Land use and forest history in an urban sanctuary in central Massachusetts

Author(s): Robert I. Bertin, Brian G. DeGasperis, Jean M. Sabloff
Source: Rhodora, 108(934):119-141.
Published By: The New England Botanical Club, Inc.
DOI: http://dx.doi.org/10.3119/04-20.1
URL: http://www.bioone.org/doi/full/10.3119/04-20.1

RHODORA, Vol. 108, No. 934, pp. 119–141, 2006

LAND USE AND FOREST HISTORY IN AN URBAN SANCTUARY IN CENTRAL MASSACHUSETTS

ROBERT I. BERTIN, BRIAN G. DEGASPERIS, AND JEAN M. SABLOFF

Department of Biology, College of the Holy Cross,
1 College Street, Worcester, MA 01610
e-mail: rbertin@holycross.edu

ABSTRACT. We investigated current forest composition in relation to land use history at Broad Meadow Brook, a 157 ha urban wildlife sanctuary in Worcester, central Massachusetts. We obtained historical information from aerial photographs dating back to 1938, maps dating to 1831, various published sources, and interviews with long-term residents. We sampled tree vegetation in 35 20 m × 20 m plots and understory vegetation in 140 5 m × 5 m subplots. We obtained ages of several dozen trees by coring. Most of the sanctuary supported dry, mixed-oak forest that has been subject to frequent fires. Disturbed oak woods bore a greater variety of plants than older oak forest, including several non-native species. Mesic forest supported *Fraxinus americana*, *Acer rubrum*, and *A. saccharum*, with an abundant *A. platanoides* understory, a legacy of nearby residential plantings. *Acer rubrum* heavily dominated wet woodland. A small, previously cultivated plot supported an open canopy of *A. rubrum* with a dense understory of herbs and shrubs and showed little tree regeneration. A wooded dump dating to the early to mid-1900s supported a greater percentage of mesic, early-successional, and non-native species than surrounding dry woodland. *Pinus strobus* and *Tsuga canadensis* were rare throughout the sanctuary, a likely result of extensive fires. The site contrasts strongly with Harvard Forest sites 48 km to the northwest in Petersham, Mass., presumably reflecting climatic differences and the greater influence of fire and other human disturbances.

Key Words: forest history, forest succession, non-native species, land use history, Massachusetts, urban forests, Worcester

A site's vegetation is determined by both environmental conditions and site history (DeWet et al. 1998). In forests of the northeastern United States, climate, topography, soil moisture, and soil fertility are important environmental factors (Bromley 1935; Glitzenstein et al. 1990; Westveld et al. 1956) and disturbances have also had important effects (Foster 1992; Motzkin et al. 1999 and references therein).

A pervasive historical pattern in the New England landscape has been the sequence of forest removal, agriculture, field abandonment, and forest regrowth (O'Keefe and Foster 1998). In southern New England, fires have also been important, practiced by the Indians and continuing in some areas to the present (Brown 1960; Day 1953; Patterson and Sassaman 1988; Rawinski 2000). Another human influence has been the introduction of non-native species, a few of which invade forest habitats

and are likely to remain regular components of the wooded landscape. Additional human disturbances include excavating, filling, dumping, and various hydrological modifications (Whitney 1994). These alterations are likely to be most frequent in and near urban areas.

Forest characteristics have been studied extensively in relation to land use history in Central Massachusetts thanks to the efforts of researchers at Harvard Forest in Petersham, Mass. (Foster 1992; Foster et al. 1992; McLachlan et al. 2000; Spurr 1956a, b). These detailed studies are central to our understanding of changes in New England forests and the substantial impacts of both natural and human disturbances. Nevertheless, historical studies are necessarily site-specific. The Petersham studies involved sites where the main human influences were agriculture and wood cutting, and fire was apparently rare. To broaden our view of the role of land use history in shaping New England forests, it is helpful to examine a range of sites reflecting the existing range of environmental conditions and patterns of disturbance. To this end, we studied the history and current forest vegetation of a wildlife sanctuary in Worcester, Massachusetts. In addition to expanding our knowledge of New England forest history, our study is intended to provide information helpful to land management and educational programs at the sanctuary.

MATERIALS AND METHODS

Study area. Broad Meadow Brook sanctuary (BMB), operated by the Massachusetts Audubon Society, is the largest urban wildlife sanctuary in New England, with 157 ha under management. It is located at 42°14′N and 71°46′W in Worcester, a central Massachusetts city with a population of 172,648 in the year 2000. The land within the sanctuary is at 138–195 m in elevation and drains southward via Broad Meadow Brook to the Blackstone River and Narragansett Bay in Rhode Island. The nearest climate station is 8.8 km WNW, at an elevation of 300 m. Here, average annual precipitation is 119 cm and the average frost-free season lasts 173 days (National Oceanic and Atmospheric Administration 1997).

The bedrock foundation of the sanctuary consists of schist and gneiss of the Nashoba formation, probably dating to the Ordovician (Zen 1983). Scattered outcrops occur in the sanctuary, but most bedrock is overlain by glacial till. Upland soils include the Canton, Paxton, Ridgebury, and Woodbridge fine sandy loams, the Whitman loam, and especially the Chatfield-Hollis-Rock Outcrop complex. Most of the

upland soils are classified as either very stony or extremely stony. Wet areas are occupied by the Freetown and Swansea mucks (United States Department of Agriculture 1985).

The principal upland vegetation at BMB is oak forest similar to that described by Westveld et al. (1956) as central hardwoods-hemlock-white pine. More mesic areas resemble transition hardwoods-hemlock-white pine (Westveld et al. 1956) and are occupied by *Acer saccharum* (sugar maple), *Fraxinus americana* (white ash), and *A. rubrum* (red maple), with smaller amounts of *Quercus* spp. (oaks) and *Carya* spp. (hickories). Wet woodland is dominated by *A. rubrum*, and other wet areas support shrub swamp or marsh vegetation.

Historical information. We obtained information on past land use at BMB from several sources. We examined aerial photographs from 1938, 1952, 1971, 1985, and 1999 as well as a map based on surveys in 1825 and 1831, which identified major areas that were forested, open, or in wetlands. Residential maps from 1870, 1886, 1911, and 1922 indicated the homesteads present at those times. City directories provided information on property ownership and on the occupations of property owners. We also examined published historical accounts of Worcester County (Anonymous 1879; Nutt 1919) and obtained oral history from two long-time residents (W. Dauderis and M. Troiano).

Field data. We sampled woodland vegetation in 2001 and 2002 at arbitrarily selected locations that seemed representative of major combinations of site conditions and land use history. In each vegetation type we established one or more transects along which we marked 20 m $\times$ 20 m plots. Within each plot we identified and measured the diameter at breast height (DBH) of all trees of at least 8 cm DBH. We estimated percent vegetation cover at heights of 10+ m and at 3–10 m, both total and for each species separately. In each corner of every plot we sampled a 5 m $\times$ 5 m subplot for understory vegetation (here meaning vegetation shorter than 3 m). In each subplot we recorded the percent cover below 3 m of each tree species and of each non-native species, along with that of any other species whose cover exceeded 5%. Data of the last type were included only to provide an indication of the dominant understory vegetation, and frequencies for this category (percent of subplots occupied) cannot be compared with those for species in the previous two categories, which did not use the 5% threshold. A few species (mostly ferns) were dying back at the time of our sampling, and for these we estimated their cover at peak leafiness.

