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Fire History and Tree Recruitment in an Uncut New England Forest

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Fire and forest histories in a hemlock–pine forest in Vermont have been reconstructed by dating fire scars and reconstructing the age distributions of living and dead trees. The ages of living red pines, white pines, and hemlocks show that most of the present forest germinated after a series of spatially overlapping fires between A.D. 1790 and 1850. The ages of cross-dated, dead red pines indicate that this was the third major recruitment interval for pines in this forest since ca. A.D. 1450. We interpret the fire scar and tree age data as recording ca. 50-yr intervals of increased fire frequency recurring every 100–200 yr in response to accumulating fuel loads that coincide with summer drought. The historical records of fires and tree ages, together with the present fuel load, suggest that the next interval of stand-regenerating fires is now overdue. Our success in cross-dating the remnants of dead red pines as old as the 15th century A.D. holds promise for extending reconstructions of fire, forest, and climate history in other parts of this tree's range. ©1994 University of Washington.

INTRODUCTION

Few forests in New England have escaped logging. Consequently, uncut forests provide a rare opportunity to discern the natural dynamics of vegetation in a landscape otherwise dominated by human disturbances. Despite its small size (42 ha), the Battell Research Forest (BRF) of Middlebury College contains a diverse mosaic of hemlock-dominated stands that have never been cut (Vogelmann, 1971). Among the hemlocks (*Tsuga canadensis* (L.)Carr.) in the BRF grow numerous red pines (*Pinus resinosa* Ait.) and white pines (*Pinus strobus* L.). Red pine is largely dependent on fire to provide the open, mineral seedbed necessary for its regeneration (van Wagner, 1971; Bergeron and Gagnon, 1987; Bergeron and Brisson, 1990). Its presence implies disturbance by fire, an inference borne out in the BRF by the presence of charred red pine stumps.

The time span and accuracy of forest history reconstructions are greatly limited by the death and decay of older recruitment cohorts (Fox, 1989). The BRF is unusual because it contains dead red pines established during two recruitment intervals that preceded the interval when most living trees germinated. These stumps double the time span of the fire history that we can reconstruct if we are limited to the record provided by living trees alone. The present paper describes the fire history of the BRF recorded by the age distributions of living and dead trees and by fire scars. The results illustrate a fire cycle that has controlled the recruitment and mortality of most pine and probably most hemlock trees in this forest over the past 500 yr.

STUDY AREA

The Battell Research Forest (BRF) is a 42-ha tract lying between 180 and 400 m altitude on the western escarpment of the Green Mountains near East Middlebury, Addison County, Vermont (44° 2′N, 73° 5′W) (Fig. 1). Westward-dipping quartzites and schists underlie the area and crop out in low cliffs and glacially scoured knobs. Soils are generally shallow, rocky, and disturbed by creep and slumps. Moisture conditions vary widely. Mesic stream gullies and spring-fed fault zones are interspersed with expanses of xeric hillslope. Middlebury College administers the forest, having received it from timber baron Joseph Battell in A.D. 1911. In his transfer of deed to Middlebury College, Battell stipulated that ". . . the spruce and pine on the lot . . . are not to be cut; except the dead and fallen trees but shall be preserved in a primitive state . . ." [Town Records, Middlebury, Vermont, (34, 622 1911).

Forest vegetation in the BRF is dominated by *T. canadensis* growing in association with a diversity of other species. Hardwood forest, disturbed by repeated logging since European settlement of the area about A.D. 1790, covers the adjacent slopes of Robert Frost Mountain (Fig. 1). West of the BRF, white pines and hardwoods cover abandoned fields in the Champlain Valley. Within the BRF, *Tsuga* or *Tsuga–Fagus grandifolia* Ehrh.

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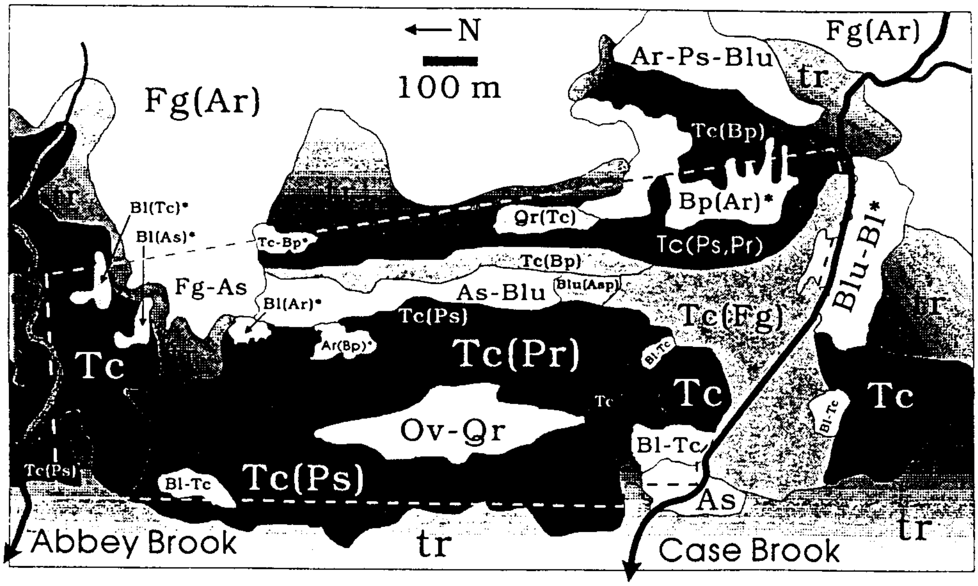

