Fire History of the White and Green Mountain National Forests

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By

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Introduction

The northern hardwood and mixed conifer-hardwood forests of northern New England are often considered "climax" forest types that can persist for many generations without stand-replacing disturbances such as fire. The Green and White Mountain National Forests in, Vermont and New Hampshire, respectively, are the largest tracts of publicly owned land in the two states and form the core of north-central New England's northern hardwood forest resource. Knowledge of disturbance regimes (including fire) for these forests is necessary for the successful implementation of modern "ecosystem management" plans for these public lands.

Stephen Pyne, in his recently published monograph "America's Fires" (1997), argues that 20th century attempts to rid forests of fire in the United States have "seriously upset many biotas as well as compromised the prospects for future fire protection" in the Untied States. He notes that it is only in the past 20 to 30 years that land managers have attempted to restore presettlement fire regimes. Those regimes are generally assumed to have been characterized by frequent burning (by Native American Indians or lightning), but this generalization may not apply to the hardwoods of the Northeast. Pyne is right, however, in calling for adequate characterization of presettlement fire regimes. With that in mind, we undertake here a comprehensive examination of the historic role of fire in Vermont and New Hampshire, where northern hardwoods occupy 40% or more of the forested landscape.

Although Clementsian mono-climax theories of forest succession have largely been discarded by modern ecologists, Bormann and Likens (1979) refer to a "steady state" condition in which forest stands in the Northeast reach a dynamic equilibrium where unidirectional change occurs slowly if at all. They identify the northern hardwood resource, in particular, as being typified by this condition. A lack of fire in the mountainous regions of northern New England contributes to the relative stability of forests, despite the fact that most tree species have maximum life spans of no more than a few centuries. Bormann and Likens (1979) note that the northern hardwood forests of inland and high-elevation regions are often referred to as being like "asbestos" in their aversion to fire. Bormann et al. (1985) cite Chittendon (1905) as reporting that even in 1903, a notoriously bad fire year in northeastern North America (Brown & Davis 1974), " the virgin forest was strikingly free of fire" with the mountainous topography of the northern one-third of New Hampshire precluding "fires from sweeping unhindered over vast areas". Bormann and Likens (1979) summarized fire data for eastern national forests and found that less than 0.05% of the White Mountain National Forest was damaged by forest fires during 1945-1976. Supporting these findings, Fahey and Reiners (1981) summarized New Hampshire fire records for the first three-quarters of the 20th century and calculated fire rotations (the number of years it would hypothetically take to burn an area equivalent to the size of a management unit given an annual rate of acres burned within that unit) that exceeded 500-1,000 years for most forest types. Although the investigation of Vermont fire history records has been less complete, estimated fire rotations of at least the length reported by Fahey and Reiners are supported by the work of others in northern New England (Siccama 1974, Lorimer 1977).

There is not universal agreement that fire is rare in the forests of central and northern New England. It seems more likely that there was a gradient in fire occurrence on the landscape, with some regions burning more than others. Henry and Swan (1974) and Foster (1988) report fire as being a significant force influencing stand development in virgin forests of southwestern New Hampshire, and Engstrom and Mann (1991) note that fires frequently burned through red pine stands near Lake Champlain in Vermont. Fuller et al. (1998), working in Worcester and Franklin Counties along Massachusetts' northern boarder with Vermont and New Hampshire, found that presettlement fire was more common in lowland areas and on outwash plains of the Connecticut Valley, and less common in upland areas. Patterson and Sassaman (1988) suggest that prior to the arrival of European colonists, fires were most common in coastal and riverine environments (where Native American Indians lived and contributed to ignitions), but rare in the more remote mountainous regions of western Massachusetts, northern Maine, and much of New Hampshire and Vermont, where Indian populations were low. However, we know from regional forest histories, that fires were widespread, even in the more isolated mountains of Vermont and New Hampshire, as loggers moved in to harvest old-growth timber 100-150 years ago.

Published accounts suggest that fire incidence in New England may have peaked during the 19th and early 20th centuries - a time when forests were heavily exploited for timber. As with much of the country, improved fire control procedures following World War II are credited with reducing fire occurrence in New England during the period 1945 to 1975 (Fahey & Reiners 1981). On the other hand, warming climate, which is documented at the present time, might favor increased fire incidence, and there is concern, well stated by Pyne (1997), that lack of recent fires could lead to fuel buildups and increase the risk of future conflagrations. Davis (1985) reports that even in the White Mountains, fire was more common during the period of the mid-Holocene temperature maxima (7,000 to 8,000 years ago) than today. So, the question remains: Does the recent period of reduced 20th century fire incidence noted by Bormann and Likens (1979) and Fahey and Reiners (1981) represent a period of unusually effective fire control that will end in conflagrations as fuels accumulate, or, does the recent decline in fire incidence in the region represent a return to presettlement conditions when fires were apparently rare throughout much of New Hampshire and Vermont? We examine fire history information from a variety of published and unpublished sources to try to answer these questions.

Regional Overview

Fire history analyses for New England have focussed mainly on 20th century fire incidence records. Fahey and Reiners (1981) evaluated the fire occurrence in Maine and New Hampshire by reviewing fire records for these two states from 1903 (1910 for NH) to 1978, and Bormann and Likens (1979) reviewed fire records for national forests of the Lake States and Northeast for the period 1945 to 1976. Fire rotations calculated for these periods are long compared to other parts of the United States, but still reflect only a short period in New England forest history - a period (the first half of the 20th century) when fire incidence may have initially been artificially high due to logging and general carelessness with fire, and then low during the next quarter century, with the decline in flammable softwoods, the increase in less flammable, second-growth hardwoods, and a general improvement in forest protection within the region. Thus, despite the detailed analyses of existing fire records by Bormann and Likens (1979) and by Fahey and Reiners (1981), the natural role of fire in north-central New England remains somewhat unclear. Our goal in this paper is to explore in greater detail the changes in fire occurrence in New Hampshire and Vermont since the presettlement period and to speculate on the potential role of fire in future landscapes of the White and Green Mountains.

The specific objectives of our research are to develop a fire history data base and narrative fire history summaries for the White Mountain National Forest in New Hampshire and the Green Mountain National Forest in Vermont within the context of the states and regions where they occur. These two national forests cover approximately 6% of the land area of Vermont (GMNF) and 12% of that of New Hampshire (WMNF) and are the largest protected areas of natural vegetation in New England. They thus can serve as natural models for the larger landscapes of which they are a part. The importance of fire in the prehistoric and historic ecosystems of these forests will be documented and evaluated relative to the roles of other disturbances such as insect and disease outbreaks, windstorms, and human influences. We will also describe how this role may have changed with human intervention during the past two-to-three centuries (i.e. through increased burning with the clearing and settlement by Europeans and with active fire suppression during the last fifty years.

Study Area

Landscape Setting

Vermont and New Hampshire (encompassing 9,614 and 9,279 square miles, respectively) are located in northern New England and include some of the most rugged terrain in the region (Figure 1). Although the general landscape can be considered gently rolling in these two states, the White and Green Mountains include areas of steep topography interspersed with numerous peaks and valleys. The Presidential Range of the White Mountains includes Mt. Washington (elev. 6,288 ft.), the highest mountain east of the Mississippi River and north of the Carolinas. In total, nearly 50 peaks above 4,000 feet in elevation can be found in the White Mountains. The Green Mountains are slightly lower with only five peaks above 4,000 feet including Mt. Mansfield (4,393 ft.), the highest peak in Vermont. Eighty-seven percent of New Hampshire and 77 percent of Vermont are forested (Frieswyk & Malley 1985). Rivers and streams are common throughout both states with the largest being the Connecticut River, which divides them below Beecher Falls. Lakes and ponds are also common. The two largest inland water bodies are Lake Champlain (in northwestern Vermont forming the boundary with New York) and Lake Winnipesaukee (the largest lake in New Hampshire covering 69.7 square miles).

The moist climate of north-central New England supports the extensive natural water network throughout these states. The White and Green Mountain National Forests were established, in fact, following the enactment of the Weeks Law (1911), which had as its goal the protection of watersheds of navigable waterways. Federal lands of the White Mountain National Forest (WMNF) cover 728,150 acres in NH and 49,346 acres in ME. The Green Mountain National Forest (GMNF), with 374,841 acres of federally owned land, is divided into southern and northern sections (Figure 1). The southern section is bounded by the Vermont border with Massachusetts on the south, with New York on the west, and crosses into the southern portion of Rutland County to the north. The northern section ranges from the northern edge of Rutland County to the southern portion of Washington and Chittenden counties. In addition to the Green Mountains, the GMNF also includes the eastern side of the Taconic Range south of Brandon, Vermont.