To estimate the age of woodland in different parts of the sanctuary, we used an increment borer to remove cores from 53 large, arbitrarily selected, canopy trees. We glued these into grooved boards, smoothed them with a scalpel and counted annual growth rings under a dissecting microscope. The ages reported here are minimum ages, since years of seedling growth are missed and some cores did not intersect the center of the trunk. We noted the presence of fire scars and multiple-trunked trees, and examined the soil for the presence of a plow horizon, indicative of prior cultivation.

RESULTS

Chronology of human history. Worcester was originally occupied by Nipmuck Indians, with a settlement reported in the late 1600s at Pakachoag Hill, 2.5 km west of the sanctuary. They practiced some agriculture (Anonymous 1879), though there is no evidence that BMB lands were farmed. It is likely that these Indians burned some local forests, as this behavior seems to have been common in oak/chestnut forests of southern New England (Day 1953; Parshall and Foster 2002; Patterson and Sassaman 1988; Whitney 1994).

The first European settlers appeared in Worcester in the 1670s, but hostilities with the Indians delayed permanent settlement until 1713 (Nutt 1919). Among the early settlers, Digory Serjent (late 1600s) and Jonas Rice (late 1600s, returning in 1713) settled about a kilometer northeast of the north edge of BMB, on the north end of Sagatabscot Hill (Anonymous 1879). The first settler of record living within the modern boundaries of BMB was Jos. Hayward in the 1830s (MacKinnon and Robakiewicz 1993). Despite this scant population, the 1831 map reveals only a third of the sanctuary remaining in forest, with wide cleared strips along what are now Massasoit Road and Granite Street.

An 1870 Worcester map still shows only five homesteads in BMB: four along modern Massasoit Road on the east side of the sanctuary, and one in the northwest corner along Granite Street. By 1886, the number of properties that supported structures had increased to ten. One sawmill was reported to be operating in this area in the 1800s (MacKinnon and Robakiewicz 1993).

Other human disturbances during the 1800s were peat extraction and quarrying of granite. The former was said to be extensive in wetlands adjacent to the brook (Anonymous 1879). Quarrying in the northwestern parts of the sanctuary near Granite Street left a small quarry and several worked rock faces (Figure 1). This was probably part of the area referred to as "near the southern end of Sagatabscot Hill," which furnished

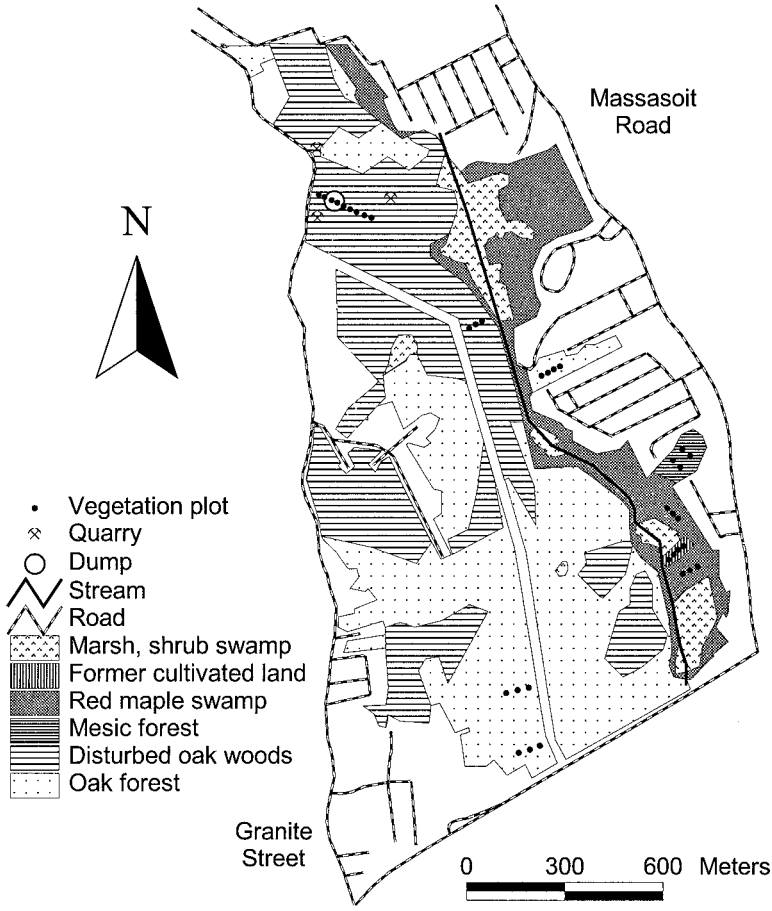

Figure 1. Map of major environmental features and sampling plots at Broad Meadow Brook Sanctuary. The strip of open land bisecting the sanctuary is a power line right-of-way.

"light-colored granite ... much used in former years" (Anonymous 1879). An 1837 report stated that a quarry in this area had been "extensively worked" (Lincoln 1837).

Ownership maps from 1886–1922 show a progressive decline in lot size, from an average of 15 ha to less than 9 ha, and a corresponding increase in the number of parcels. This accompanied a shift in occupation away from agricultural jobs. The percentage of residents of the Broad Meadow Brook area who were engaged in agricultural

pursuits declined from 100% in 1870 to 30% by 1911, according to Worcester City directories. This shift mirrors a regional abandonment of agricultural land as the country's agricultural production shifted west. The last working farm in the area was a pig farm in the northwest corner of the sanctuary that operated until about 1940 (M. Troiano, pers. comm.).

Additional disturbances during the 1900s included tree diseases, the hurricane of 1938, dumping, and fire. The chestnut blight eliminated tree-sized *Castanea dentata* (chestnut) from southern New England around 1920 (Korstian and Stickel 1927). According to a long-time resident, the hurricane of 1938 damaged numerous trees on the property (W. Dauderis, pers. comm.). Rubbish dumps were operated at several locations until the mid-1900s (M. Troiano, pers. comm.). Troiano also reported numerous fires during the mid- and late 1900s, including one in the 1950s that burned both upland and marshland, and smoldered in the marshland peat for many months. The largest recent burn was a ground fire in 1991 that burned approximately half of the sanctuary, according to sanctuary staff.

Beginning in the early 1900s and continuing to the present, expansion of residential developments became a major source of disturbance near the sanctuary's perimeter. Hydrological modifications included channelization of parts of Broad Meadow Brook during the 1930s (MacKinnon and Robakiewicz 1993), and creation of a network of shallower ditches in a shrub swamp at the south end of the property, probably also in the early 1900s. Small amounts of timber were cut from the forests in the 1900s according to Dauderis (pers. comm.). A 25 m wide power line right-of-way running the length of the property was cleared in the late 1950s, and the Broad Meadow Brook Sanctuary was established in 1990.

Current vegetation. We divided vegetation plots into six categories corresponding to different combinations of environmental conditions and history (Table 1; Figure 1). In approximate order from wettest to driest these were 1) red maple swamp, six plots; 2) former cultivated land, four plots; 3) mesic forest, four plots; 4) wooded former dump, two plots; 5) disturbed oak woods, ten plots; and 6) oak forest, nine plots. Below we describe the main features of each vegetation type.