FIG. 1. Forest vegetation in and around the Battell Research Forest, Vermont. Dashed white line shows forest boundary. The following abbreviations are used: tr, transitional communities; Tc, hemlock (*Tsuga canadensis* (L.)Carr.); Fg, (*Fagus grandifolia* Ehrh.), Ar, red maple (*Acer rubrum* L.); As, sugar maple (*Acer saccharum* Marsh.); Pr, red pine (*Pinus resinosa* Ait.), Ps, white pine (*Pinus strobus* (L.); Blu, yellow birch (*Betula lutea* Michx.); Bp, paper birch, (*Betula papyrifera* Marsh.; Qr, red oak (*Quercus rubra* L.); Bl, black birch (*Betula lenta L.*); Asp, mountain maple (*Acer spicatum* Lam.); Ov, hop hornbeam (*Ostrya virginiana* (Mill.) Koch.). Asterisks designate large gaps created by a windstorm in A.D. 1950.

stands occur in mesic sites such as the vales of Abbey and Case brooks. *Tsuga–P. resinosa* stands grow on the most xeric sites and *Tsuga–P. strobus–P. resinosa* stands occur in intermediate moisture conditions.

Vermont's climate is humid and continental, with a mean annual precipitation of 82 cm and a mean annual temperature of 7°C at Burlington, 50 km to the north of the BRF (Ingram and Wiggans, 1968). The average January temperature at Burlington is −7.6°C, and the average July temperature is 20.7°C. At Cornwall, 30 km west of the BRF and 100 to 300 m lower, the average length of the frost-free period is 145 days (Hopp *et al.*, 1964).

METHODS

Vegetation Map

We mapped living forest vegetation on two 1:1900-scale, vertical aerial photographs: one a normal color, early autumn view and the other a black-and-white winter view. Observations on forest composition were made over the 6 months of field work. Because the BRF is small, we were able to visit every 20 m^2 of the tract. Forest types were determined subjectively by partitioning the landscape to maximize differences in species' presence/absence and importance values at a scale amenable to mapping that was generally >0.3 ha. Following subjective delineation of a forest type, we positioned 10 × 10-m plots within each type in a stratified random fashion. Plot number ranged from 2 to 16 depending on the number required to include every canopy tree species. The names of vegetation types reflect the relative dominance of each tree species according to an importance value calculated as the percentage of the total number of stems times the percentage of the total basal area. Names separated by hyphens indicate that species importance values differ by less than 2×. Species with names enclosed by parentheses had importance values two to eight times less than those the dominant species.

Ages of Living Trees, Dead Trees, and Fire Scars

We cored all living trees as close to the root crown as practical in 12 plots ranging from 150 to 300 m^2 located in representative portions of the major stand types in the BRF (Fig. 2). Because the study area is a nature preserve, we avoided taking multiple cores from the same tree. In the laboratory, we polished cores with 400-grit or finer sand paper before counting annual rings under a dissecting microscope.

We assigned ages to dead red pines by cross-dating individual trees within a tree-ring chronology based on full and partial sections from stumps and snags as well as cores from living red pines. Sections were collected with a hand saw or a chain saw. Dead trees were identified to species based on bark fragments and wood anatomy (Koehler, 1917). Continuous ring series more than 50 yr long from living and dead trees were described in skeleton plots (Stokes and Smiley, 1968). The computer program COFECHA (Holmes, 1983) was used to detect ring-counting errors and to suggest cross-dating relationships. The statistically suggested cross-dates between wood

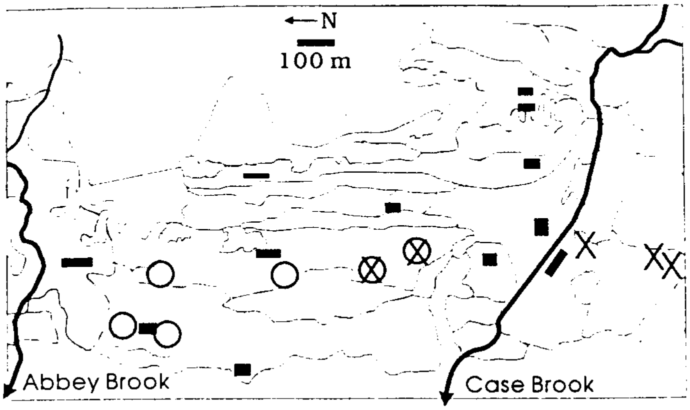

FIG. 2. Locations of tree-coring plots (dark rectangles) in the Battell Research Forest. Dead red pines scarred by fire in A.D. 1792/3 are depicted by "X." Dead red pines scarred by fire in A.D. 1806/7 are depicted by "O." Trees bearing scars from both fires occur in a zone of overlap.

samples were tested by direct, visual comparison of ring patterns. Because potential errors in estimating germination dates were often >5 yr we did not cross-date cores from living hemlock trees nor from living red pines, except those used in cross-dating the dead red pines.

Fire scar dates were calculated from sections of dead red pines after cross-dating. In some cross-sections we were able to determine the season when a fire occurred by looking for interruption of cell formation in early-wood or late-wood portions of annual rings (Dieterich and Swetnam, 1984; Schweingruber, 1989, p. 205). Failure to identify the season of burn results from either (1) cracking that obscures interruptions in cell deposition (2) a fire that occurred after late wood deposition in late summer, or (3) a fire that occurred in the spring before early wood deposition (McBride, 1983).