Climate

Climate strongly influences the occurrence of fire in a landscape. The ignition and spread of fires depend upon precipitation patterns, wind speed, and daytime humidity depression. New Hampshire and Vermont have similar climates, with local variations a function of topography and site conditions. Higher elevations are generally cooler and wetter, and experience longer periods of snow cover than the valleys and lowlands. The average annual precipitation for Vermont is 38 inches (34 inches in Burlington), while New Hampshire has approximately 36 inches (Concord station - National Climate Data Center 1999). On the higher peaks, precipitation can exceed 100 inches per year. It is more or less evenly distributed through the seasons with a monthly average of approximately 3 inches. Consistent precipitation throughout the year maintains fuel moisture levels and facilitates decomposition of both fine and heavier fuels. The drier months are January through March (although much of the area is covered in snow), with July and August in Vermont and July, August, and November in New Hampshire being somewhat wetter (based on Burlington, VT and Concord, NH weather station data [National Climate Data Center 1999]). Snowfall averages 64 and 78 inches per year for Concord, NH and Burlington, VT respectively, with measurable snowfall in eight of the twelve months. The growing season varies from 90 to 150 days depending upon latitude and elevation (Kingsley 1985).

Relative humidity in the region is generally moderate with overnight humidity throughout the year generally greater than 70% and daytime humidity greater than 40% (National Climate Data Center 1999). In the spring, the region tends to have dry frontal storms and in the fall, there can be stagnant high-pressure systems, both of which provide appropriate drying conditions for fire ignitions (Foster 1988, Pyne 1982). If these conditions persist, occasional periods of short but intense drought can increase fire danger, especially in conifer stands, which have thick duff due to a slow decomposition and a general lack of burning.

Other parameters influence fire frequency beyond drought conditions and source of ignition. Fuel accumulation and flammability are important factors contributing to the infrequent occurrence of fire in northern New England. Historically, logging contributed significantly to increased fuel loads and the incidence of extreme fire behavior, especially on the more heavily conifer-dominated forests of New Hampshire (Goodale 1999). Windstorms, ice damage (like that resulting from the 1998 ice storm in central New England), and insect/disease outbreaks similarly may create fuel loads that will support intense fires. In the Pisgah Forest in southwestern NH, more than half of the recorded fires occurred within 20 years of windstorms (Foster 1988). Thus, exogenous disturbances coupled with locally intense drought can lead to conditions that will allow fire to burn in the otherwise non-flammable deciduous forests of New Hampshire and Vermont.

Forest Types

Elevation differences across the landscape and the range in latitude across New Hampshire and Vermont affect the regional distribution of forest tree species (Westveld et al. 1956, Siccama 1974). Southern and coastal areas of New Hampshire support xeric oak and pine forests, the higher elevations support spruce-fir and red pine, and patches of early successional forest occur on recently disturbed sites. The overall matrix within which these types occur is northern hardwood forests comprised of maple, beech, and birch. Elm/ash/red maple and aspen/birch contribute to the deciduous forest matrix, which collectively covers 67% of forested land in Vermont and 47% in New Hampshire (Frieswyk & Malley 1985a & b) (Table 1, Figures 4 and 5). Although conifers such as hemlock, white pine and red spruce mix with northern hardwoods on some sites, these forests generally contain low amounts of available fuel and occur on fire-protected sites (Patterson, in press). Disturbances generally occur at the patch or stand level (Bormann & Likens 1979), so it is rare for extensive areas to develop high fuel loads at one time. The conifer-dominated forests (spruce-fir, white-red pine, pitch pine, oak-pine) occur in patches throughout the larger matrix of deciduous forests, frequently occupying sites that are better drained, contain higher amounts of fuels, and are thus more susceptible to fires. Conifers comprise 42% of New Hampshire and 28% of Vermont forest lands. The increased flammability of these types was evident in the results of a study by Engstrom and Mann (1991) who report that prior to 1922, non-lethal fires occurred frequently and locally intense, tree-killing fires occurred periodically in red pine stands in northern Vermont. The composition of forest types in the WMNF and GMNF are generally similar to the overall composition of the states of which they are a part. The WMNF is 58% northern hardwood and 18% spruce/fir, while the GMNF is 52% northern hardwood and only 3% spruce/fir (WMNF 1999, GMNF 1999). Most of these stands occur at higher elevations where fire weather conditions are less likely to favor wildfire occurrence and spread.

Regional Fire Regimes

The northern hardwood forest type stretches from southeastern Canada and Maine across the Great Lakes region to Minnesota and south along the Appalachian Mountains. The occurrence of fire throughout this region is highly variable with an estimated natural fire rotation of 60-100 years in the Boundary Waters Canoe Area in Minnesota (Heinselman 1973, Swain 1973) to more than 800 years in northeastern Maine (Lorimer 1977). Variation in the occurrence of fire in the Northeast is due to regional variations in climate, topography, and soils. The pattern of fire occurrence generally increases from east to west. "In the north-central United States and south-central Canada, lightning ignitions are common, and fire is frequent even in the absence of anthropogenic fire" (Patterson & Backman 1988). In contrast, dry lightning strikes and resulting fires are rare in the northern hardwood forests of New Hampshire and Vermont, so it is not surprising that humans have historically caused most of the large conflagrations in New England.

The U.S. Forest Service is currently reissuing an updated version of it's "Effects of Fire on Flora" volume. Patterson (in press) provides a detailed discussion of fire regimes of northern hardwood forests. A draft of Patterson's contribution is included as an appendix to this report (see Appendix A). Fire regimes of other major forest types occurring in Vermont and New Hampshire are included in the revised "Flora" volume, which is scheduled to go to press in late January 2000. This work will be a valuable resource for fire managers, and should be added to the libraries of the W&GMNF when it becomes available. Because its publication is imminent, we include only the northern hardwoods section as an example of the kinds of information contained in the complete volume.

<u>Human Populations</u>

The current distribution of human settlements in Vermont and New Hampshire is focussed in and near the major cities along the coast and rivers valleys (Figure 6). The more northerly and mountainous regions lack these dense populations. The majority of the populations of Vermont and New Hampshire are located in the southern counties with the exception of Burlington, VT along Lake Champlain in the northwest. In the prehistoric landscape, human population densities were lower overall, but the centers of Native American settlements were similar to those of today (Olson 1978, Fahey & Reiners 1981). In the northern and mountainous regions, Indian populations were sparse and nomadic, whereas in more southerly regions, densities were higher and tribes were more settled and more likely to practice agriculture (Olson 1978, Bormann & Likens 1979). The human settlements, both prehistoric and current, generally overlap with the more-fire prone natural communities (i.e. the white pine and oak-dominated forests).

Although permanent settlements are lower in the mountainous regions typical of the Green and White Mountain National Forests, seasonal recreational use is heavy. This use, plus continued (albeit at levels much lower than in the 19th century) logging, is the reason that humans continue to be a primary source of ignitions for wildfires on the White and Green Mountain National Forests.

Methods

Fire history determinations in the Northeast require a multifaceted approach (Patterson et al. 1983, Patterson & Backman 1988). Techniques including evaluation of written records (individual fire reports), historical accounts, old photographs (both landscape and aerial), fire scar and stand origin analyses, sedimentary analyses (pollen and charcoal), and comparative studies (reading the landscape) are appropriate. The combination and synthesis of information from a variety of sources provides the best detail for the role of fire on the landscape from presettlement time through the present. The methods used for this study are described below.

<u>Sedimentary Studies</u>

Fossil pollen and charcoal analyses are the only effective method for investigating the occurrence and effects of presettlement fires in the Northeast (Patterson et al. 1987, Clark & Patterson 1997). Regional summaries are available from Patterson and Backman (1988) and Clark and Royal (1997). The literature on fossil pollen and charcoal studies for Vermont and New Hampshire is sparse. Davis (1985) and Spear (1989, Spear et al. 1994) report on paleoecological studies in the White Mountains. No other published works were found. An unpublished paper on Little Rock Pond provides sketchy information on the fire history of a portion the Green Mountain National Forest (McDonnell & Drake, unpublished).

Individual Fire Reports

Most fires occurring in the Northeast during the 20th century have been reported by local, state, or federal agencies. Individual fire reports often include detailed information on the date, size, location, and/or cause of fires. Summaries of fire reports are available for some areas of the Northeast (e.g. Fahey & Reiners [1981] for the states of Maine and New Hampshire; Patterson et al. [1983, 1984] for Acadia National Park in Maine and Cape Cod National Seashore in Massachusetts; Patterson [1994] for the Waterboro barrens in Maine; Akers [1994] for the Concord, NH barrens; and Finton [1998] for the Ossipee Lake region of New Hampshire). Bormann and Likens (1979) summarize fire reports for northeastern national forests and compare fire histories of these forests with those of the Lake States. For this report, information of varying degrees of specificity was gathered from a variety of sources (Table 2). In general, we were able to acquire more specific information for Vermont than for New Hampshire. Both states have periods of time when only the most basic statistics are available. Most 20th century fire records for New Hampshire were destroyed some time after Fahey and Reiners (1981) completed their initial review in the late 1970's.

Data description and limitations.

New Hampshire

- Summary data (# fires, #acres) by year for 89 years from 1910 to 1998 (Fahey & Reiners had data for 69 years from 1910-1978).
- Number of fires by month for 40 years: September 1916 – June 1924, July 1926 – June 1958 (not including railroad caused fires).
- Annual number of fires by cause for 31 years: 1909, FY1910-FY1912, 1961-1974, FY1975-FY1987.
- Number of fires and acres burned annually by county for 45 years: Sept.-Oct. 1908, May-Aug. 1909, FY1910-FY1912, FY1917-FY1924, FY1927-FY1954 (not including RR fires), FY1955-FY1958.