1. Red Maple Swamp

This type characterized flat, wet areas adjacent to Broad Meadow Brook and its associated marshes. The water table was at or near the surface for much of the year and supported at least one vernal pool. This swampland supported fewer tree species than other wooded areas, with

Table 1. Characteristics of tree vegetation in different woodland types at Broad Meadow Brook. Vegetation abbreviations: RM = red maple swamp, FC = former cultivated land, MF = mesic forest, FD = former dump, DO = disturbed oak woods, OF = oak forest.

Characteristics	Vegetation Type					
	RM	FC	MF	FD	DO	OF
No. plots	6	4	4	2	10	9
Avg. tree diam. (cm)	27	23	26	17	21	30
% Cover 10 m+	75	52	65	35	43	48
% Cover 3–10 m	20	22	30	50	24	29
No. species/plot	2.0	3.0	5.3	3.5	4.5	2.9
Intro. species/plot	0.0	0.0	1.0	2.0	0.2	0.0
Stems/plot	16.0	9.0	21.5	20.0	12.0	10.6
Prop. mult. trunk	0.20	0.11	0.06	0.10	0.26	0.01

Acer rubrum comprising 90% of the tree canopy and half of the subcanopy (Tables 2, 3). A greater variety of tree seedlings was present in the understory than in the canopy, with both *Fraxinus americana* and *Prunus serotina* (black cherry) having greater frequencies and percent cover than *A. rubrum* (Table 4). Multiple-trunked trees represented 20% of all trees. Five *A. rubrum* and *F. americana* trees in this area had ages of 64–94 years. Consistent with the older end of this range, aerial photos show these areas as closed canopy forest by 1938.

The most common understory plants were *Symplocarpus foetidus* (skunk cabbage) and *Osmunda cinnamomea* (cinnamon fern), each recorded in half of the subplots, with *Aralia nudicaulis* (wild sarsaparilla), *Aster acuminatus* (whorled aster), and *O. claytoniana* (interrupted fern) also prominent. Nine non-native species were recorded from the 24 subplots, with an average of 1.7 species per subplot (Table 5). Most frequent were *Berberis thunbergii* (Japanese barberry, 71% frequency), *Lonicera morrowii* (Morrow's honeysuckle, 25%), *Acer platanoides* (Norway maple, 25%), and *Rosa multiflora* (multiflora rose, 17%).

2. Former Cultivated Land

The only area that had previously been plowed was a two-hectare rectangle that remained largely open until at least 1952. Two of the larger trees had ages of 32 and 44 years. This low-lying woodland was only about 1 m higher than adjacent red maple swamp. Tree canopy cover was only 52%, allowing a rank growth of understory shrubs and herbs. *Acer rubrum* comprised two-thirds of the tree canopy and most other trees were *Fraxinus americana* and *Ulmus americana* (American

Table 2. Percent cover of canopy (> 10 m) tree species in 20 × 20 m plots in six woodland types at Broad Meadow Brook. Vegetation abbreviations: RM = red maple swamp, FC = former cultivated land, MF = mesic forest, FD = former dump, DO = disturbed oak woods, OF = oak forest.

Species	Percent Cover in Canopy					
	RM	FC	MF	FD	DO	OF
Acer platanoides			14			
Acer rubrum	70	35	13	10	4	
Acer saccharum			13			
Ailanthus altissima				15	< 1	
Betula alleghaniensis	2					
Betula lenta						
Betula papyrifera					< 1	
Betula populifolia					< 1	
Carya glabra			2		1	
Carya ovata	< 1		2			
Fraxinus americana	4	8	10	2		
Juglans cinerea		2				
Populus tremuloides		2		5		
Prunus serotina					5	
Quercus alba			2		2	10
Quercus coccinea				< 1	9	20
Quercus rubra	< 1		10		13	6
Quercus velutina				5	12	14
Ulmus americana		5				

elm; Table 2). The composition of the subcanopy was similar to that of the canopy, but with the addition of *Prunus serotina* and with less *Ulmus* (Table 3). The major tree species in the understory were *P. serotina*, *A. rubrum*, and *F. americana* (Table 4). Other common understory species were *Parthenocissus quinquefolia* (Virginia creeper, 38% frequency), *Solidago rugosa* (rough-stemmed goldenrod, 31%), *Rubus allegheniensis* (blackberry, 25%), and two dogwoods (*Cornus amomum*, 25%; *C. racemosa*, 19%). Nine non-native species were present in the subplots, of which three species were present in at least 30% of the 12 subplots: *Alliaria petiolata* (garlic mustard), *Berberis thunbergii*, and *Lonicera morrowii*. Collectively, non-native species contributed approximately 4% of understory cover versus 56% for native species, with an average of 1.7 non-native species per subplot (Table 5).

3. Mesic Forest

This area was forested by 1938 and occupied a hillside behind residential properties along Massasoit Road. The average number of tree

Table 3. Average percent cover of tree species in the subcanopy (3–10 m) in 20 × 20 m plots in six woodland types at Broad Meadow Brook. Vegetation abbreviations: RM = red maple swamp, FC = former cultivated land, MF = mesic forest, FD = former dump, DO = disturbed oak woods, OF = oak forest.

	Percent Cover in Subcanopy					
Tree Species	RM	FC	MF	FD	DO	OF
Acer platanoides			12			
Acer rubrum	12	12	3	5	6	9
Acer saccharum	< 1		12			
Ailanthus altissima				5	1	
Betula alleghaniensis	4					
Betula lenta					< 1	< 1
Betula papyrifera					< 1	< 1
Betula populifolia					1	< 1
Carpinus caroliniana	< 1		2			
Carya glabra			< 1		1	
Carya ovata	2		< 1		< 1	
Castanea dentata						2
Crataegus sp.					< 1	
Fraxinus americana	< 1	6	< 1	2		
Malus pumila		< 1				
Ostrya virginiana			< 1			
Pinus strobus						< 1
Populus tremuloides				10		
Prunus serotina		5			3	< 1
Quercus alba			< 1		4	7
Quercus coccinea				10	2	4
Quercus rubra	1		< 1		2	2
Quercus velutina				2	4	4
Rhamnus cathartica				5	< 1	
Sassafras albidum						< 1
Ulmus americana	3	< 1	< 1			

species per plot (5.3) was greater than in the other vegetation types (Table 1), with five species each contributing at least 10% canopy cover: *Acer platanoides*, *A. rubrum*, *A. saccharum*, *Fraxinus americana*, and *Quercus rubra* (red oak; Table 2). Of these, only *A. platanoides* and *A. saccharum* were prominent in the subcanopy, each with 12% cover (Table 3). Several tree species were common in the understory, including *A. platanoides*, present in all 16 subplots, *A. saccharum* (69% frequency), *F. americana* (63%), *Prunus serotina* (38%), *Ulmus americana* (38%), and *Q. velutina* (black oak, 25%; Table 4). Two canopy trees in this woodland had ages of 79 and 73 years, and the largest understory *A. platanoides* was 39 years old. Large individuals of this

Table 4. Average percent cover and relative frequency of tree species in the understory (< 3 m) of six woodland types at Broad Meadow Brook. Data are from 5 × 5 m subplots. Vegetation abbreviations: RM = red maple swamp, FC = former cultivated land, MF = mesic forest, FD = former dump, DO = disturbed oak woods, OF = oak forest.