We made corrections for section (dead red pines) or core height (living red pine and hemlock) above germination level and for missed pith, the two main sources of error in estimating germination date. We estimated the section/core height correction (Table 1) using data from 50 red and white pine saplings killed by a fire in July 1988 on Hogback, a steep bedrock ridge at the same altitude and with similar exposure and soils as red pine stands in

TABLE 1
Growth-Rate Estimates Used in Height of Core/Section Corrections with One Standard Deviation (in Parentheses)

Species	Growth rate 0 to 20 cm height ($cm\ yr^{-1}$)	Growth rate 20 to 40 cm height ($cm\ yr^{-1}$)	Mean age at 20 cm height (yr)	Mean age at 40 cm height (yr)
Pinus resinosa, *Pinus strobus*	4.1 (2.3)	8.8 (3.6)	6.4 (3.5)	9 (4)
Tsuga canadensis	5.4 (4.7)	7.7 (5.6)	6.6 (4.4)	10.3 (5.7)

the BRF. Hogback is located 20 km north of the BRF in Monkton, Vermont. We sectioned these saplings at root crown, 20 cm, and 40 cm heights and then calculated rates of radial and height growth. We used only those saplings from Hogback (2 red pines and 14 white pines) whose ring density in the inner 2 cm of radius at 40 cm height fell within 1 standard deviation of the mean of the same measurement on BRF red pines. We used 21 *Tsuga* saplings from Hogback to estimate rates of hemlock height growth below 40 cm. Ring densities in the inner 1-cm of radius of these 21 saplings at 40 cm height fell within the mean ±1 standard deviation of 18 *Tsuga* trees from BRF.

When cores missed a tree's pith, we estimated the radius of missing wood using circle templates of different radii. We then counted the number of rings across this same distance in the innermost intact wood. This number of rings then was added to the count of actual rings. By experimenting with cores that actually contained piths (17 *Tsuga*, 30 *P. resinosa*), we found that this method consistently underestimated the number of rings (Table 2). We calculated errors in age estimates as the combined variances in growth-rate estimates, ages of missed piths, and covariance (Bevington, 1969) between growth rates and tree ages at various heights.

RESULTS

Taphonomy of Red Pines

Dead red pines persist in the BRF as fallen or standing snags (trunk >2 m long) and stumps (trunk <1 m long) with attached root masses (Fig. 3). Red pine stumps are most abundant in stands where this species grows today but some occur in other *Tsuga*-dominated forest types (Figs. 2 and 4). Red pine snags and stumps are frequently in growth position, although some of the best-preserved specimens lie in boulder fields below cliffs where the trees once grew. As the species' Latin name implies, red pine wood often has a high resin content. Resin is often concentrated around old fire scars. Consequently, wood containing scars is preferentially preserved. Because most scars occur near the root crown, this part of dead red pines is most frequently preserved. Wood with narrow rings tends to be better preserved in the dead red pines than wood with wide rings. Therefore, we suspect that our sample of dead red pines is biased in favor of slow-growing, fire-scarred individuals.

Cross-Dating Dead Trees

We collected cross sections from 76 dead red pines. These probably represent 50% of the dead red pines in the BRF that still retain root masses. Preservation varied from excellent (intact bark and pith) to extremely poor (partial radii of intact wood, no bark, and no pith). We

TABLE 2
Corrections to Missing Pith Estimates with One Standard Deviation (in Parentheses)

	Core missed by					
	0–5 mm	5–10 mm	10–20 mm	20–30 mm	30–40 mm	40–50 mm
			Pinus resinosa			
Correction to pith estimate (yr)	+2.5 (2.6)	+2.6 (4.1)	+3.5 (5.7)	+4.8 (7.3)	+5.2 (10.3)	+3.5 (17.8)
			Tsuga canadensis			
Correction to pith estimate (yr)	+1.5 (9.7)	+5.8 (14.4)	+7.9 (27.5)	+13.4 (31.9)	+23.3 (36.3)	+29.4 (42.9)

were able to cross-date 32 of these sections (Fig. 5) relying on 6 individual marker rings and 3 marker-ring sequences discovered during skeleton plotting. Three of the oldest living red pines help link the dead tree chronology to the present.

Useful marker rings (years A.D.) in the BRF material are as follows:

1823, 1816, 1723, 1595, 1586. These years are represented by unusually narrow annual rings.

1899. Both early and late wood are narrow in this year. Slow-growing trees usually laid down a double ring (Fig. 6). This marker ring is common in living red pines at the BRF that germinated after A.D. 1800.

1752–1755. The 1752 and 1755 rings have relatively narrow late wood in contrast to wider rings in 1753 and 1754 (Fig. 6). In addition, wide early wood and narrow late wood characterizes the 1750 ring. The 1755 ring often has faint, double late wood.

1670–1675. The 1670 ring is relatively narrow, 1671 and 1672 rings are wider, while 1673, 1674, and 1675 are narrow (Fig. 6).

FIG. 3. A charred red pine stump in a *Tsuga*-pine stand in the Battell Research Forest. This stump was not cross-dated but nearby stumps had pith dates of ca. A.D. 1650. Most of the surrounding forest of white pines and hemlocks was established between A.D. 1790 and 1850.