White Mountain National Forest

- Summary data (# fires, #acres) by year for 60 years: 1927-1956, 1968-1973, 1975-1998. (Bormann & Likens compiled data for 32 years from 1945-1976).

Vermont

- Detailed information on 5,573 individual fires for 30 years: 1913,1915, 1922-1923, 1926-1933, 1935, 1977-1978, 1980-1986, 1991-1998. The information includes date of the fire (year-month-day), county & town, cause, and total acres burned.
- Summary data (# fires, #acres) by year for 91 years from 1908 to 1998.
- Number of fires and acres burned by month for 56 years: 1913, 1915, 1922-1923,1926-1933, 1935-1961, 1977-1978, 1980-1986, 1991-1998.
- Number of fires annually by cause for 70 years: 1913, 1915, 1922-1923, 1926-1933, 1935-1961, 1963-1971, 1976-1989, 1991-1998.
- Acres burned annually by cause for 44 years: 1913, 1915, 1922-1923, 1926-1933, 1935, 1963-1971, 1976-1989, 1991-1998.
- Number of fires annually by county for 56 years: 1913, 1915, 1922-1923, 1926-1933, 1935-1961, 1977-1978, 1980-1986, 1991-1998.
- Acres burned annually by county for 30 years: 1913, 1915, 1922-1923, 1926-1933, 1935, 1977-1978, 1980-1986, 1991-1998.

Green Mountain National Forest

- Summary data (# fires, #acres) by year for 24 years from 1975 to 1998. (Bormann & Likens compiled data for 32 years from 1945-1976).

Limitations

Our analysis of the historic fire occurrence in Vermont, New Hampshire, and the Green and White Mountain National Forests is limited by the quantity and quality of data we acquired. Most of our data were derived from town fire reports (usually archived by the state) and are therefore only as accurate as the original reports. Incomplete data required that estimates for the nearly 100-year time period (1908-1998) be based on a smaller data set with some years not represented. In most situations, our data, although missing years, ranged from the early part of the century to the end, thus capturing some of the variability in fire occurrence through the century. In some instances, particularly with the New Hampshire data, it was not clear if all fires were included in the summaries. This was particularly true for railroad caused fires. When railroad fires were listed separately, we added them in the total from other sources, but in several years it is not clear if they were included in the state reports. A printout of the number of fires and acres burned on the National Forests provided information for 1975-1995. This information was limited in that it listed acres burned to the nearest acre, resulting in fires less than an acre recorded as burning zero acres, although this should not affect our calculations as the acreage was so small. Some additional information was available for the National Forests, but these sources were usually incomplete (especially with regard to fire area). More complete information may change the detailed calculations in our report, but the overall trends in fire size and occurrence would not change.

What is missing

We were not able to acquire complete data for all years as indicated above. The largest gap in information is fire occurrence by vegetation type. Fahey and Reiners (1981) attempted to resolve this problem, and developed a very rough estimate of fire occurrence by forest type by first assigning each town in New Hampshire to a single forest type based on a USFS type map for the state. They then calculated fire occurrence by type based on the town fire records. Although their results are informative, they contain some obvious inconsistencies, such as the 510-year estimated fire rotation for New Hampshire aspen and birch - species which are unlikely to persist for several centuries in the absence of fire. Given the heterogeneity in vegetation within an area the size of a town and the lack of more specific data, we chose not to calculate fire rotations by type.

Efforts to obtain complete fire records for the two National Forests were unsuccessful. We queried the individual Forests and the Northeast Forest Experiment Station in Radnor, PA, but were unable to obtain data comparable to that used by Bormann and Likens (1979) in their summary of data through the mid-1970's. Efforts to obtain even these data were unsuccessful.

Historic (Written) Accounts

Information was gathered on individual fires from published and unpublished studies and written fire accounts. Reports and articles from the White Mountain National Forest, Hubbard Brook Research Station, Appalachia (the journal of the Appalachian Mountain Club), and Forest Notes (Society for the Protection of New Hampshire Forests) were reviewed for information on fire incidence, locations burned, acreage burned, and probable ignition sources. Charles Cogbill shared information on forest composition and disturbances that he has collected from historic land survey records for Vermont and New Hampshire.

Regional Geographic Data Bases

GIS data were downloaded from the Vermont Center for Geographic Information web site including town and county boundaries, population, and Green Mountain National Forest boundaries. Bruce Reid provided GMNF stand data. Data for New Hampshire (including town and county boundaries) were downloaded from the New Hampshire Geographic Information System (NH GRANIT) web site. Geographic information for the White Mountain National Forest (including WMNF boundaries, stand data, and historical land use as interpreted by Christine Goodale) was provided by Norma Jo Sorgman of the WMNF.

Data analysis

Raw data gathered from these sources were entered into Microsoft Excel and Microsoft Access to calculate summaries and averages by state, year, county (town), cause, and month for number of fires, number of acres burned, and average acres per fire. Fire rotations were calculated based on the size of an area of interest and the annual rate with which land burns within that area. Fire rotations are different from fire return intervals, which are calculated as the average number of years between successive fires in individual stands. We were able to calculate fire rotations for Vermont and New Hampshire as a whole, but because we have not examined fire histories at the individual stand level, we do not report fire return intervals. Where such figures have been reported elsewhere (e.g. Engstrom & Mann 1991), we use them to contrast stand-level with landscape-level occurrences of fire.

Summary information was entered as GIS data layers to overlay with other spatial data and to display the information in map form. Information derived from GIS data layers was used to determine the area covered by forest types for the National Forest Land.

Results

Pre-historic Fire Occurrence

During the Wisconsin epoch, glaciers dominated the New England landscape. These began to retreat 16,000 years ago, and northern New England landscapes were exposed by about 12,000-to-14,000 years ago. Early Paleo-Indian sites indicate that the region was first populated by humans soon after the retreat of the Wisconsin ice sheets. As the glaciers retreated and the climate warmed, vegetation colonized the newly developing soils. Initially, tundra species appeared followed by boreal conifer species and then by deciduous hardwoods, hemlock and white pine (Deevey 1939, Davis 1959). Forests changed as the climate warmed and individual species migrated onto suitable sites. In areas where the climate and soils remained suitable for early invaders, remnants of early post-glacial forests remained (e.g. spruce and fir at higher elevations in the mountains and jack pine on some rocky outcrop areas). The current vegetation is dominated by northern hardwoods and hemlock on the lower slopes in mountainous regions and in northern New England. Transition pine-oak forests occur on more xeric sandy soils and/or warmer, south-facing slopes in southern Vermont and New Hampshire (Westveld et al. 1956).

Paleoecological studies show that fires occurred throughout New England forest history, particularly during periods of warming and where fire-susceptible vegetation (e.g. pine and oak) was present (Davis 1985, Spear 1989, Spear et al. 1994, Backman 1984, Patterson & Backman 1988). Charcoal fragments in sediments of several southern New England sites show that fires were common in coastal pine-oak forests (Backman 1984, Motzkin et al. 1993, Winkler 1997). Less information is available for inland sites in New Hampshire and Vermont. Lorimer and Frelich (1994) and Patterson (in press) review sediment studies for the northern hardwood region as a whole and found that major fire events were usually recorded at intervals greater than 1,000 years in the Northeast, with periods of more frequent fire recorded for northern hardwood stands in the Great Lakes region. Here we review the few published studies of sedimentary charcoal in Vermont and New Hampshire.

Charcoal accumulations in Mirror Lake (located within the Hubbard Brook watershed north of Plymouth in the southern White Mountains) have varied over the last 14,000 years with rates 2-to-5 times higher between 11,000 and 7,000 years before present (BP) than in recent millennia (Davis 1985, Spear 1994). Conifers were abundant on the landscape surrounding Mirror Lake during this period of higher charcoal accumulation (spruce and fir 11,000-9,000 years ago; white pine 9,000-7,000) (Davis 1985), and the climate is believed to have been characterized by hot, dry summers that may have facilitated the ignition and spread of forest fires (Davis 1985, Spear 1994). Deciduous species like white birch and aspen, which were abundant during the early white pine period, typically occur as successional species following fires (Swain 1973, Spear 1994). Fire-sensitive species such as hemlock and beech either did not occur or were uncommon until after 7,000 BP (Spear 1994). By this time, fire was an infrequent visitor to the Mirror Lake watershed as evidenced by low charcoal accumulation rates in sediments (**Figure x - from Davis**). Of particular interest is the fact that fire incidence did not increase with the catastrophic decline of hemlock populations circa 4,800 BP. Patterson (in press) observed increased fire incidence at this time (and at about 3,000 BP when hemlock again declined locally) for sites on the Maine coast. Perhaps this is further evidence the mountain environments of central New Hampshire are less conducive to fire.