Tree Species	Percent Cover/Relative Frequency in Understory					
	RM	FC	MF	FD	DO	OF
Acer platanoides	0.1/0.25	0.1/0.19	1.8/1.0		0.1/0.18	
Acer rubrum	0.4/0.71	3.2/0.50	0.6/0.13	0.8/0.25	3.7/0.88	3.3/0.83
Acer saccharum	0.3/0.29		2.0/0.69		0.0/0.03	
Ailanthus altissima				3.9/0.63	0.1/0.10	
Betula alleghaniensis	0.2/0.33				0.1/0.10	0.0/0.06
Betula lenta					0.1/0.03	0.5/0.08
Betula populifolia					0.4/0.18	0.0/0.06
Carya cordiformis					0.0/0.03	
Carya glabra			0.1/0.19		0.7/0.30	0.0/0.03
Carya ovata	0.4/0.42		0.2/0.13	0.1/0.13	0.7/0.30	0.0/0.03
Castanea dentata			0.2/0.13			2.0/0.67
Crataegus sp.					0.2/0.18	0.1/0.06
Fagus grandifolia						0.0/0.03
Fraxinus americana	1.4/0.92	0.2/0.44	0.6/0.63	0.4/0.13	0.3/0.30	
Fraxinus pensylvanica				0.1/0.13		
Juglans cinerea		0.1/0.19				
Nyssa sylvatica	0.2/0.13					
Pinus strobus					0.0/0.03	0.1/0.03
Populus tremuloides				0.2/0.25	0.0/0.03	
Prunus serotina	1.0/0.75	1.8/0.69	0.4/0.38	0.8/0.50	2.7/0.80	0.3/0.28
Quercus alba				0.2/0.13	1.6/0.63	3.1/0.86
Quercus coccinea				0.4/0.13	0.8/0.23	1.0/0.44
Quercus rubra	0.1/0.25		0.1/0.19	0.2/0.25	1.7/0.60	1.9/0.97
Quercus velutina	0.1/0.17		0.1/0.25	0.6/0.38	3.9/0.95	1.3/0.81
Rhamnus cathartica				0.6/0.38		
Sassafras albidum					0.0/0.05	0.6/0.31
Ulmus americana	0.3/0.17		0.7/0.38	0.1/0.13		

species in an adjacent backyard (age 67 years) probably served as a seed source.

Understory cover averaged only 19%, reflecting the dense maple overstory. Non-native species contributed over a quarter of this total. The most common native species were *Toxicodendron radicans* (poison ivy, 44% frequency) and *Osmunda claytoniana* (13%). The most frequent non-native species were *Acer platanoides* (100% frequency), *Ribes sativum* (European red currant, 19%), *Alliaria petiolata* (13%), *Berberis thunbergii* (13%), and *Euonymus alata* (winged euonymus, 13%; Table 5).

Table 5. Percent cover and relative frequency of non-native species in the understory (< 3 m) of six woodland types at Broad Meadow Brook. Data are from 5 × 5 m subplots. Vegetation abbreviations: RM = red maple swamp, FC = former cultivated land, MF = mesic forest, FD = former dump, DO = disturbed oak woods, OF = oak forest.

	Percent Cover/Relative Frequency in Understory					
Non-Native Species	RM	FC	MF	FD	DO	OF
Acer platanoides	0.1/0.25	0.1/0.19	1.8/1.00		0.1/0.19	
Alliaria petiolata		1.0/0.38	0.8/0.13	0.1/0.13	0.0/0.08	
Ailanthus altissima				3.9/0.63	0.1/0.11	
Berberis thunbergii	0.5/0.71	0.2/0.31	0.5/0.13		0.0/0.03	
Celastrus orbiculatus	0.0/0.08	0.3/0.06		13.5/0.88	3.8/0.50	
Chelidonium majus				0.1/0.13		
Euonymus alata	0.0/0.08		1.5/0.13			
Euonymus europaea			0.5/0.06			
Ligustrum sp.		0.1/0.06				
Lonicera morrowii	2.4/0.25	1.7/0.44		0.7/0.25	0.1/0.03	
Malus sp.				0.1/0.13	0.1/0.08	
Nepeta cataria				0.1/0.13		
Polygonum cuspidatum		0.0/0.06				
Rhamnus cathartica				0.6/0.38	0.5/0.19	
Rhamnus frangula	0.0/0.04				0.0/0.03	
Ribes sativum	0.0/0.04	0.0/0.06	0.5/0.19			
Rosa multiflora	0.1/0.17	0.1/0.13			0.0/0.06	
Solanum carolinense				0.1/0.13		
Sorbus aucuparia	0.0/0.08			0.1/0.13	0.0/0.06	
Non-native spp. per subplot	1.7	1.7	1.6	2.9	1.4	0.0
Non-native cover (%)	3.3	3.6	5.5	19.1	4.8	0.0

4. Wooded Former Dump

Judging by the surrounding vegetation, this area was originally oak forest. The original soil has been covered with a meter or more of dumped material, probably dating from the early and middle 1900s. Refuse included metal and glass along with some rubber and leather items in an apparently organic-rich matrix. Consistent with this area's recent history of disturbance, average tree diameter (17 cm) was smaller than in other vegetation types (23–28 cm) and the canopy cover lower (35% cover at > 10 m, 50% cover at 3–10 m; Table 1). The largest *Ailanthus altissima* (tree-of-heaven) growing on the dump was 38 years old and a nearby *Rhamnus cathartica* (common buckthorn) was dated at 33 years. The most prominent canopy species included the non-native *A. altissima* (15% cover) along with *Acer rubrum* (10%), *Populus tremuloides* (quaking aspen, 5%), and *Quercus velutina* (5%; Table 2).

The 3–10 m stratum also contained early successional species, including *P. tremuloides*, *R. cathartica*, and *Ailanthus altissima* (10%, 5%, 5% cover, respectively). Other major contributors to this layer were *Q. coccinea* (scarlet oak, 10% cover), *Celastrus orbiculata* (Oriental bittersweet, 10%), and *Acer rubrum* (5%; Table 3).

The understory contained further evidence of disturbance. Common tree species included *Ailanthus altissima* (63% frequency), *Prunus serotina* (50%), *Quercus velutina* (38%), *Rhamnus cathartica* (38%), *Acer rubrum* (25%), *Q. rubra* (25%), and *Populus tremuloides* (25%; Table 4). Non-native species dominated the understory, making up 19% cover compared to total understory cover of 30%. The most common were *Celastrus orbiculatus* (88% frequency) and *Lonicera morrowii* (25%; Table 5). The average number of non-native species per subplot (2.9) and cover contribution of non-natives in the understory were higher than in any other vegetation type.

5. Disturbed Oak Woods

Ten plots were placed in this vegetation type, characterized by 1) a predominance of oak species in the canopy and 2) occurrence in areas that were fields or open woodland in 1952 aerial photographs. Six large canopy trees in or near these plots were 43–55 years old.