1635–1639. Both the 1635 and the 1639 annual rings are narrow and double (Fig. 6).

Fire Scars

Between 23 and 25 different fires are recorded in the 32 cross-dated red pine stumps (Appendix). The uncertainty comes from cross sections in which we could not distinguish the season of burn. Fires recorded by >1 scarred tree occurred in 1584/5 (2 trees), 1654/5 (3), 1792/3 (5), 1806/7 (5), and 1851/2 (2). Stumps scarred by the 1851/2 fire are restricted to a circa 400-m^2 area. To simplify calculation of the intervals between fires in the 42-ha study area, we assumed that fires occurred in late summer after late wood deposition unless this was contradicted by the season of burn interpreted from a scar. Where more than one section had a fire scar dated to the same two years and one of these scars could be interpreted as to season of burn, we assigned this latter date to all scars in that group of sections. The interval between fires averaged 18.3 yr ± 14.4 (1σ) from the first recorded fire in midsummer of 1504 A.D. to the last one in 1851/2. No fires were recorded by either scars or historical sources since 1851/2. Intervals of more-frequent fires occurred between about 1650 and 1685 ($\bar{x}$ = 6 ± 5.1 yr) and again between 1790 and 1850 ($\bar{x}$ = 11.8 ± 6.3 yr) (Fig. 7). In contrast, between 1504 and 1655 A.D. fires occurred at

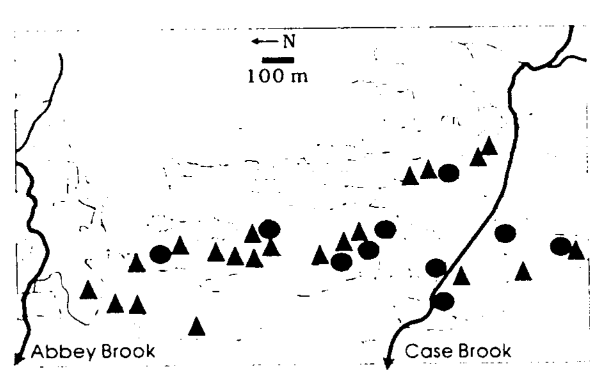

FIG. 4. Locations of one or more dead red pines in the Battell Research Forest that germinated between A.D. 1450 and 1520 (circles) and between A.D. 1650 and 1700 (triangles).

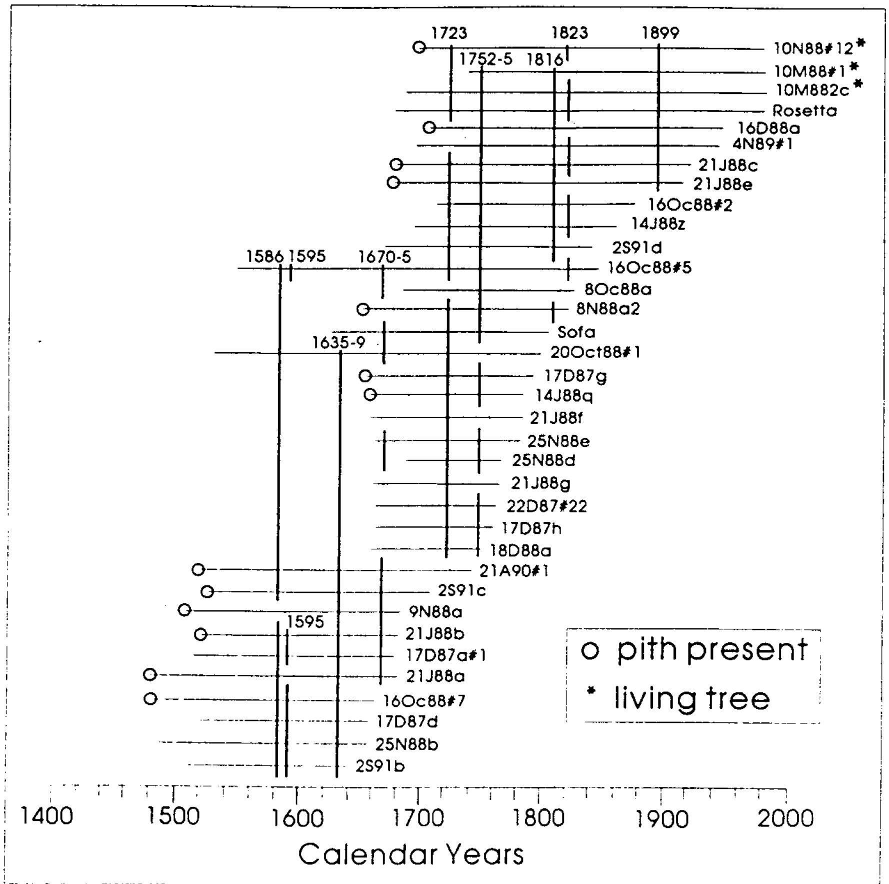

FIG. 5. Cross-dating ties with the red pine chronology from the Battell Research Forest. Horizontal lines represent the continuous span of annual rings preserved in cores from living trees or in cross sections from dead trees. Vertical lines represent individual marker rings or marker ring sequences (Fig. 6). Dashed arcs indicate the absence of a marker ring or ring sequence in particular cores or cross sections. Numerous living red pines contain the distinctive A.D. 1899 marker ring.

an average interval of 30 ± 12.6 and 26.7 ± 17 yr between 1685 and 1792 A.D.