Higher charcoal abundances in near-surface sediments at Mirror Lake (**Figure x**) correspond to extensive regional logging in the 19^{th} century. Fires were more common regionally, but not within the watershed itself (Bormann et al. 1985). The unpublished work by McDonnell and Drake at Little Rock Pond south of Rutland in the southern section of the Green Mountain National Forest shows that, for the Holocene as a whole, fire occurrence followed a similar pattern in central Vermont. Thus, the paleoecological record, incomplete as it is, suggests that fire was relatively unimportant regionally in pre-settlement, hardwood-dominated forests of the Green and White Mountains. Additional work is needed to document fire histories that today support jack and red pine and where lightning fires, in particular, may have been more common in prehistoric time.

Native Americans have been present in the New England landscape for more than 10,000 years, and their use of fire to drive game, clear underbrush, and prepare ground for planting is well-documented (Bromley 1935, Day 1953, Patterson & Sassaman 1988). In New England, Indian population centers primarily occurred along the coast and in river valleys, much as is the case with modern population centers and these densely populated areas have generally overlapped the more flammable forest types in New England (Fahey & Reiners 1981). These areas have thus been characterized by more frequent fires in both historic and prehistoric times as people have made use of fire to clear land for agriculture, maintain wildlife habitat, or as for “psychic relief” (Schiff 1959, Pyne 1982). In addition to accidental and careless fires, and those caused by malicious intent, wildfires have sometimes been caused by escaped “controlled” burns, so fire has been a pervasive component of New England forests for a very long time. But in northern New England, Indian populations were small and migratory, and agriculture was limited (Bormann et al. 1985). Indians traveled the shores of streams and lakes while hunting, fishing, and trapping (Olson 1978) and thus made less use of large scale burning for agricultural purposes. Specific sites within the White and Green Mountain National Forests were undoubtedly fired frequently by Indians, but climate and fuels of low flammability apparently combined to prevent most of these fires from spreading across the larger landscape. Only with the generation of “unnatural” fuel loads during recent periods of extensive logging have human-caused fires spread to consume large acreage in the two Forests.

Historic Fire Occurrence

Fire Incidence. Charcoal in lake and bog sediments of the Northeast increases at all but the southern-most sites following European settlement (Patterson & Backman 1988). Early European settlers used fire in a manner similar to that used by native Americans to prepare land for cultivation (Ruffner & Patterson, in prep.) and often established towns in areas previously used by Indians (i.e. along the coast and in major river valleys). Land clearing activities increased greatly, however, with vast acreage burned to prepare agricultural fields (Whitney 1993). Forests were further reduced in size and extent, as additional wood was needed for building, heating and cooking. Occasionally fires would escape and burn large areas of forests.

The charcoal present in sediment cores increases during the early settlement period (the 17th through the late 18th centuries) in southern New England, but people were slow to move into the more remote areas of northern New England. The extensive pine forests around Ossipee, NH were, for example, not opened to logging until the late 18th century (Finton 1998). The earliest town records for Vermont and New Hampshire indicate that fires were less common there than to the south. Charles Cogbill (personal communication) reviewed early surveyors' records for the two states and found that fire was rarely mentioned. Only one fire was recorded in the 90 towns reviewed for Vermont, while for 45 towns scattered across New Hampshire no fires were mentioned. Cogbill did find that the lower Merrimack and Saco River areas contained abundant pine with early records having occasional references to fires, but he concludes that for Vermont and New Hampshire as a whole, wind storms were a more important disturbance factor than fires at the time of presettlement.

The forests of Vermont and New Hampshire did not remain free of fires, however, in the late 19th and early 20th centuries, several large fires are recorded as having burned in these two states. New Hampshire's fires were likely due to the large-scale timbering that was occurring there. Piles of slash (which provided fuel loads that were previously not present on the landscape) dried quickly when exposed to the sun and wind and would often ignite and spread fire across the county-side. The largest fires occurred following logging operations between 1880 and 1923 (see pp. **12-14**) (Van Alstine 1961, Hale 1958). Not only did logging provide fuel for fires, but also the equipment used to harvest and mill timber also caused sparks that ignited conflagrations. Before the introduction of spark arrestors on locomotives, trains, often hauling wood from cut-over land, were an additional source of ignitions. This proved to be such a problem that for a time, wildfires caused by locomotives were recorded separately as "railroad fires" in New Hampshire. Fire incidence increased in proportion to logging activity through the early decades of the 20th century when effective fire control measures were implemented (Fahey & Reiners 1981). Thus, for at least the last several millennia, fire may have had its greatest impact on Vermont and New Hampshire forests during the period encompassing the late 19th and early 20th centuries when logging was at its zenith and before effective fire control began (Fahey & Reiners 1981).

Logging and land clearing are not the only factors contributing to increased incidence of fire on the landscape. A variety of natural disturbances can also create large fuel loads, which increase fire hazard at least for a time. Ice storms (like the one that occurred in central New

Hampshire and Maine in January, 1998), hurricanes (e.g. the great storm of 1938) and wind events can cause locally to regionally important increases in fuel loads by toppling trees and breaking branches. The importance of these increased fuel loads to increased fire hazard depends upon the rate at which the dead branches decay. In New Hampshire and Vermont, the rate of slash decomposition is size and species dependent. Smaller stems of hardwoods decompose to the point where they represent low fire danger in three-to-seven years, whereas stems of similar size of red spruce may take 15-to-17 years (Spaulding & Hansbrough 1944)(**Figure ??**). Larger branches and logs take longer to decay, but prolonged winter snow cover and generally moist climates usually preclude these fuels from becoming available to burn. Although no large fire in this century has burned an area impacted by one of these natural disturbances, prehistoric evidence indicates that fires may have occurred after major wind storms (Foster 1988).

During the 20th century, the southern-most counties of both Vermont and New Hampshire have experienced a greater number of fires than northern counties (figures 7 & 8). These portions of the two states have more fire-susceptible vegetation and larger human populations. New Hampshire has had more fires than Vermont, often twice as many (Figure 9), but the incidence of fire in both states has generally been 1/10th that of their smaller neighbor - Massachusetts (with 8,284 square miles but a population of nearly 6 million) - to the south. In the early part of the century, New Hampshire also had more total acreage burned than Vermont (Figure 10). From 1910 to 1940, wildfires annually burned 2,700 acres in Vermont and 8,300 acres in New Hampshire. The average acres burned per fire per year for both states was been nearly identical (16 acres/fire for NH and 19 for VT for the period). After 1950 the size of fires greatly decreased to an average of less than 3 acres per fire in each state.

Compared to the states within which they are located, the White and Green Mountain National Forests currently have far less fire. For the period 1983 to 1998, only 0.12 fire occurred per thousand acres in the federally owned portions of the WMNF compared to 1.53 fires per thousand acres in the rest of New Hampshire (Table 3). During the same time period, USFS owned land in the Green Mountain National Forest had approximately 0.06 fire per thousand acres compared with 0.55 fire per thousand acres for Vermont as a whole. Fire size in the two Forests is also small - generally less than one acre. Vegetation on the Green and White Mountain National Forests is primarily northern hardwoods (52% of GMNF, 58% of WMNF) with alpine and spruce/fir communities at high elevations. Haines et al. (1975) report that on the WMNF for the period 1960-1969, 56% of the area burned was classified as hardwood while 26% was classified as conifer forests. On the GMNF, for the same period, 55% of the burned area was conifer forests, 26% grass and 16% hardwoods. During this period from 1960-1969, a total of only 14 acres burned on the WMNF and 13 acres on the GMNF.

Large Fire Occurrence. In the past, several large fires affecting tens of thousands of acres have occurred in the White Mountains (e.g. the 35,000 acre Rocky Branch fire in 1912, and the18,000 acre fire in Kilkenny and Berlin in 1903). Historic accounts indicate that early fires on several mountain tops were severe enough to remove the organic soils (Fobes 1953), although these fires are generally not described in sufficient detail to determine their extent or the year in which they occurred. Information compiled by Christine Goodale from forest survey maps for the period 1911-1930 indicates that approximately 10% (or 68,000 acres) of the WMNF was classified as "previously burned" when it was acquired by the federal government. Although she has dates for many of the fires, it is not clear how long after a fire an area might be recognized as previously burned.

Several of the largest fires occurred during the late 19th and early 20th centuries in the Franconia Notch region (a 12,000 acre Franconia/Zealand Valley fire in 1888 and a second Zealand fire in 1903 are among the best known examples). These fires were largely fed by slash generated by extensive logging operations and Bormann et al. (1985) note that the incidence and extent of forest fires in the White Mountains region greatly increased with the advent of widespread commercial logging. Timber harvesting, especially of conifers, has declined in recent decades, and since World War II there have been no fires of the magnitude of early conflagrations. Since 1975, the largest fires on the WMNF and GMNF were 105 and 270 acres, respectively. Even in 1947 when there were large fires elsewhere in New England (including several thousand acres in Ossipee, NH and 211,000 acres in Maine), the WMNF did not see an increased incidence of fire (no more than 3 acres per year for 1946-1948).

Large fires for which we have obtained some information are summarized below. The list is by no means complete, but to add additional fires would require going through virtually all the town records and histories for the two states. We do feel that our search has uncovered the most important large fires, at least those known to have occurred since about 1800.

Large Fire Descriptions.