Oaks contributed most canopy cover, with *Quercus rubra*, *Q. velutina*, and *Q. coccinea* each contributing at least 10% of the 44% total (Table 2). *Acer rubrum* was the most common subcanopy species, contributing a quarter of the 24% cover, and oaks collectively accounted for half (Table 3). A quarter of sampled trees (especially *Prunus serotina*, *A. rubrum*, and *Rhamnus cathartica*) had multiple trunks and fire scars were evident on many older trees.

Among understory trees, *Quercus velutina* had the highest frequency (95%), followed by *Acer rubrum* (88%), *Prunus serotina* (80%), *Q. alba* (white oak, 63%), and *Q. rubra* (60%; Table 4). Other common understory species were typical of dry, disturbed habitat. They included the native *Rubus allegheniensis* (30%), *Vaccinium angustifolium* (early lowbush blueberry, 30%), *Gaylussacia baccata* (huckleberry, 23%), *Pteridium aquilinum* (bracken fern, 20%), and the sedge *Carex pensylvanica* (18%) as well as the non-native *Celastrus orbiculatus* (50% frequency) and *A. platanoides* (19%; Table 5). Eleven non-native species were recorded in the 32 subplots, comprising 4.8% cover (9% of total cover), and averaging 1.4 species per subplot (Table 5).

6. Oak Forest

Nine plots were located in dry oak forest, characterized by widely spaced, single-trunked trees, averaging 10.9 stems per 400 m^2 plot. Cores from ten canopy trees revealed ages of 59–99 years, and these areas were wooded in both 1938 and 1952 photographs. These trees grew more slowly than those in the disturbed oak plots, with average diameter increments of 0.49 mm versus 0.80 mm for *Quercus coccinea*, 0.76 mm versus 1.01 mm for *Q. rubra*, and 0.54 mm versus 1.02 mm for *Q. velutina*. The last two differences are significant according to t-tests, despite the small sample sizes ($t = 2.65$, $p < 0.05$, $N = 3, 3$; $t = 4.03$, $p < 0.05$, $N = 4, 3$). Most trees were canopy individuals of at least 20 cm DBH (83% of the 96 individuals sampled). Evidence of fires was widespread, including multiple fire scars on most large trees and blackened dead wood in a few places on the ground.

The canopy consisted almost exclusively of oaks (*Quercus coccinea*, 20% cover; *Q. velutina*, 14%; *Q. alba*, 10%; *Q. rubra*, 6%; Table 2). *Acer rubrum* contributed most subcanopy cover (9%), followed by *Q. alba*, *Q. coccinea*, *Q. velutina*, and *Q. rubra* (7%, 4%, 4%, 2%, respectively) and fractional percentages of several other species (Table 3). Sixteen tree species were present in the understory, with the four oaks, *A. rubrum*, and *Castanea dentata* being the most common (Table 4). Apart from tree seedlings, the understory was dominated by ericaceous species (especially *Gaylussacia baccata*, 56%, and *Vaccinium pallidum*, late lowbush blueberry, 28%) and *Pteridium aquilinum* (31%). No non-native species was observed in any of the 40 subplots.

DISCUSSION

Forest history. The dominant forest type at BMB prior to European influence was probably mixed-oak forest with appreciable *Castanea dentata* and smaller amounts of other species. This forest type is consistent with that described by Cogbill et al. (2002) for south-central Massachusetts based on early proprietor's records and witness trees. It is also typical of that described by Bromley (1935) for southern New England, including Douglas Woods, 18 km to the south. In Douglas, *Quercus alba*, *Q. coccinea*, and *Q. velutina* predominated, with scattered *Pinus strobus* and *C. dentata* on ''sterile, rocky ground'' that was frequently burned. Most authors (Day 1953; Little 1974; Parshall and Foster 2002; Patterson and Sassaman 1988) believe that fire was widespread in oak forests of southern New England in pre-colonial times, reflecting the Indians' efforts to enhance wildlife habitat and to make

travel and hunting easier, though this view has been challenged (Russell 1983). Regular burning would have produced open wooded uplands, with large and widely spaced oaks and chestnuts underlain by low herbaceous vegetation or fire-tolerant shrubs, especially *Vaccinium* spp. and *Gaylussacia baccata* (Brown 1960). *Quercus alba* is likely to have been more prevalent than today (Abrams 2003; Cogbill et al. 2002). Early written accounts of Worcester's forests lack detail but are consistent with the above description. Whitney (1793) referred to ''oak, walnut [hickory] and chestnut on the higher lands, some pine on the small plains and valleys'' and Dwight (1821) characterized Worcester forests seen on a 1796 excursion as ''oak, chestnut, hickory, etc. with interspersions of white and yellow pine.''

Mesic and wet areas would have had different mixes of tree species (''ash, birch and maple'' according to Whitney 1793) and a thicker understory. Wet woodlands were undoubtedly dominated by *Acer rubrum* as a result of this species' ability to withstand both wet and shaded conditions, with *Ulmus americana* probably more common than it is today, due to the absence of Dutch elm disease (*Ceratocystis ulmi* Moreau). *Tsuga canadensis* (hemlock) could have been common, since it is long-lived (Bromley 1935), highly shade tolerant (Hicks 1998), and does well in swamps and lowland woods in other parts of central Massachusetts (Foster et al. 1992). However, its rarity on the sanctuary today suggests that local seed sources have been absent for a long time. Mesic woodlands seem likely to have been dominated by mixed hardwoods, perhaps similar to the forests described by Foster et al. (1992) for the Prospect Hill tract in Petersham, Mass., 48 km to the northwest, based on pollen evidence. This site included *Fagus grandifolia* (beech), *Betula alleghaniensis* (yellow birch) and *B. lenta* (black birch), *A. saccharum*, and *Quercus rubra* along with some *Pinus strobus* and *T. canadensis*. The more southerly location and 100 m lower elevation of BMB may have favored more hickory and oak than in the Prospect Hill tract. Additionally, fire-sensitive species such as *F. grandifolia*, *T. canadensis*, and *P. strobus* may have been less common given the small size of the mesic woodlands and the extensive surrounding fire-prone oak forest.

Initial clearing of BMB forests likely occurred in the 1700s, with woodlands near roads being cleared first (e.g., Foster 1992). Because *Pinus strobus* (a favored timber species; Cronon 1983) was apparently not common in the area (Cogbill et al. 2002), the initial cutting may have been mostly of hardwoods for firewood and to clear ground for pastures, eliminating two-thirds of the forest by the 1830s. The greater proportion of woodland remaining at BMB than the 16% reported by Lincoln

(1837) for Worcester as a whole may reflect the location of BMB on the city's outskirts and the poor agricultural potential of BMB land. All BMB woodland was evidently cut before the next record of land use, namely the 1938 aerial photograph. Although several areas were wooded on both the 1831 map and in the 1938 photograph, trees in these areas had a maximum age of under a century. Thus it is likely that virtually the entire sanctuary was in some form of agriculture during the mid- to late 1800s, coincident with the peak of agriculture and forest removal in the state (Foster 1992; Whitney 1994).