Based on ages of living trees and of stumps, the intervals of more frequent fires, 1650–1685 and 1790–1850 A.D. involved the entire BRF (see next section). However, discerning the extent of individual fires within these intervals is difficult. The best evidence exists for the extents of the 1792/3 and the 1806/7 fires. Stumps scarred in A.D. 1792/3 occur in the southern half of the forest, stumps scarred in A.D. 1806/7 occur in the northern half, and stumps bearing both scars occur between these groups (Fig. 2). This distribution of scars indicates an overlap in fire extent during the last interval of frequent fires and suggests that repeated burning of several overlapping patches may be typical during frequent fire intervals.

Age Distribution of Living and Dead Trees

The estimated germination dates of living pines and hemlocks in the 12 study plots reflect the importance of the A.D. 1790 to 1850 interval of more frequent fires in stimulating the recruitment of the present forest (Figs. 7 and 8). We plotted germination dates on a decadal scale because the mean error involved for estimates of ages is 7.5 ± 15 yr for pines and 21 ± 16 yr for hemlocks. Some recruitment of living pines may have begun as early as the A.D. 1770s, with 3 trees germinating between A.D. 1776 and 1785 and 7 between A.D. 1786 and 1795. However, germination date estimates for 7 of these 10 older trees overlap with the post-1792 age classes at 1 standard deviation, leaving only 3 pines that germinated in the two decades preceding the A.D. 1792/3 fire. The majority of living pines began growth after A.D. 1795 and before A.D. 1870 (Fig. 8). The existence of a 60-yr interval after A.D. 1790 when pines were recruited supports our reconstruction of a series of closely timed fires burning in an overlapping mosaic.

The 32 cross-dated, dead red pines (Appendix) record two earlier recruitment events at the BRF, one between about A.D. 1450 and 1520 (n = 12) and another between about A.D. 1650 and 1700 (n = 20) (Fig. 8). Dead trees from these two earlier recruitment intervals are interspersed closely with one other and with the coring plots (Figs. 2 and 4), indicating that the age distribution we reconstruct here is not an artifact of lumping different forest patches with different recruitment histories. The