New Hampshire:

1800 - Prior to the first "great" Mt. Monadonock fire (in Jaffrey), the mountain was described as being covered with spruce. Records and historical accounts indicate that a fire in this year destroyed not only the vegetation, but also the soil at the top of this mountain (Biennial Report of the New Hampshire Forestry Commission, 1909-1910; Fobes, 1953). The burning off of the soil and vegetation resulted in the bald granite mountain top present to this day. A second fire around 1820 also occurred on this mountain.

1885 - A 4,960-acre slash fire occurred in the Moriah and Bull Brook areas now part of the White Mountain National Forest.

1888 - The Zealand Valley region of the White Mountains was impacted by two large fires within 15 years. The first fire, in 1888, was started by a careless smoker and burned 12,000 acres (Fobes, 1953). Although this fire was patchy due to wetlands in the Valley and prior removals of softwood timber, it still burned more than two million feet of spruce logs on the skidways and $50,000 in standing pulpwood (Hale, 1958; Biennial Report of the New Hampshire Forestry Commission, 1909-1910; Van Alstine, 1961). In 1903 the Valley saw a second large fire that burned approximately 8,000 acres of new and previously burned areas.

1903 - This was one of the worst fire years for New Hampshire. An estimated 84,255-to-200,000 acres burned throughout the state. Several fires burned thousands of acres each during the spring and early summer. These included the Wild River Valley Fire (southeast of Gorham), which burned 16,850 acres in a "very severe" slash fire, and the 18,000-to-30,000 acre Upper Ammonoosuc fire (Kilkenny & Berlin) (Biennial Report of the New Hampshire Forestry Commission, 1903-1904). 1903 was a year with unusual drought early in the year - April rainfall was well below normal (Natti, 1975; Biennial Report of the New Hampshire Forestry Commission, 1909-1910). The fires were primarily on land that had been harvested, so large timber was not destroyed, although soils and re-growth were impacted. The spring fire season finally ended on June 12th with a large rainstorm that caused flooding and washed away many bridges (Van Alstine, 1961).

1908 - Owls Head, Franconia Branch (in the White Mountain National Forest) had a 11,200 acre fire that started from a lightning strike (Van Alstine, 1961).

1911 - Two droughts in 1911 (one of 30 days and the other of 35 days) resulted in favorable conditions for the start and spread of fires (Natti, 1975). Nearly 60,000 acres burned across the state with the majority in the pine and scrub barrens of the Concord and Ossipee areas. The 1911-1912 Biennial Report of the New Hampshire Forestry Commission lists large fires in Freedom (4,110 acres), Ossipee (3,580 acres), Wakefield (6,595 acres), Berlin (3,012 acres), and Concord (3,316 acres).

1912 - The Rocky Branch Area in the White Mountain National Forest burned in a "very severe" 35,000 acre late summer fire that lasted 12 days (**citation?).**

1928 - Several large fires (approximately 1,000 acres each) burned through scrub and pine in the Concord Pine Barrens (Biennial Report of the New Hampshire Forestry Commission, 1927-1928). Based on the age of the current mature pines, Finton (1998) believes that these fires, along with additional fires in 1937, were the last truly large fires to have burned in the area.

1941 - More than 700 fires burned approximately 37,000 acres during this year of high fire danger. More than 30,000 acres burned during just two days in April including the Marlow-Stoddard fire that burned across 23,350 acres, caused $155,000 in damage, and cost $38,000 to extinguish (Natti, 1975). This single fire threatened two villages, and destroyed seventeen farms and summer camps, two portable sawmills, and a firetower (Hale, 1958). "From March to December 1941 there were no outstanding periods of low fire danger. Weather records for seventy years indicated an all time low in precipitation and an all time high in temperature for the year. In every month but two, the rainfall was below normal. The mean relative humidity for April was 33% as compared to a normal of 61% and for fifteen days it was below 30%" (Biennial Report of the Forestry and Recreation Commission, 1941-1942). The larger fires started or later burned into hurricane and lumber slash areas that were inaccessible and difficult to approach. Due to the dryness, the 1941 fires burned deep into the humus and required a great mop-up effort.

1947 - This year was one of the worst fire years in northern New England, with 211,000 acres burning in Maine alone. New Hampshire did not have the large fires that Maine had, although it did have "hundreds of fires" (Wickham, 1997) with 7,500 acres burning in one day. The sandplain and barrens areas near Ossipee and the southern part of New Hampshire along the Maine border had the largest fires. Of the 26 largest fires that burned in New Hampshire during October 1947, only four were more than 1,000 acres and only seven of the remainder were greater than 100 acres. These fires “destroyed more than 70 homes and nearly 15,000 acres in more than 30 communities” (Wickham, 1997). The largest fire of October occurred in Farmington and Rochester where more than 7,000 acres burned and cost $35,000 to extinguish (Wickham, 1997). During the years 1947-1948 only two fires were reported for the White Mountain National Forest burning approximately 2 acres. (Biennial Report of the Forestry and Recreation Commission, 1947-1948).

1953 - Following record hot weather in June, lightning strikes ignited many fires. During a seven day period, New Hampshire experienced 46 fires, 28 of which were caused by lightning. The largest fires were on Mt. Shaw in Moultonboro and on Grantham Mountain. The 1,500 acre fire on Mt. Shaw began with a lightning strike, but was not reported until a week after it began (Wickham, 1997). The fire occurred on the lower hardwood slopes thereby sparing the spruce/fir areas near the summit (Alexander, 1978). It cost approximately $105,000 to suppress this fire while damage estimates were only $20,000 (Biennial Report of the New Hampshire Forestry and Recreation Commission, 1953-54). The Grantham Mountain fire was also started by lightning, but with the point of ignition near the summit (Alexander, 1978). The fire burned slowly for a week consuming both vegetation and soil and eventually burning 1,500 acres and costing approximately $125,000 to control. Unlike the Mt. Shaw fire, the Grantham fire burned through primarily spruce forest.

1957 - A fire in the towns of Ossipee, Freedom, and Madison burned nearly 3,000 acres. The fire started from a “spark” which escaped the incinerator at the New England Box plant on April 21st (Finton, 1998; Biennial Report of the Forestry Division, 1957-1958), and fire burned 2,924 acres of scrub oak and pitch pine. Three camps on the shore of Lake Ossipee’s Broad Bay were destroyed.

For New Hampshire, there have been no fires since 1957 to match the size of those burning in the early part of the century.

Vermont:

1857 - Entire range burned east of Manchester and Sunderland. (*****What “range”? reported where/by whom?)

1869 - A 1,628-acre fire burned at Pico Peak in Sherburne. The fire burned nearly all the hardwoods and spruce (Hawes, 1909). After the fire, the surviving spruce trees were harvested.

1903 - As with New Hampshire, Vermont had several large fires. In Brighton and Huntington 1,200 acres burned. In Duxbury 1,900 acres burned while no organized attempt was made to stop the fire, which killed all the spruce but only scarred most hardwoods. A third fire of 1,000 acres burned in Eden. This fire burned a hardwood and spruce ridge, but most of the spruce had been harvested prior to the fire.

1908 - During the summer and fall an estimated 20,000-to-25,000 acres burned in many fires. Eight burned 1,000 acres or more including the 1,330 acre Bald Mountain fire, the 5,100 acre Plymouth fire, the 4,900 acre Belvidere/Eden fire, and the 1,000 acre Groton/Peacham fire. Some of these fires were light burns with only the leaves and other fine fuels burning with no damage to standing trees, while other fires burned hot due to large amounts of slash remaining after timber harvest. One such slash fire burned for 10 days (Hawes, 1909).

Fires greater than one thousand acres are not common in Vermont, with less than half a dozen occurring since 1910. During the first half of the 20th century, the average size of Vermont fires was greater than 10 acres. The second half of the century saw a marked decrease in average size with less than 3 acres burned per fire for more than half of the years since 1950.

Fire Cause. For as long as records have been kept, lightning-caused fires have occurred infrequently in Vermont and New Hampshire. Only rarely have they burned more than one acre per lightning strike. In New Hampshire reports of lightning fires averaged 17 per year (0.3 fire per 100,000 acres) for the 30 years for which records are available during 1909 –1987. In Vermont during a similar time period (1913 – 1998: 44 years of data), there was an average of only 6 lightning-caused fires per year (0.1 fire per 100,000 acres), and these fires burned an averaged of only 9 acres per year across the entire state. Human ignitions, even during the early part of the 20th century when the reported number of fires were low (small fires were generally under-reported in the early years), were at least 5-to-20 times greater in number than lightning fires. Lightning fires have presumably always been rare in the Northeast, where lightning storms are usually accompanied by heavy rain and prolonged droughts are less common than in other areas of the country, so it seems reasonable to assume that the majority of fires have always been caused by humans and their activities (from arson to machinery use to escapes of controlled fires).