Most of the sanctuary was ill suited to agriculture owing to soils that were stony and, judging by current vegetation, also dry and nutrient poor. The limited agricultural potential and insufficient stream gradient for extensive mill development probably limited early use by colonists. Only six households were present as late as 1870, when Worcester was a thriving city of 41,000 (Nutt 1919). The limited agricultural use is reflected in the paucity of stone walls and little evidence of plowing. Most unplowed land was probably used at least briefly for pasture. Had it been used exclusively for woodlots (i.e., never cleared), one would expect to see many multiple-trunked individuals of oak and other stump-sprouters. However, trees with single trunks are the norm over most of the sanctuary, indicating an origin from seedlings rather than stumps. Some cutting may have occurred in the red maple swamps, where 20% of sampled stems were multiple-trunked. Such cutting would be consistent with the practice of using marginal land, including poorly drained sites, for cutting firewood (Whitney 1994).

Much of the land fell from agricultural use in the late 1800s or early 1900s, reflected in maximum tree ages of 70–100 years over most of the sanctuary. While *Pinus strobus* is a typical old-pasture invader in much of New England (Bromley 1935; Spurr 1956a), the current rarity of pine at BMB suggests that it was uncommon in the post-agricultural landscape of this site. Even if pine had become established after abandonment of pasture and then been selectively cut, we would expect to see many remaining individuals that were too young or misshapen to be cut. A more likely pioneer assemblage is the mixture of deciduous species found today in the sanctuary's youngest woods. Dominant species are *Betula populifolia* (gray birch), *Populus* spp. (aspens), and *Prunus pensylvanica* (pin cherry), along with some oaks, hickories, and *Acer rubrum*. Any fires would have eliminated the thin-barked birches, aspens, cherries, and maples, leaving oak-dominated woodland.

Agriculture persisted for longest in the northwest corner of the sanctuary, these lands apparently being abandoned 50–70 years ago. This

area currently supports large, well-branched, open-grown oaks, consistent with the savanna-like vegetation visible in 1952 and 1971 aerial photographs. The vegetation in this area differs from that in regions of the sanctuary that are designated as oak forests, containing greater diversity in all layers and more non-native species. Two thorny taxa that were common here [*Crataegus* spp. (hawthorns) and *Rhamnus cathartica*] are often present on abandoned pastures (Stover and Marks 1998), presumably reflecting their avoidance by grazers.

The difference between plots in disturbed oak woods and oak forest probably reflects a combination of environmental and historical factors. While the most common soil type in plots of both types is Chatfield-Hollis-Rock Outcrop complex, the disturbed plots may be slightly more mesic than the plots in oak forest. Greater moisture would have made them more attractive to farmers and might account for their more recent agricultural use. Correlations between patterns of land use and environmental conditions have often been suggested (Foster 1992; Glitzenstein et al. 1990). Greater moisture could also explain the more rapid tree growth on these sites, though other factors could also account for this. Disturbed oak woods contain more *Quercus rubra* and fewer individuals of *Q. alba*, *Q. coccinea*, and *Q. velutina* than the oak forest. Of the four oak species, *Q. rubra* is most often found under mesic conditions (White et al. 1990), and its acorns are least likely to germinate under dry conditions (Korstian 1927).

The cultivated land appears to have been abandoned in the mid-1900s, according to aerial photographs, later than the times of abandonment of most agricultural land at BMB. Later abandonment of cultivated land than pasture land has also been observed on other sites (Foster 1992), reflecting the former's greater versatility.

The mesic forest has been largely wooded since at least 1938. The numerous canopy individuals of *Fraxinus americana* (one with an age of 73 years) and *Quercus rubra* were probably established shortly after abandonment, reflecting high light availability. Maples (*Acer rubrum*, *A. platanoides*, and *A. saccharum*) have been increasing since, reflecting their better shade tolerance, and have established a dense subcanopy. *Acer platanoides* seeded into woodland in the 1960s from neighboring residential plantings dating from around 1930.

Several regional disturbances in the early to mid-1900s affected BMB forests. Chestnut blight [*Cryphonectria parasitica* (Murrill) Barr] eliminated tree-sized chestnuts before 1920 (Korstian and Stickel 1927). The former abundance of this tree in oak forest at BMB is attested by its presence in 60% of 40 subplots in this vegetation type. There is no

evidence that the chestnut's demise was accompanied by an invasion of early successional species. The replacing trees were undoubtedly oaks, as was true at other southern New England sites (Korstian and Stickel 1927), causing a rapid change from oak-chestnut forest to oak forest. The presence of chestnut sprouts in this woodland is clear evidence that these areas were wooded rather than in pasture in the early 1900s, otherwise no chestnut stumps would have been available to initiate sprouts. In striking contrast, chestnut was absent from all 36 subplots in disturbed oak woods, land that was still in pasture when chestnut blight appeared.

The second major disturbance was the hurricane of 1938. This storm passed northward through Massachusetts, with the eye traveling up the Connecticut River Valley. Because the storm arrived when soils were saturated from previous rains, its effects on forests were especially severe. At Harvard Forest in Petersham, 70% of the standing volume of timber was toppled (Foster and Boose 1992; Spurr 1956b). While a local resident described tree damage at BMB (W. Dauderis, pers. comm.), effects were probably less severe than in Petersham. Broad Meadow Brook lies 40 km further from the storm track than Harvard Forest. Also, *Pinus strobus*, which was particularly at risk because it often grows as a canopy emergent (Spurr 1956b), was apparently rare. Finally, most of the forest was young, probably a few decades old. Small trees are less susceptible to damage than larger trees, since wind damage increases with tree height (Foster and Boose 1992). Windthrow mounds were rare on the sanctuary, suggesting that damage was restricted largely to broken limbs and tops, with little influence on forest composition.

Although we recorded *Ulmus americana* in mesic woodland and in red maple swamps, Dutch elm disease undoubtedly has reduced the frequency and average size of this tree. We recorded one elm of 40 cm DBH, but most were less than half this diameter, despite the capacity of this species to grow to a large size.

Fire has been frequent in BMB woodlands, as evidenced by comments of long-time residents and the presence of multiple fire scars on large trees. Fire-scarred trees were present in all 19 of our oak plots. Most recent fires have apparently been set by vandals. The fires have undoubtedly influenced tree species composition. Almost all canopy trees in dry woodland (oak forest and disturbed oak woods) were oaks, which are relatively fire resistant, and they presumably represent the first cohort of oaks established after pasture abandonment. The most common species in our oak forest plots (*Quercus coccinea*, *Q. alba*, *Q. velutina*) were the same three species favored by fire on upland sites in

western Rhode Island (Brown 1960). The subcanopy and understory included a wider range of tree species than the canopy, and *Acer rubrum* was particularly common. Most of the maples sprouted from stumps since the most recent fires. In contrast, most oaks were single-trunked, presumably reflecting their greater fire tolerance and the absence of fires intense enough to cause mortality of large individuals. The evident fire history of Broad Meadow Brook contrasts with the apparent rarity of fires in most forest tracts in Petersham, which support many fire-sensitive taxa including *Pinus strobus*, *Tsuga canadensis*, *Fagus grandifolia*, *Betula* spp., and *A. rubrum* (McLachlan et al. 2000).