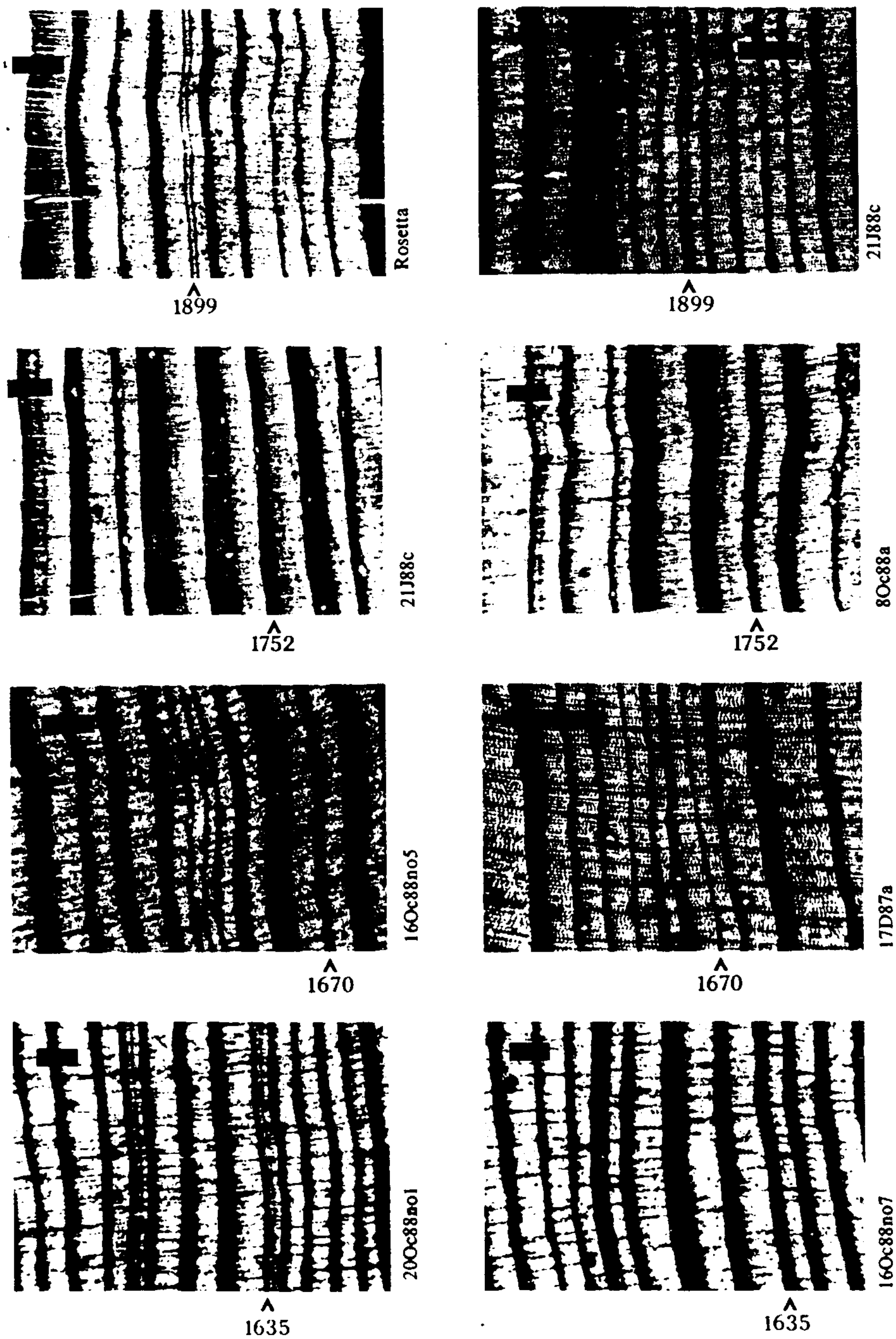

FIG. 6. Marker rings and ring sequences in the red pine chronology. Photomicrographs show key rings and ring sequences from pairs of representative cross sections. Trees were growing towards the left in all pictures. Section identification numbers are on lower right side of each photograph. Black scale bars are 1 mm long.

recruitment interval recorded by dead red pine that germinated between A.D. 1650 and 1700 corresponds to an interval of more frequent fires between A.D. 1650 and 1685 (Figs. 7 and 8). The fire scar record is badly faded in the years preceding about A.D. 1550.

DISCUSSION

The Battell Research Forest is interesting for several reasons. First, it is among Vermont's largest uncut forests, having escaped logging because of rugged terrain, generally small tree size, and because its was damaged by fire near the time of initial European settlement. After examining hundreds of logs and stumps, we failed to detect any trace of logging activity within the hemlock-dominated community types of the BRF. Second, recruitment of trees, including hemlocks, has been conditioned by fire. Fire is usually considered to play a relatively minor role in the forest dynamics of northern New England (Lorimer, 1977; Bormann and Likens, 1979) in

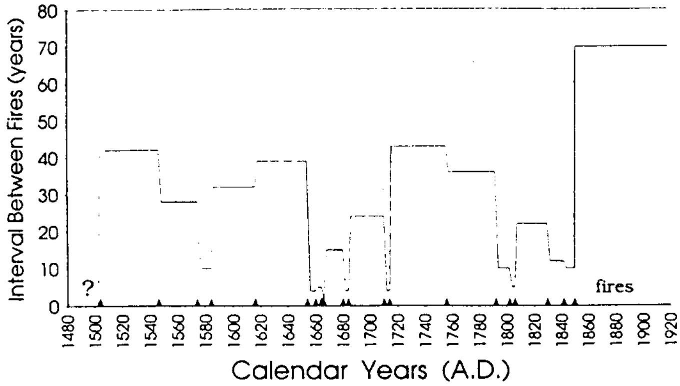

FIG. 7. Intervals between fires from A.D. 1500 to 1920 in the Battell Research Forest. In the A.D. 1920s, state and federal agencies began a program of active fire suppression. No fires occurred in the BRF after A.D. 1851/2. Intervals of more frequent fires occurred between ca. A.D. 1650–1715 and ca. 1790–1850.

comparison to the Great Lakes region (Clark, 1990a; Frelich and Lorimer, 1991), the Laurentian Highlands (Cogbill, 1985), and the western cordillera (Martin, 1982). Third, preservation of dead red pines in the BRF that germinated as long ago as the A.D. 1400s is unusual in the humid, northeastern United States.

Fire Regime

The hardwood forests of northern New England are noted for their relatively long fire rotation intervals. Fahey and Reiners (1981) estimated a fire rotation interval between 230 and 5200 yr for hardwood forests in Maine and New Hampshire. Even for the pine forest type that is most similar to the vegetation of the BRF, these authors suggested rotation times of 200 to 440 yr. Red spruce–hemlock–pine vegetation in New Brunswick has a fire rotation time of 230 yr (Wein and Moore, 1977).

However, small islands of fire-prone and fire-dependent conifer vegetation exist within the sea of relatively nonflammable hardwood forests in northern New England (Strimbeck, 1988; Engstrom and Mann, 1991). Fifty kilometers north of the BRF, in Bolton, at least one fire occurred in six small (<2 ha) red pine stands every decade between A.D. 1851 and 1920 (Engstrom and Mann, 1991). Two fires may have occurred in the same years at Bolton and the BRF in A.D. 1829/30 and 1851/2.

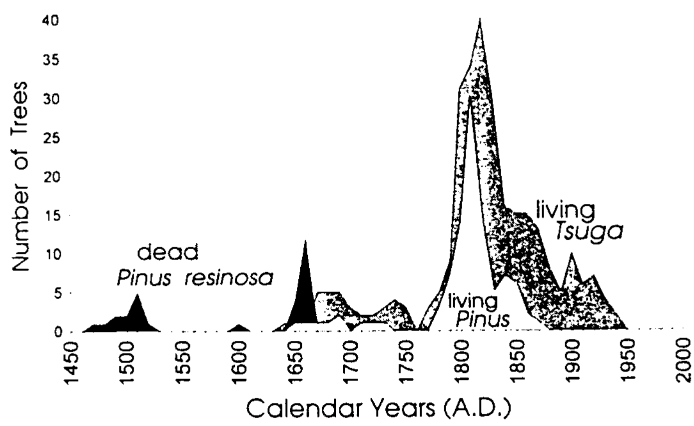

FIG. 8. Age distributions of living red pines (n = 56), living white pines (n = 41), dead red pines (n = 32), and living hemlock trees (n = 198) in the Battell Research Forest. Three recruitment intervals are indicated, the most recent between A.D. 1790 and 1850.