The specific causes of human-caused fires in New Hampshire have changed from the early part of the 20th century to the present. The 1903-1904 Report of the Forestry Commission (New Hampshire Forestry Commission 1905) lists “in order of importance” railroads, carelessness in clearing land, fishermen and campers, and maliciousness as the principal causes of forest fires. The principal causes during the period 1961-1987 include (in order of number of fires) children, smokers, brush burning, and incendiary (maliciousness). This change in cause reflects the change in forest use and technology. Causes of fires are similar in Vermont. Although campfires, arson, and equipment fires averaged only 6-to-7 fires per year, these human-caused fires did burn 2-to-3 times more acreage than lightning-caused fires. The majority of fires on the White and Green Mountain National Forests are also caused by human activities, with less than 10 fires caused by lightning on each Forest for the 20 years between 1975 and 1995 (25% of fires on GMNF, 8% on WMNF).

The building and use of railroads following the Civil War created a new ignition source for fires in New England. Early trains were powered by steam engines. Sparks and hot ashes emptied from boilers (and often dumped onto the tracks) caused numerous fires as the railroads crossed vast areas of woodland (Van Alstine 1961, Hale 1958). Railroad fires were so common at the turn of the 20th century that New Hampshire tracked them separately from other forest fires in the state. Not until the advent of the diesel-powered locomotive after World War II did railroad-caused fires begin to subside. From 1913 to 1950, Vermont averaged more than 20 fires/year due to railroads (17% of the total number of fires) and from 1919 to 1950 New Hampshire averaged 140 railroad-caused fires/year (30% of the total number of fires per year).

Fire Season. New Hampshire was described in the 1903-1904 Report of the Forestry Commission (New Hampshire Forestry Commission 1905) as having two fire season: "The first and most dangerous fire season is due to begin soon after the snow melts in the spring and continues till the leaves come out." For New Hampshire, this means early April through the end of May. The second season is in the fall, from the middle of September to the last of October. These fire seasons have been consistent throughout this century. Vermont has similar fire seasons with most fires occurring in April and May, and a second peak in October. These fire seasons reflect the incidence of human-caused fires. An analysis of lightning fires in Vermont found that the peak season for lightning fires is in July with a smaller peak in May, but since lightning fires are rare, a summer fire season is not defined.

Changing Patterns in Fire Occurrence. New Hampshire and Vermont, both realizing the destructiveness of fires, passed fire control laws in 1893 and 1904 respectively. These laws established a forest fire warden system and determined who would cover the cost of putting out fires: the towns or the states. With the construction of fire look-out towers and the advent of Smokey Bear fire prevention campaigns (in the late 1940's), the average size of fires decreased to below 10 acres. By 1960, the average size of a fire was less than 5 acres (Figure 10). Continued population growth and forest use, plus more efficient detection and reporting, caused the reported number of fires per year to increase through the 1970's. More recently, however, fire incidence is decreasing. New Hampshire has seen a greater increase and subsequent decline in fires than Vermont, which had a fairly consistent number of fires throughout the first half of the 20th century. Although the reported number of fires increased, the acreage burned has decreased dramatically in both states, especially since the mid-1950's. In New Hampshire the average acres burned decreased from over 12,000/year during the 1910's to less than 300/year during 1990-1998's (Table 4). Annual acres burned in Vermont declined from almost 2,500 to a little more than 400 during the same time periods. These data suggest that although there may be more fires reported now than in the early 20th century, the fires are generally very small.

Fire rotations. Fire rotations are a useful way to evaluate and compare the overall importance of fire in units of interest. Rotations that exceed the expected life-span of individual trees - perhaps 300-to-500 years for conifer and hardwood species endemic to Vermont and New Hampshire - suggest a less important role for fire in forest stand dynamics. Fire rotations substantially less than expected life spans of suggest, on the other hand, that fire may strongly support the regeneration and maintenance of fire-dependent species. Conversely, fire may act to limit the extent of fire intolerant species in landscapes that burn frequently.

Calculated fire rotations by state increase as the number of acres burned per year decreases. For the decade 1910 to1919, when the average acres burned per year was high, the fire rotation for New Hampshire as a whole is 500 years, while the rotation time increased more than forty-fold to 21,000 years by the end of the century (1990-1998, see Table 5). In Vermont rotation times increased from 2,500 years to nearly 15,000 years during the same time. State-wide fire rotations do not account for fire occurrence in more fire-susceptible forest types such as the dry pine communities of the coastal and southern parts of New Hampshire and oak and red pine areas in both states, but rather average rotations for all stand types. Because fire data for the two states were not coded by the vegetation type within which individual fires burned, we can not calculate fire rotations by type. Fahey and Reiners (1981), using the since destroyed individual fire reports for New Hampshire, calculated fire rotations for northern hardwoods and spruce/fir of 700-2,500 years. Bormann and Likens (1979) describe northern hardwoods of New England as being an "asbestos forest" due to their apparent low incidence of fire. Lorimer and Frelich (1994) estimated rotation times for stand-replacing fires in presettlement hardwood forests in northern Maine, New York, Pennsylvania, Michigan, and Wisconsin of 800 to 1,400 years - figures that suggest that fires are rare in northern hardwoods thoughout their range.

Given the dominance of northern hardwoods on the Vermont and New Hampshire landscapes, our data, which include the last 38 years of the 20th century, certainly support the conclusions of others and suggest, in fact, that fire rotations for the two states are even longer than those estimated in previous studies (13,700 years for VT, 10,000 years for NH, Table 5). (We do not report fire rotations for the two National Forests, because rough estimates suggest that they exceed 20,000 years - a length of time that is greater than the current interglacial period.)

The long fire rotations we and others calculate based on 20th century data have undoubtedly been influenced by increasingly effective fire control measure, but they are consistent with paleoecological studies which suggest that fire was rare in presettlement forests of the White and Green Mountains. Our data add more than 20 years to existing fire summaries for New Hampshire and strengthen the conclusion of Fahey and Reiners (1981) that "fire has been a relatively unimportant ecological factor in northern hardwood forests of northern New England". Our analysis of Vermont fire records adds to those previously conducted in New Hampshire and Maine to further strengthen the conclusion that fire is rare on most sites in mountainous regions of northern New England.

Unique Habitats

Although the majority of forest lands in New Hampshire and Vermont are classified as northern hardwoods, which rarely burn, some sites including barrens and some ridgetops at lower elevations do support fire-prone vegetation. Site-specific fire histories for these communities are available from historical accounts, fire reports and photographs (Akers 1994, Finton 1998), and/or dendroecological studies (Engstrom & Mann 1991, Mann et al. 1994, Carlson, pers. comm.). These studies provide more information on fires in specific vegetation types than we were able to compile statewide or for the national forests as a whole.

Pitch pine-scrub oak barrens are found on dry, sandy soils in Ossipee and Concord, New Hamshire, and near Burlington, Vermont (Howe, 1910). Local histories for Ossipee and

Concord indicate that barrens vegetation and/or greater abundances of red pine have been present in these areas since at least the time that white settlers arrived (Bouton 1856, Cook 1998). Akers (1994) and Finton (1998) reviewed the incidence of fire in the Concord Pine Barrens and discovered that although most fires were under 100 acres, there were at least two large, 20th century fires that each burned approximately 1,000 acres. Finton (1998) also reviewed historical reports for fires in the Ossipee area, and documented the occurrence of large fires. During particularly dry periods (as occurred in 1911, 1928, 1947, and 1957), these barrens often experienced large fires including a fire a 2,500 acre Ossipee fire in 1957 (see large fire descriptions).

Ridgetop red pine stands in both Vermont and New Hampshire also burn more frequently than is typical for forested lands state-wide. Mann et al. (1994) found that red pine stands at Battell Research Forest in the Green Mountains burned approximately every 20 years from 1504 to 1852. Engstrom and Mann (1991) describe the fire history on a ridge system near Bolton in northern Vermont. Low intensity fires ocurred frequently, whereas large, tree-killing fires occurred at longer intervals. They estimate that fire return intervals were as low as 3-to-5 years in the late 1880s, although the mean return interval for their entire study period (1815 to 1987) was 35-40 years. Carlson (pers. comm.) studied a ridgetop red pine ecosystem in North Conway, NH taking more than 440 increment cores and/or wedges from red pines located on four mountain tops along the ridgeline. He documented approximately 20 individual fires occurring between 1805 and 1995 and three major periods of red pine recruitment (in the 1880's, 1900's, and 1910's). He postulates that these may have occurred after large, stand-replacing fires.

Baldwin (1979) described the distribution of jack pine in New England and New York. This species occurs infrequently across the northern New England landscape and is often found on the "hottest and driest sites" - areas that most likely burned in the past. Burns on such sites would have likely left a barren rock or minimal soil substrate. Although cones found on jack pine in New Hampshire and Vermont are generally of the open-cone variety (i.e., they do not require heat from a fire to release seeds), the species probably benefits from periodic fires which expose mineral seed beds and reduce competition from less fire-tolerant species. Information on the specific occurrence of fire in stands described by Baldwin is as yet unavailable.

Fires in spruce/fir forest types are well documented from the boreal regions in Canada. Although spruce/fir communities are present in Vermont and New Hampshire, they apparently burn infrequently. Cogbill (pers. comm.) found that the spruce communities of the White and Green Mountains are unlike those of Canada in that fire is not the most common stand replacing disturbance. He believes that, rather than fire, chronic and episodic winds as well as ice and snow provide the disturbances necessary to regenerate these stands. Sprugel documents wave-regeneration in high elevation fir stands, but there is little evidence that the large concentrations of fuel resulting from episodic blowdowns in these stands contributes to a significantly higher incidence of fire.