Trees unable to withstand fires, including thin-barked species (*Acer rubrum*, *Fagus grandifolia*, *Betula* spp.) and non-sprouting conifers like *Pinus* and *Tsuga* (Bromley 1935; Brown 1960; Little 1974; Nichols 1913; Swan 1970) were rare or absent in dry woodland at BMB. While *P. strobus* colonizes burned areas if seed sources are available (Brown 1960), seedlings and saplings are readily killed by fires. The two conifers are common in central Massachusetts (Spurr 1956a; Westveld et al. 1956). In all our plots combined, however, we recorded only one pine sapling and no hemlocks, reflecting their nearly complete absence from the sanctuary. Their absence from mesic or wetter sites seems unlikely to reflect recent fires, since we found no evidence of such fires in these habitats. The 1938 hurricane and harvesting of pine for timber (Abrams 2001; Bromley 1935) and hemlock for tanbark (O'Keefe and Foster 1998; Russell et al. 1993) could have reduced conifer abundance. In other Massachusetts forests subject to such harvesting and destruction, however, the species are still prominent (Foster et al. 1992; McLachlan et al. 2000). Rather, we suggest that centuries of fire and a predominance of fire-prone oak forest around the smaller mesic and wet woodlands prevented pines from becoming common in this area both during the pre-colonial period and more recently. These two species seem to be less common in Worcester generally than in nearby rural areas. Rawinski (2000) found just four pine saplings in 46 plots covering nearly two hectares of oak woodlands in Worcester. In another survey of 32 woodlots of all kinds in Worcester, white pine and hemlock were only the 14th and 40th most common tree species, respectively (Bertin et al. 2005). These species may have difficulty coping with the varied disturbances, including fire, typical of urban woodlands.

Non-native species. We encountered 20 non-native species in our 140 subplots. Most frequent were *Acer platanoides*, *Alliaria petiolata*, *Berberis thunbergii*, *Celastrus orbiculatus*, and *Lonicera morrowii*, all

highly invasive in Massachusetts (Weatherbee et al. 1998). Non-native species were not evenly distributed across woodland types. Oak forest was notable for its lack of non-natives. The difficulty of non-natives getting established in dry wooded habitats has been noted previously (Rejmánek 1999). Eleven non-native species were recorded in disturbed oak woods, though five of these were identified in only one or two subplots. As noted previously, the disturbed oak plots may have been slightly more mesic, on average, than the plots in oak forest. The former had more recently been used for agricultural purposes than the latter, and several of them were close to the dump plots and possibly influenced by the high density of non-native species there.

Almost all subplots in the remaining vegetation types contained one or more non-native species. Many of these subplots were in areas of intensive past human use (dump, cultivated land) or near long-established residential areas that undoubtedly provided seeds of several exotics, including *Acer platanoides*, *Euonymus alata*, *Berberis thunbergii*, and *Ribes sativum*. Several of the common invasives are likely to become permanent parts of the forest communities, barring eradication efforts.

Future trends. Forest development in the oak and disturbed oak sites at BMB will depend heavily on fire. Frequent fires will assure an oak-dominated canopy, as has been predicted for other parts of the Northeast (Abrams 1992; Brown 1960; Little 1974; White et al. 1990). Low fire frequency would favor *Acer rubrum*, the most common subcanopy species (Little 1974). Increases in *A. rubrum* have occurred elsewhere, and have been attributed to a combination of fire suppression and this species' ability to thrive under conditions of low light, water, and nutrients (Abrams 1998; Lorimer 1984). *Pinus strobus* and *Tsuga canadensis*, though favored by fire suppression, will presumably remain rare due to the paucity of nearby seed sources.

Changes in substrate associated with the dump will have long-lasting effects on this patch of woodland. Early successional species, such as *Populus tremuloides*, *Ailanthus altissima*, and *Rhamnus cathartica*, will probably persist for a few decades, reflecting the presence of saplings under a relatively open canopy. More shade-tolerant species will gradually increase, including oaks typical of the surrounding woodland and other species seemingly favored by the altered substrate, such as *Fraxinus americana*, *Carya ovata*, *Prunus serotina*, and *Acer rubrum*.

Acer platanoides is likely to increase in mesic forest, reflecting the abundance of saplings and its high shade tolerance. This woodland

seems headed for an *A. platanoides–A. saccharum* codominance, with smaller amounts of *A. rubrum*. Major declines are likely for *Fraxinus americana* and *Quercus rubra*, both of which were poorly represented in the subcanopy, reflecting their inability to thrive under a maple canopy (Hicks 1998). *Fraxinus americana* also has suffered from a regional decline associated with a mycoplasma-like organism and perhaps other factors (Hicks 1998).

In the formerly cultivated plots, *Acer rubrum* will remain dominant for many decades, reflecting growth of existing individuals. The open canopy will also permit growth of *Fraxinus americana*, *Prunus serotina*, and perhaps *Ulmus americana*. The moist substrate would seem well suited to *A. saccharum* and *A. platanoides*, though seedlings of these species were rare, perhaps for lack of nearby seed sources. Successional changes are likely to be slowed by the paucity of tree seedlings, apparently due to rank growth of shrubs and herbaceous species.

The red maple swamp seems unlikely to change much, with *Acer rubrum* remaining as the overwhelming dominant. *Betula alleghaniensis*, *Ulmus americana*, and perhaps *Fraxinus americana* will probably remain as minor components of the forest. Seedlings of several species (*Prunus serotina*, *Quercus velutina*, *Q. rubra*, *A. saccharum*, *A. platanoides*, *Carya ovata*) seem unlikely to thrive because of either the dense canopy, or high water table, or both.

In summary, Broad Meadow Brook includes a mosaic of woodland types whose species composition and canopy structure bear the imprint of site conditions and history of land use. Environmental factors are largely responsible for producing the difference between oak forest, mesic forest, and red maple swamp. Fire has had major effects on the composition of the drier woodlands and probably accounts for the general rarity of fire-intolerant species like *Tsuga*, *Pinus*, and *Fagus*. Abundance and size of *Ulmus americana* and especially *Castanea dentata* are limited by introduced pests. Species introductions have had the greatest effect on mesic woodland near a residential area, where *Acer platanoides* has become common. Substrate alterations associated with a former dump have had long-lasting effects on both canopy and understory vegetation. Changes in forest composition are likely to continue on much of the sanctuary, reflecting recovery from past disturbances, altered fire regimes, and management practices.

ACKNOWLEDGMENTS. Thanks to Walter Dauderis and Michael Troiano for sharing their knowledge of the study area, to Richard Lent for help with GIS software, and to Deborah Cary and the staff of the

Broad Meadow Brook office of the Massachusetts Audubon Society for providing access to and information about the sanctuary.

LITERATURE CITED

ABRAMS, M. D. 1992. Fire and the development of oak forests. BioScience 42: 346–353.

———. 1998. The red maple paradox. BioScience 48: 355–364.

———. 2001. Eastern white pine versatility in the presettlement forest. BioScience 51: 967–969.

———. 2003. Where has all the white oak gone? BioScience 53: 927–939.

ANONYMOUS. 1879. History of Worcester County, Massachusetts. 2 vols. C. F. Jewett and Co., Boston, MA.

BERTIN, R. I., M. E. MANNER, B. F. LARROW, T. W. CANTWELL, AND E. M. BERSTENE. 2005. Norway maple (*Acer platanoides*) and other non-native trees in urban woodlands of central Massachusetts. J. Torrey Bot. Soc. 122: 225–235.

BROMLEY, S. W. 1935. The original forest types of southern New England. Ecol. Monogr. 5: 63–89.