The estimated germination dates of living and dead red pines cluster in three intervals (Fig. 8). Numerous fires burned within the BRF between these recruitment intervals. These were probably low-intensity surface fires, probably <300 kW/m (van Wagner, 1983), that killed forest-floor vegetation but rarely killed trees and hence failed to create canopy openings supporting regeneration by red pines. In contrast, medium- and high-intensity fires, probably burning in a partially overlapping mosaic of patches, destroyed canopy trees and allowed recruitment of both hemlocks and pines during the intervals A.D. 1450–1520, 1650–1710, and 1790–1850.

Fire, Climate, and Fuel

What caused the intervals of more frequent fires in the BRF? Climatic forcing is a likely explanation, although the intervals between the three recruitment episodes we find in the BRF do not match the duration of climatic cycles occurring during the Little Ice Age (Grove, 1988). Furthermore, proxy records of summer drought and warmth correlate only sporadically with the timing of fire swarms at the BRF.

For instance, widespread fires occurred in the Laurentian Highlands between A.D. 1661–1663 and 1779–1791 (Cogbill, 1985), perhaps coinciding with the past two intervals of more frequent fires at the BRF. Fires occurred in the Pisgah Forest in southwestern New Hampshire about A.D. 1665, 1775–1778, in 1790, and between 1800 and 1805 (Foster, 1988). Regional climate is the likely cause for fire synchrony at this large spatial scale. Increased fire frequency at the BRF between about A.D. 1790 and 1850 may correlate in part with an interval of summer drought between A.D. 1790 and 1810 in the Hudson Valley (Cook and Jacoby, 1977). However, this same record indicates dry summers between A.D. 1755 and 1775 during an interval of lower fire frequency at the BRF. Potomac River stream flow (Cook and Jacoby, 1983) was at or above normal between A.D. 1790 and 1815 in late summer but experienced a low flow stage for the 20 yr after 1850, a fireless interval at the BRF. In southwestern Quebec, drought conditions occurred between A.D. 1475 and 1500 and again between A.D. 1790 and 1800 during the earliest and latest intervals of increased fire frequency and red pine recruitment at the BRF (Archambault and Bergeron, 1992). However, drought conditions also occurred between A.D. 1590 and 1610 as well as between A.D. 1700 and 1750, intervals with lower fire frequency at the BRF. In conclusion, while intervals of higher fire frequency in the Battell Research Forest may occur during periods of regional drought, all regional droughts do not increase fire frequency there. This is not surprising, since weather and climate parameters may account for only 11 to 30% of the variance in fire occurrence (Flannigan and Harrington, 1988; Clark, 1989).

The time required for fuel accumulation modulates the control of climate and weather over fire occurrence (Clark, 1989) and may be a critical factor in the BRF's fire cycle. Although ignitions and small, low-intensity fires may occur at any time in the BRF given suitable weather, fuel accumulation may require 150–200 yr (Clark, 1988) to reach a point where it can support intense fires capable of damaging and killing canopy trees. Fuel accumulation and flammability often follow a U-shaped pattern through time after an intense fire (Romme, 1982; Agee and Huff, 1987). Trees killed or injured by a fire (Starker, 1934; Wyant *et al.*, 1986) contribute fine and especially coarse fuel types to the fuel load, causing an initial increase in stand flammability in the first few decades following a fire. The occurrence of closely timed fires involved in a positive feedback loop between fire damage and fuel load have been inferred from historical studies (Hemstrom and Franklin, 1982; Barrett *et al.*, 1991) and observed in the present century (Pyne, 1982). As decay proceeds and while the regenerating trees are young, flammability declines. Thereafter, self-thinning rebuilds the fuel load toward a peak that often coincides with replacement of initial canopy trees with trees recruited from the understory (Romme, 1982; Agee and Huff, 1987; Clark, 1990b).

Cyclic changes in flammability due to fuel characteristics mean that invervals of increased fire frequency and their accompanying tree recruitment episodes will be quasi-periodic. The system's sensitivity to climatic forcing will vary depending on fuel loading (Clark, 1988) and occur during windows separated by one to several centuries of insensitivity. This predicts the conditional relationship we suggest earlier between droughts and intervals of more frequent fires in the BRF.

A Role for Windstorms?

Windstorms may have helped create fuel loads supporting intense fires in the BRF. In the Pisgah Forest in southwestern New Hampshire, more than half the recorded fires occurred within 20 yr after windstorms (Foster, 1988). Trees toppled by the A.D. 1938 hurricane in central New England prompted widespread concern over fire danger (Pyne, 1982). Although it is unknown if the hurricane of A.D. 1635 (Foster, 1988) affected western Vermont, this storm does precede the A.D. 1650–1685 interval of increased fire frequency in the BRF by 15 yr. Similarly, the hurricane of A.D. 1788, the windstorm of 1804, and the hurricane of 1815 in central New England (Foster, 1988) may have affected the BRF and partly stimulated the latest, more-frequent fire interval between about A.D. 1790 and 1850.