With the exception of spruce and fir, the unique communities and sites described above probably burn more frequently than statewide fire rotations would indicate. Because fires occurring in these fire-prone sites are included in the calculation of fire rotation statewide, rotations in the less fire-prone forest types (e.g. northern hardwoods) amay be even longer than the state-wide averages indicated earlier. Additional site-specific studies within select areas of interest (e.g. paper birch stands known to occupy old burns on the White Mountain National Forest) would provide more information about the past and potential occurrence of fire on these sites.

Trends: From the Past to the Future

Fire regimes change as factors affecting the ignition and spread of fire in a particular area change. Bormann and Likens (1979) point out that "Many factors determine the susceptibility of a forested ecosystem to intense fires (such as recurrence of severe drought years, frequency of lightning, vigor of the vegetation, propensity to accumulate burnable matter, and human activities)." Fire incidence and acres burned in New Hampshire and Vermont increased after settlement and reached their peak during the later half of the 19th and the early years of the 20th centuries. During this period, abandoned fields were growing into woodlands, and large-scale logging was occurring in the forests of the White and Green Mountains. The large-scale fires that occurred around the turn of the century resulted in a new era of forest fire protection for New England (Pyne 1982).

The current trend of decreasing fire size reflects improved detection and suppression practices as well as a restoration of hardwoods forests as the dominant vegetative cover. Bormann and Likens (1979), using national forests data, and Fahey and Reiners (1981) for New Hampshire observe that although fire numbers increased due to more people using the woods, the acres burned during the 30 years following World War II declined. Our data suggest a continuation of this trend through 1998. Between 1980 and 1998 the average size of a fire in Vermont was less than 2.5 acres and less than 1 acre in New Hampshire. This compares with an average of 31-to-32 acres/fire for both states between 1910 and 1919. This decrease in the average size of a fire was in contrast to the number of fires being reported. From 1910-1929, an average of 330 fires per year was reported for New Hampshire and only 115 per year for Vermont. Between 1980 and 1998, the number of fires per year nearly doubled to 575 for New Hampshire and 215 for Vermont. The total acreage burned annually in the two states declined dramatically from the beginning to the end of the century.

From a management perspective, the low fire occurrence in northern hardwood forests may simplify the tools needed to maintain this ecosystem. Unlike fire-dependent ecosystems that may require prescribed fires to preserve the system and its species, the northern hardwood ecosystem does not appear to require such management (Lorimer & Frelich 1994). There are, within the region as a while, certainly ecotypes that require for their maintenance. These should be identified and appropriate management plans should be developed for them, but they are the exception rather than the rule (on an areal basis at least).

Conclusions

Vermont and New Hampshire, with their mountainous terrain, moist climate, numerous natural fire breaks (streams, rivers, & lakes), and low amounts of available fuel are unlikely to support naturally occurring, large-scale fires. Portions of these states do contain fire-susceptible vegetation (such as pine stands on dry or shallow soils and xeric oak-pine communities near the coast), but the larger matrix of northern hardwood forests may only experience natural, stand replacing fires every 1,000 years or more. Fire occurrence in the late 19th and early 20th century was greatly increased from presettlement times due to human activities. The decreased fire incidence on the landscape in the later half of the 20th century suggests that forests of the region may be returning to a fire regime more typical of presettlement conditions, when fires were rare on much of the landscape. Management of these areas should reflect the change in fire regime and may not require the large-scale reintroduction of fire as has been suggested for ecosystems outside northern New England.

The White Mountain and Green Mountain National Forests are the largest protected natural areas in their states. These forests have experienced usage by humans for millennia but especially during the earlier part of the 20th century. This use changed the landscape as well as the processes that occur there. With the return of a fire regime characterized by less frequent fire, the forests may return to their presettlement vegetation composition, although other factors such as disease or insect outbreaks and climate change could alter this prediction. Fire may be a useful tool in this landscape to manage for specific communities or to attain specific management objectives, but frequent fire is not required for the preservation of the northern hardwood forest as a whole. Fire history studies at these sites may determine if fire is important to their long-term maintenance.

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Appendix A

Rainbow article

Appendix B
Data for Vermont

Appendix C
Data for New Hampshire

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Fire Regime Characteristics

FRES ecosystem type 18 (maple - beech - birch), commonly known as the "northern hardwoods forest", occurs on mesic and fire protected sites in the U.S. Lake States and Northeast and in southeastern Canada (Figure 1). Northern hardwoods are commonly referred to by foresters as "asbestos" forests (Vogel 1967; Bormann and Likens 1979), because they contain low amounts of available fuel and occur on sites that are unlikely to burn (e.g. down wind of firebreaks or in mountainous areas with low fire incidence and moist microclimates). The dominant hardwood species, including sugar maple, yellow birch, beech and (in the Midwest) basswood, are components of SAF cover types 24 (hemlock-yellow birch), 25 (sugar maple-beech-yellow birch), 26 (sugar maple-basswood), 27 (sugar maple), 18 (black cherry-maple), 108 (red maple), and 109 (hawthorn). They are components of Kuckler's maple-basswood (K99), beech-maple (K102), and the northern hardwoods (K106), northern hardwoods-fir (K107), and northern hardwoods-spruce (K108) forests. Northern hardwoods mix with boreal spruce and fir to the northeast (Figure 2), and with hemlock, white pine and northern oaks to the south and west. Component species, especially beech and sugar maple, extend south at mid elevations in the Appalachian Mountains to western Virginia and North Carolina where they occur in Kuckler's mixed mesophytic (K103) forest type. Although northern hardwoods have experienced some fire during the 100-300 years since Europeans began settling North America (Bormann and Likens 1979), evidence suggest that in prehistoric times fire was very rare. Where hardwoods mix with conifers such as white pine, hemlock and red spruce, fire is, and probably has been, more common.

Fuels

Because, in part, of the lack of concern about fire incidence in northern hardwood, few studies have quantified fuels in these forests. Data that are available were often collected for purposes other than quantifying fuel available to support wildland fires (e.g. Tritton 1980). Hart et al. (1962) estimated an average annual accumulation of litter in a New Hampshire northern hardwood stand as 3.16 t/ha. Leaf litter decomposition rates with reported half-times (years required to loose one-half of the original dry weight) of 1.1 (for yellow birch) to 2.5 (for beech) are high (Gosz et al. 1973), and duff accumulations low (typically 5-8 cm, Hart et al. 1962).

Gore and Patterson (1986) sampled downed wood in six New Hampshire northern hardwood stands including The Bowl, a large tract of old growth northern hardwoods, and a recently clear-cut stand. Fuel particles were sampled by 1-, 10-, 100- and 1000-hr timelag classes. Fuel loads in the 1- and 10-hr categories (i.e. those fuels most likely to support fire in the humid Northeast) were low (1-6 t/ha) across all but the recently cut stand (Table 1 - Table 3 from Gore &Patterson). The total mass of downed wood declined precipitously in the first 10 years following cutting and stabilized at 42 t/ha in the old-growth stand (Figures 3 and 4). Patterson et al. (1983) report similarly low values for northern hardwood stands on Mt. Desert Island, Maine.

Fuel loads (all time-lag classes) in stands burned in 1947 and ca. 1880 averaged 22.4 and 26.5 t/ha respectively, with duff depths of 5.8 and 2.50 cm. Fuel depths were low at 7.6 to 15.2 cm.

Postfire Plant Communities

Pre-1900 Succession

To accurately portray historic fire regimes in northern hardwood forests, it is necessary to distinguish between the periods before and after settlement by Europeans. Although limited data are available for pre-settlement northern hardwood forests, evidence suggests that fires were rare. Backman and Patterson (1988) report charcoal evidence for fire in sediments from a small, western Massachusetts pond. Samples dating to 300-700 years ago contained abundant beech, sugar maple and birch pollen and little charcoal. Charcoal abundance increased with settlement, while beech and maple pollen declined. Samples from Lake Wood on Mount Desert Island, ME (Figure 5) span more than 6,000 years. During the period 2000 to 6000 years BP, northern hardwoods and hemlock were dominant on the watershed. During that time, the only fires indicated by charcoal analysis occurred in conjunction with sharp declines in hemlock (assumed to have occurred as a result of insect or disease outbreak, Davis 1981). Hemlock declines ca. 4800 and 3000 BP were followed by periods in which one or more fires burned the watershed. The intervening samples spanning 1000-1500 years show no evidence of fire. (Charcoal that does occur is at levels that typically indicate regional rather than local fires.) With the rise in importance of spruce and cedar about 2000 BP, the incidence of fire increases with return intervals of 200-400 years. The abundance of maple, beech and hemlock decline simultaneously. The watershed of this pond burned in a catastrophic fire in 1947, and today contains only one small (approx. 2 ha) stand of hemlock and no northern hardwood stands. The forest is dominated by seral hardwoods (aspen, and paper and gray birch), northern red oak, and white and red pine.