BROWN, J. H., JR. 1960. The role of fire in altering the species composition of forests in Rhode Island. Ecology 41: 310–316.

COGBILL, C. V., J. BURK, AND G. MOTZKIN. 2002. The forests of presettlement New England, USA: Spatial and compositional patterns based on town proprietor surveys. J. Biogeogr. 29: 1279–1304.

CRONON, W. 1983. Changes in the Land. Hill and Wang, New York.

DAY, G. M. 1953. The Indian as an ecological factor in the northeastern forest. Ecology 34: 329–346.

DEWET, A. P., J. RICHARDSON, AND C. OLYMPIA. 1998. Interactions of land-use history and current ecology in a recovering ''urban wildland.'' Urban Ecosyst. 2: 237–262.

DWIGHT, T. 1821. Travels in New England and New York, Vol. 2. S. Converse, New Haven, CT.

FOSTER, D. R. 1992. Land-use and vegetation dynamics in central New England: An historical perspective. J. Ecol. 80: 753–772.

——— AND E. R. BOOSE. 1992. Patterns of forest damage resulting from catastrophic wind in central New England, USA. J. Ecol. 80: 79–98.

———, T. ZEBRYK, P. SCHOONMAKER, AND A. LEZBERG. 1992. Post-settlement history of land use and vegetation dynamics of a *Tsuga canadensis* (hemlock) woodlot in central New England. J. Ecol. 80: 773–786.

GLITZENSTEIN, J. S., C. D. CANHAM, M. J. MCDONNELL, AND D. R. STRONG. 1990. Effect of environment and land-use history on upland forests of the Cary Arboretum, Hudson Valley, New York. Bull. Torrey Bot. Club 117: 106–122.

HICKS, R. R., JR. 1998. Ecology and Management of Central Hardwood Forests. John Wiley & Sons, Inc., New York.

KORSTIAN, C. F. 1927. Factors Controlling Germination and Early Survival in Oaks. Bull. 19, Yale Univ. School Forestry, New Haven, CT.

——— AND P. W. STICKEL. 1927. The natural replacement of blight-killed chestnut in the hardwood forests of the Northeast. J. Agric. Res. 34: 631–648.

LINCOLN, W. 1837. History of Worcester, Massachusetts, from its Earliest Settlement to September, 1836. Moses D. Phillips and Co., Worcester, MA.

LITTLE, S. 1974. Effects of fire on temperate forests: Northeastern United States, pp. 225–250. *In*: T. T. Kozlowski and C. E. Ahlgren, eds., Fire and Ecosystems. Academic Press, New York.

LORIMER, C. G. 1984. Development of the red maple understory in northeastern oak forests. Forest Sci. 30: 3–22.

MACKINNON, W. AND P. ROBAKIEWICZ. 1993. Ecological management plan for Broad Meadow Brook Wildlife Sanctuary. Unpubl. ms., Massachusetts Audubon Society, Worcester, MA.

MCLACHLAN, J. S., D. R. FOSTER, AND F. MENALLED. 2000. Anthropogenic ties to late-successional structure and composition in four New England hemlock stands. Ecology 81: 717–733.

MOTZKIN, G., P. WILSON, D. R. FOSTER, AND A. ALLEN. 1999. Vegetation patterns in heterogeneous landscapes: The importance of history and environment. J. Veg. Sci. 10: 903–920.

NATIONAL OCEANOGRAPHIC AND ATMOSPHERIC ADMINISTRATION. 1997. Local climatological data; annual summary with comparative data, Worcester, Massachusetts. National Oceanic and Atmospheric Administration, National Climatic Data Center, Asheville, NC.

NICHOLS, G. E. 1913. The vegetation of Connecticut. Torreya 13: 89–112, 199–215.

NUTT, C. 1919. History of Worcester and its People. 2 vols. Lewis Historical Publishing Co., New York.

O'KEEFE, J. AND D. R. FOSTER. 1998. An ecological history of Massachusetts forests. Arnoldia 58 (2): 2–31.

PARSHALL, T. AND D. R. FOSTER. 2002. Fire on the New England landscape: Regional and temporal variation, cultural and environmental controls. J. Biogeogr. 29: 1305–1317.

PATTERSON, W. A., III AND K. E. SASSAMAN. 1988. Indian fires in the prehistory of New England, pp. 107–135. *In*: G. P. Nichols, ed., Holocene Human Ecology in Northeastern North America. Plenum Publishing Company, New York.

RAWINSKI, T. J. 2000. Fire-maintained Oak Woodlands in the Area of Worcester, Massachusetts: Vegetation Ecology, Wildlife, and Conservation. Report for Massachusetts Dept. Fish., Wildl., and Environm. Law Enforcement, Div. Fish. Wildl., Natural Heritage and Endangered Species Program, Westborough, MA.

REJMÁNEK, M. 1999. Invasive plant species and invasible ecosystems, pp. 79–102. *In*: O. T. Sandlund, P. J. Schei, and Å. Viken, eds., Invasive Species and Biodiversity Management. Kluwer, Dordrecht, The Netherlands.

RUSSELL, E. W. B. 1983. Indian-set fires in the forests of the northeastern United States. Ecology 64: 78–88.

———, R. B. DAVIS, R. S. ANDERSON, T. E. RHODES, AND D. S. ANDERSON. 1993. Recent centuries of vegetational change in glaciated northeastern United States. J. Ecol. 81: 647–664.

SPURR, S. H. 1956a. Forest associations in the Harvard Forest. Ecol. Monogr. 26: 245–262.

———. 1956b. Natural restocking of forests following the 1938 hurricane in central New England. Ecology 37: 443–451.

STOVER, M. E. AND P. L. MARKS. 1998. Successional vegetation on abandoned cultivated and pastured land in Tompkins County, New York. J. Torrey Bot. Soc. 125: 150–164.

SWAN, F. R., JR. 1970. Post-fire response of four plant communities in south-central New York State. Ecology 51: 1074–1081.

UNITED STATES DEPARTMENT OF AGRICULTURE. 1985. Soil survey of Worcester County, Massachusetts, northeastern part. U.S.D.A., Soil Conservation Service, Washington, DC.

WEATHERBEE, P. B., P. SOMERS, AND T. SIMMONS. 1998. A Guide to Invasive Plants in Massachusetts. Massachusetts Div. Fish. Wildl., Westborough, MA.

WESTVELD, M., R. I. ASHMAN, H. I. BALDWIN, R. P. HOLDSWORTH, R. S. JOHNSON, J. H. LAMBERT, H. J. LUTZ, L. SWAIN, AND M. STANDISH. 1956. Natural forest vegetation zones of New England. J. Forest. 54: 332–338.

WHITE, D. W., W. WORTHEN, AND E. W. STILES. 1990. Woodland in a post-agricultural landscape in New Jersey. Bull. Torrey Bot. Club 117: 256–265.

WHITNEY, G. G. 1994. From Coastal Wilderness to Fruited Plain. Cambridge Univ. Press, Cambridge, U.K.

WHITNEY, P. 1793. Worcester County: America's First Frontier. Isaiah Thomas, Worcester, MA.

ZEN, E.-AN. 1983. Bedrock geologic map of Massachusetts. U.S. Geological Survey, Washington, DC.