swan	25+ turkey vulture mocking-bird cardinal	4 heath hen great auk passenger pigeon Labrador duck	1 gray cheek thrush	9	7	15	14	5 bald eagle peregrine falcon Eskimo curlew roseate tern piping plover
Reptiles	30	24 14 snakes 9 turtles 1 lizard	6 turtles				1 five-lined skink	7	4	3	48	6 5 sea turtles 1 Plymouth redbelly
Amphibians	23	22 7 frogs 3 toads 12 salamander		1 mudpuppy salamander					2	6	36	
Fish	78	30	21	27	1		1	3	3	3	20.5	1 shortnose sturgeon
Total	659	618		41	28+	6	11				18	19
Plants	2,700			950			50	106	80	50	14	2

* End.- Endangered, Th.- Threatened, SC - Special Concern

increase in mature forests and corresponding species of plants and animals (Dickson and McAfee, 1988). While the forests mature they will be affected by many new processes. Ownership patterns have changed rapidly during the second half of the twentieth century as more urban dwellers have "bought a piece of the woods," leading to a highly fragmented pattern of relatively small individual parcels (Figure 19). Consequently, in the suburban backyard as well as the north woods there is an increasing challenge to manage, regulate and even understand large forest areas as the property maps become more heterogenous and as conflicting viewpoints proliferate (Harper *et al.*, 1992). Equally invisible as the property boundaries are the novel stresses being imposed on our forest ecosystems. Across New England atmospheric inputs of nitrogen (NO_x) form a gradient increasing to the north and west and with elevation (McNulty *et al.*, 1990). Nitrogen, the major limiting nutrient for plant growth in New England forests, acts initially as a fertilizer, quite probably enhancing productivity and altering the competitive balance among species. At higher concentrations it may actually saturate the soils and lead to negative consequences including nutrient loss through leaching (Aber *et al.*, 1989). Increasing levels of CO_2 (Figure 20), which are implicated in future global warming, are also exerting a subtle and largely undetected impact on forest communities. Plant growth, predator relations, competitive interactions and organic matter quality are all modified by CO_2 concentrations, leading to altered community interactions and ecosystem function (Bazzaz and Fajer, 1992). Finally, our forests face the continued impact of introduced and native pathogens as predator relations and abundances change. As I write this epilogue the old-growth hemlock forest located a mile from my Harvard Forest office and from which we have learned so much concerning long-term forest dynamics is being threatened by native insect populations (eastern hemlock looper) and an introduced species (wooly adelgid). As they have through their long past, our woods are poised to be tested for resilience, and are certain to change.