Only in the Bigwoods maple-basswood forest of Minnesota and at Crawford Lake in southeastern Ontario (prehistoric northern hardwoods) have presettlement fires been associated with northern hardwood stands. Vankat (1979) suggests that the boundaries of the maple-basswood association as a whole are indistinct due to past Indian burning practices. Grimm (1984) notes that Bigwoods existed (at the time of settlement in the mid-19th century) largely because of protection by landscape features including the Minnesota River to the southwest and morainal lakes interspersed in Des Moines lobe drift of the Wisconsin glacial epoc. Until the 19th century, fires ignited by Native American Indians spread from prairies to the west and burned portions of Bigwoods. Because fires were fragmented by the landscape features noted above, hardwoods persisted, whereas oak forests, prairies and savanna existed on the larger south-central Minnesota landscape. Noting the low shrub and herb cover and high decomposition rates of hardwood fuels, Grimm concludes that Bigwoods is "not very flammable" and speculates that fires burning into Bigwoods did so as patchy creeping ground fires. He notes that "the fire regimes of deciduous forests, such as bigwoods, are much different from the commonly perceived model of a forest fire regime, in which fuels and fire danger increase with time and in which intense crown fires commonly cause great destruction of forest." This is consistent with our observations in northern hardwood stands on Mt. Desert Island. Stands burned in 1947 currently support forests dominated by sprouts of beech and sugar maple rather than seral hardwoods (Patterson et al. 1983).

At Crawford Lake, McAndrews and Boyko-Diakonow (1989) speculate that prehistoric shifts from northern hardwood to oak and white pine dominated forests occurred as a result of pre-Columbian Indian agricultural activities (including "clearing the forests through cutting and burning"). Campbell and McAndrews (1993) later revised this interpretation to emphasize Little Ice Age climatic cooling as a casual factor in shifts from northern hardwoods to oak and white pine, but Clark and Royal (1995) did additional work and expressed support for the original explanation of McAndrews and Boyko-Diakonow (1993). A vigorous debate ensued (Campbell and McAndrews, 1995; Clark, 1995). Although the relative importance of Indian burning vs. climate change in presettlement changes in the larger northern hardwood region remains open, it seems likely that changes evident in the Crawford Lake pollen profiles were at least in part the product of human manipulation of the forest. Clark (1995) concludes that additional studies of Indian effects on northern hardwood forest composition are needed, but there is little evidence that Indian burning alone (i.e. without accompanying agricultural activity) was as important in northern hardwoods as it apparently was in oak forests to the south (Abrams, 1992).

Siccama (1971) and Lorimer (1977) examined 18th and 19th century land survey records for portions of northern Vermont and Maine respectively - areas where the natural vegetation is assumed to be "northern hardwoods-spruce-fir" (sensu Westveld et al. 1956). These records contain quantitative information on the species composition of the forests as well as observations on the extent of burned land. Siccama (1971) found no reference to burned land in Vermont and Lorimer (1977) estimated that less than 10% of his study area in northeastern Maine had been burned. Lorimer calculated a fire rotation of 806 years, but argued that this figure is probably too low, as large fires in ca. 1803 and 1825 may have been associated with land clearing operations, which were beginning to affect his study area by the early 19th century. Return intervals of a few (for spruce-fir forests) to many (for northern hardwoods) centuries are consistent with the paleoecological data from Mt. Desert Island noted above.

Post-1900 Succession

There is little information on 20th century fire occurrence in northern hardwood stands of the Northeast and Lake States. Bormann and Likens (1979) summarize fire records for ten national forests from northcentral Minnesota to Maine - a region they broadly refer to as the "northern hardwood forest", but these forests contain several FRES ecosystem types, with FRES Type 18 dominant on only a few [e.g the Green and White Mountain National Forests (GM&WMNF) of Vermont, New Hampshire and western Maine]. Based on fire records from 1945 to 1976, they conclude that forests in the Green and White Mountains are "among the least burnable in the 'northern hardwood region'". On average, only 3-4 ha/405,000 ha per year burn on the GM and WMNF. Perhaps the best summary of fire occurrence for northern hardwoods of the Northeast is that of Fahey and Reiners (1981) who examined fire occurrence by vegetation type for Maine and New Hampshire using fire records for the first six decades of the 20th century. They calculate fire rotation's in northern hardwoods of 910 yrs for Maine and 770 years for New Hampshire.

For Maine they calculate lower and upper limits (taking into account the dramatic decline in acreage burned in the later part of the period) of 450 and 4970 years. Work currently in progress (W.A. Patterson, unpublished data) documents the continued trend toward lower acreages burned (i.e. longer rotations) during the later half of the 20th century for New Hampshire and low 20th century fire occurrence in Vermont - the state with the largest representation in northern hardwoods. Bormann and Likens (1979) conclude that fire has been a relatively unimportant ecological factor in northern hardwoods, and Fahey and Reiners (19801) agree, although they acknowledge that northern hardwoods have burned in the past, especially when adjacent stands were clearcut during the logging period and when stands were affected by blowdown (Lorimer, 1977; Stearns, 1949). Records that are available suggest that modern stands have been more influenced by fire (chiefly as a result of anthropogenic fire during the period 1850 to 1950) than will be future stands, but the evidence suggests that even present northern hardwood stands have been influenced to a far smaller degree by fire than have other vegetation types in the Northeast.

Bormann and Likens (1979) cite several authors as indicating that "northern hardwood forests are relatively resistant" to burning. Indeed, Stearns (1949), who examined a virgin northern hardwood stand in northern Wisconsin, notes that although hot slash fires "burned to the edge of the virgin stand they did not penetrate into it more than a few rods." Beech and sugar maple stands surrounded by flammable spruce and fir on Mt. Desert Island, Maine burned in the 1947 fire, but, interestingly, these hardwood stands have returned to their original stand composition more rapidly than any other forests type burned on the Island Table 2 from Patterson et al. 1983 and Patterson, unpublished data). Although northern hardwood species are widely viewed as having little resistance to fire, maple and birch sprout vigorously from the stump and beech suckers from the root system as vigorously as aspen (Fowells, 1965). On Mt. Desert Island, this capacity for rapid vegetative reproduction appears to limit invasion of northern hardwoods by seral aspen and white and gray birch, which are short lived and can not persist in competition with beech, maple and yellow birch in the absence of frequent, stand-replacing disturbances (Patterson et al. 1983). The present dominance of white birch on some sites in the White Mountains is probably more a reflection of increased incidence of fire and logging in the last century than an indicator of the long-term importance of fire on the landscape. As management shifts toward longer harvest rotations and reduced volume removal, northern hardwoods will likely regain their historic position of importance on mesic, fire protected sites in the Northeast. Where northern hardwoods mix with conifers including hemlock, white pine, spruce and fir, fires are likely to be more common, especially in the wake of catastrophic wind storms (Stearns, 1949; Lorimer, 1977; Foster, 1988). Should climate warm, as predicted by some, northern hardwoods (and reduced fire incidence) may return to some sites at the present hardwood-boreal forest boundary while giving way to transition hardwood-conifers to the south, although the increased presence of human ignition sources on the landscape may alter fire-vegetation relationships evident in presettlement forests.

List of Figures

Figure 1. The extent of northern hardwood forests in northeastern North America (redrafted from Bormann and Likens 1979).

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Figure 3. Mass of downed wood in New Hampshire northern hardwood stands as a function of stand age. (from Gore and Patterson 1986)

Figure 4. Downed wood in old growth northern hardwoods - The Bowl Research Natural Area, White Mountain National Forest.

Figure 5. 6,000 year pollen and charcoal diagram for Lake Wood, Acadia National Park, Mt. Desert Island, Maine.

Tables

Table 1. Average mass (tonnes/ha) of downed wood in diameter class by time since cutting for New Hampshire northern hardwood stands. (from Gore and Patterson 1986)

	Years Since Stand was Clearcut				
Class (cm)	1	15	50	100	Uncut
<0.6	7.6	2.4	3.3	1.1	2.0
0.6-2.5	14.6	4.9	5.3	6.1	5.4
2.5-7.6	40.0	3.7	6.4	2.2	4.6
>7.6	24.2	21.4	17.1	45.0	29.9
Total	86.4	32.4	32.1	54.4	41.9

Table 2. Average basal area (mý/ha) by species for Mt. Desert Island northern hardwood stands burned in 1947 and before 1880 (W.A. Patterson, unpublished data).

	Stand Burned in 1947		Stand Burned before 1880	
	Sample Year			
	1980	1992	1980	1992
Red Spruce	-	0.1	0.6	1.6
Hemlock	0.1	0.1	0.4	-
Paper Birch	4.8	4.3	4.0	4.2
Yellow Birch	0.1	0.3	0.1	0.7
Red Maple	0.3	1.2	0.4	0.9
Sugar Maple	4.4	3.1	7.0	5.0

White Ash	0.1	-	1.5	1.1
American Beech	11.7	15.0	9.6	9.2
Striped Maple	0.5	1.6	0.9	2.2
Bigtooth Aspen	0.7	1.5	0.2	0.4
Others	0.5	0.2	0.3	0.2
Totals	23.2	27.4	25.0	25.5

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