Red and white pines were not recruited in gaps formed by the Great Appalachian Windstorm of A.D. 1950 (Ludlum, 1985) which created a number of >1-ha gaps in the BRF (Fig. 1). For this reason and the well-known importance of fire in the regeneration of red and white pine, we doubt that wind disturbances initiated the episodes of past pine recruitment in the BRF. Some hemlock recruitment probably occurred in gaps created by windthrows between A.D. 1790 and 1850. However, hemlocks, too, are well-known colonizers of fire-created gaps in other hemlock–pine forests in the northeastern United States (Hough and Forbes, 1943; Henry and Swan, 1974). From the surge of hemlock recruitment between A.D. 1790 and 1850, we suspect that fires were probably the major stimulant of this species's regeneration in prehistoric times as well.

APPENDIX

Cross-Dated, Dead *Pinus resinosa* from the Battell Research Forest

Cross-section	Outermost ring (yr A.D.)	Distance to pith (cm)	Inner Ring (yr A.D.)	Estimated pith date (yr A.D.)	Section height above root crown (cm)	Estimated germination date (yr A.D. ± 2s)	Ring marker year (yr A.D.)	Fire scar dates (yr A.D.)	Season of burn
Rosetta	1983	0.3	1674	1669	45	1657 ± 10	1899,1823,1816, 1752–1755 1723	1792/3	?
2S91c	1709	0	1526	—	25	1519 ± 8	1670–1675, 1635–1639, 1586	1546/7, 1584/5 1616/17, 1654/5	?
16O88#5	1849	1.2	1546	1504	5	1500 ± 8	1823, 1752–1755, 1723, 1670–1675, 1595, 1586	1570–86, 1792/3, 1802/3	?
14J88q	1789	0	1660	—	30	1652 ± 8	1752–1755, 1723	None	—
8N88a2	1822	0	1661	—	20	1657 ± 6	1816, 1752–1755, 1723	1806/7	?
17D87g	1792	0	1659	—	15	1655 ± 4	1752–1755, 1723	None	—
Sofa	1810	1.2	1628	1609	20	1600 ± 10	1752–1755, 1723, 1670–1675, 1635–1639	1792/3	?
21J88c	1923	0	1675	—	75	1662 ± 10	1899,1823,1816, 1752–1755, 1723	1792/3, 1806/7	?

APPENDIX —*Continued*

Cross-section	Outermost ring (yr A.D.)	Distance to pith (cm)	Inner Ring (yr A.D.)	Estimated pith date (yr A.D.)	Section height above root crown (cm)	Estimated germination date (yr A.D. ± 2s)	Ring marker year (yr A.D.)	Fire scar dates (yr A.D.)	Season of burn
14J88z	1861	1.5	1690	1672	30	1662 ± 12	1823, 1816, 1752–1755 1723	1806 1792/3 1709/10	Late summer 1806 ?
16D88a	1948	0	1700	—	40	1691 ± 8	1899,1816, 1752–1755	1807	Early summer
21J88e	1919	0	1671	—	45	1661 ± 8	1899,1816,1752–1755	1792/3, 1851/2	?
16O88#2	1879	0.6	1714	1708	15	1702 ± 10	1823,1816, 1752–1755, 1723	1806/7	Late summer
21J88a	1686	0	1481	—	45	1471 ± 8	1670–1675, 1635–1639, 1586	1504, 1584/5, 1654/5	Mid-summer 1504 ?
21A90#1	1746	0	1521	—	25	1512 ± 8	1670–1675, 1635–1639, 1586	1574/5, 1655, 1664/5	? Early summer 1655 ?
9N88a	1694	0	1511	—	10	1509 ± 4	1670–1675, 1635–1639	1654/5	?
25N88b	1661	0.3	1492	1488	10	1483 ± 6	1635–1639, 1586	None	?
17D87a#1	1687	0.2	1514	1509	5	1505 ± 6	1670–1675, 1635–1635, 1595, 1586	None	—
16O88#7	1668	0	1493	—	5	1492 ± 2	1635–1639, 1595, 1586	None	—
21J88b	1692	0	1521	—	25	1514 ± 8	1670–1675, 1635–1639, 1595, 1586	1659/60	?
20O88#1	1806	3.5	1531	1499	5	1493 ± 14	1723, 1670–1675, 1635–1639	1666	Mid-summer
4N89#1	1947	1	1689	1666	40	1654 ± 12	1899, 1823, 1816, 1752–1755	1829/30, 1841/2, 1851	? Late summer
17D87d	1660	0	1519	—	60	1508 ± 8	1635–1639, 1595, 1586	None	—
8Oct88a	1829	12	1682	1668	20	1658 ± 14	1752–1755	1792/3	?
2S91d	1844	0	1668	—	10	1666 ± 2	1816, 1752–1755, 1723	1681	Late summer
2S91b	1647	0	1512	—	10	1510 ± 2	1635–1639, 1595, 1586	None	—
25N88e	1788	0	1658	—	5	1657 ± 2	1752–1755, 1723, 1670–1675	1685	Mid-summer
17D87h	1769	0	1663	—	5	1662 ± 2	1752–1755, 1723	None	—
18D88a	1756	0	1660	—	10	1658 ± 2	1752–1755, 1723	None	—
21J88f	1792	0	1659	—	20	1655 ± 8	1723	None	—
21J88g	1775	0	1661	—	20	1657 ± 8	1752–1755, 1723	1713	Late summer
22D87#22	1773	0	1663	—	10	1655 ± 10	1752–1755	1756/7	?
25N88D	1775	30	1685	1660	5	1651 ± 2	1752–1755, 1723	1685	Mid-summer

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