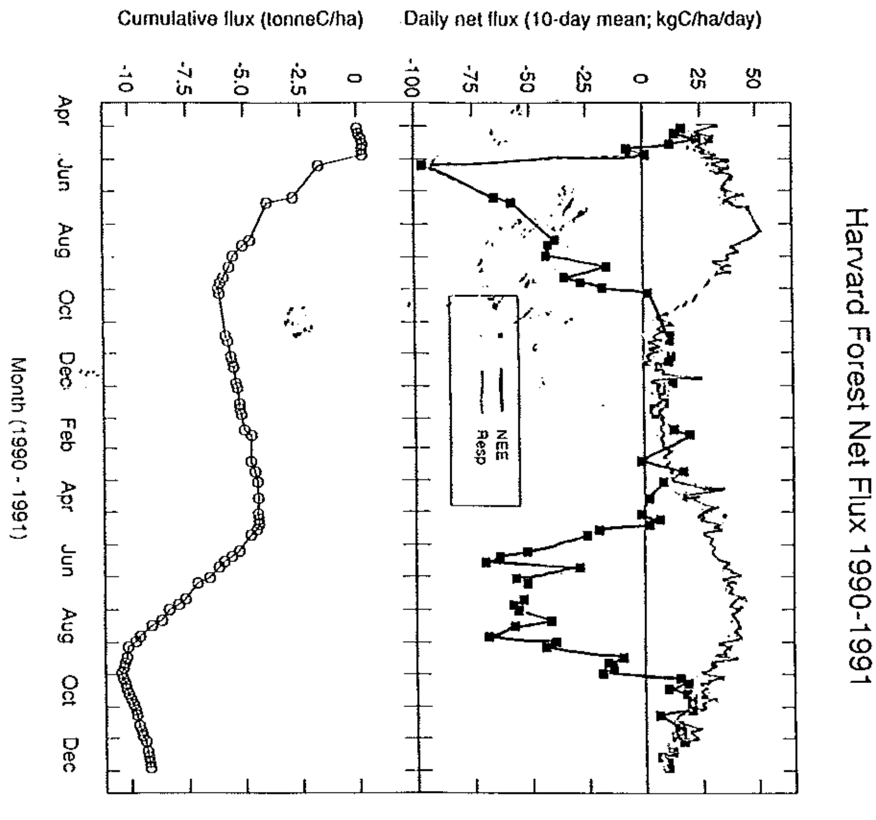


Figure 18. Exchange of CO_2 from mixed hardwood-conifer stands at the Harvard Forest, Petersham, Massachusetts. The upper panel depicts the mean net ecosystem exchange (NEE) and respiration (Resp) averaged over 10-day periods, in KgC/ha/day, plotted against day of the year. Lower panel depicts cumulative net CO_2 exchange (tonneC/ha) for April 1990 - December 1991. As is typical for most of New England this relatively young forest (55 years old) is accumulating considerable quantities of carbon. As a consequence temperate forests may be a major sink for carbon on a global basis. From Wofsy *et al.* (1993).

Table 2. Timber growth versus removal in the New England states from 1935 to 1985. Growth exceeded removal in all but the earliest period as indicated by the percent (G:R) increase. Data were obtained from Baldwin (1942, 1949), Irland (1982) and USDA (1990). Values given in millions of cubic feet of wood.

	1935			1944			1952		
	Growth	Removat	G:R	Growth	Removat	G:R	Growth	Removat	G:R
Softwood	193	244	79%	419	375	112%	491	339	145%
Hardwood	315	327	96%	478	386	124%	302	149	203%
Total	508	571	89%	897	761	118%	793	488	163%

	1976			1985		
	Growth	Removat	G:R	Growth	Removat	G:R
Softwood	838	395	212%	440	356	124%
Hardwood	506	243	208%	478	386	124%
Total	1304	638	211%	1057	565	187%

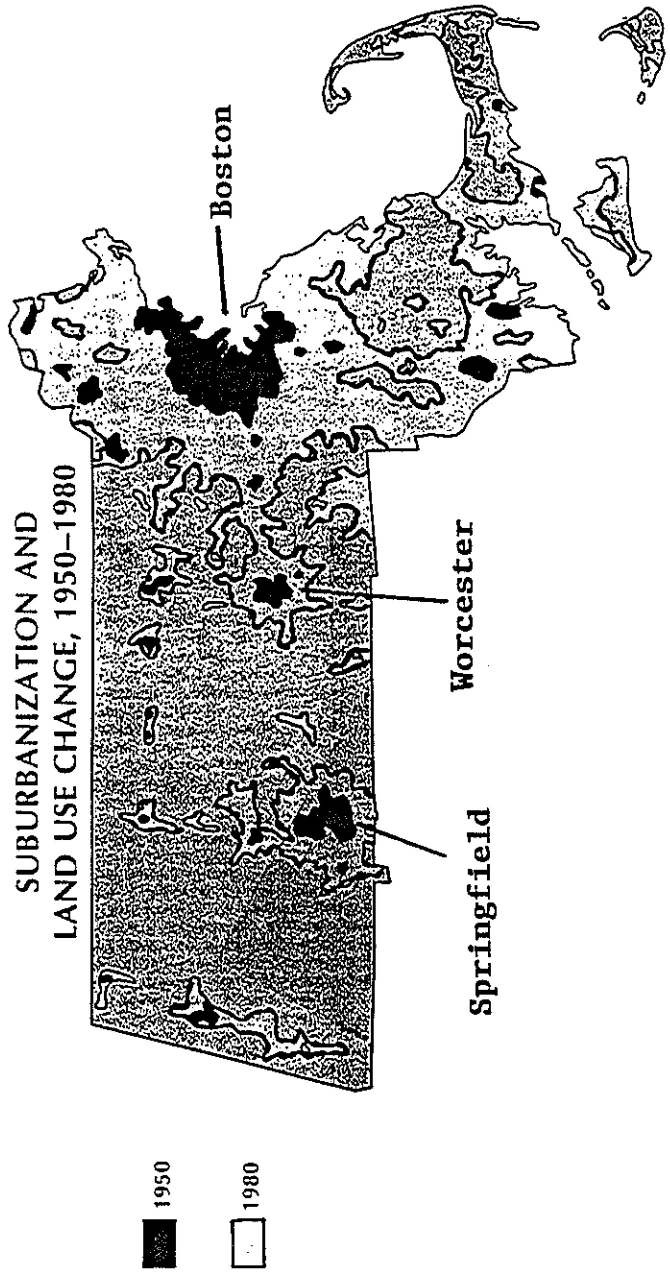


Figure 19. The progression of suburbanization in the state of Massachusetts during the last half of the 20th century. A growing population and improved road transportation system have resulted in a conversion of former agricultural and industrial towns to residential communities around the major cities of Boston, Worcester and Springfield. Modified from Wilkie and Tager (1991).

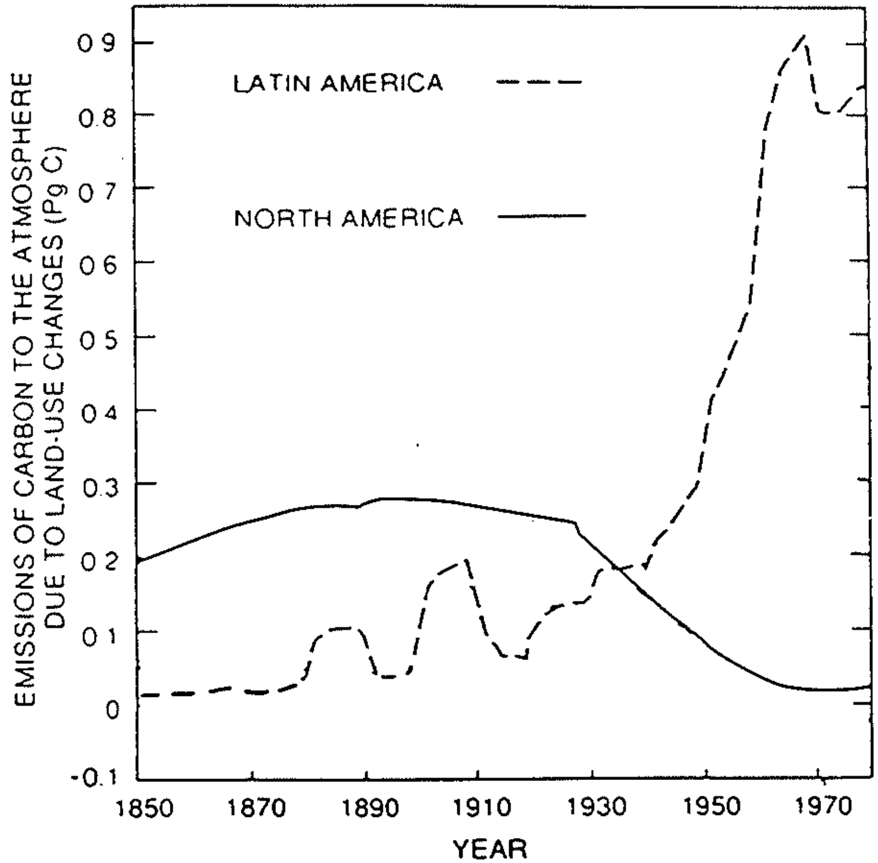


Figure 20. The annual net flux of carbon to the atmosphere (PgC = 10^{15} grams) from North America and Latin America resulting from human land-use. The graphs illustrate that whereas deforestation and increased agricultural activity across Central and South America have led to accelerated release of CO_2 during the last 50 years, the same period has witnessed decreased emissions in North America. A major contributor to this continent-wide decline is the conversion of former agricultural land back to forest and consequent storage of carbon in forest ecosystems. From Dale *et al.* (1991).

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