Fire and the Development of Oak Forests

In eastern North America, oak distribution reflects a variety of ecological paths and disturbance conditions

Marc D. Abrams

O

ak (Quercus) represents one of the most dominant species groups in the eastern deciduous forest of North America (Table 1). In certain eastern regions, oak dominance reflects the importance of this genus in presettlement forests (Abrams and Downs 1990, Spurr 1951, Whitney and Davis 1986). Yet, in other regions, the current distribution of oak greatly exceeds that of the original vegetation (Abrams 1986, Howell and Kucera 1956, Nowacki et al. 1990). Thus, the development of oak species has occurred through a variety of ecological pathways and disturbance conditions.

The dominance of oak in presettlement forests is particularly interesting because most oaks are considered early to midsuccessional species. Indeed, most recent studies indicate the potential for widespread oak replacement by more shade-tolerant species in mature forests (Christensen 1977, Lorimer 1984, Nowacki et al. 1990). However, this phenomenon may vary with regional and edaphic factors and be more pronounced on mesic rather than on xeric sites (Abrams 1986, Host et al. 1987, McCune and Cot
tam 1985, Nowacki and Abrams 1991). These observations have led researchers to ask the following questions about oak ecology in eastern forests: What factors promoted oak dominance in certain presettlement forests? What factors retarded oak development in presettlement vegetation types currently dominated by oak? What conditions during the initial postsettlement period perpetuated oak dominance or facilitated an increase in oak? What factors are currently causing oak regeneration failure and promoting the invasion of most oak understories by later successional species?

Although a suite of factors, such as climate change, logging, animal and insect grazing, and disease, have affected the dominance of oak, the answers to these questions may relate directly to historical changes in the influence of fire in the eastern deciduous biome. Fire, whether it has occurred to a low, moderate, or high degree, seems to be the common denominator for the development of oak forests on upland sites and their past and present ecological status. This article reviews pre- and postsettlement forest conditions for the major oak-dominated ecosystems throughout eastern North America to discern how the influence of fire and human activity have affected the past and present ecology of oak forests and how these factors will likely continue to affect forests in the future.

Paleoecology of eastern oak forests

During the last 18,000 years, dramatic shifts in species assemblages occurred in eastern North America. Approximately 18,000 years B.P., pine (Pinus) dominated forests in the southeast, whereas spruce (Picea) dominated in the northern and central regions (Webb 1988). By 10,000 years B.P., oak forests occupied most of the eastern United States, except for the northern tier, which was primarily pine, spruce, and birch (Betula) forests. Oak forests continued to dominate the eastern United States through 500 years B.P., with pine in the southeast and north-central regions.

Oak species not only have a long history of domination in eastern forests but also their presence is often associated with recurring fire. An investigation of late Quaternary vegetation at various sites in the mid-Atlantic region revealed long-term domination by pine and oak coupled with the presence of charcoal (Watts 1980). On several of the study sites, a change from pine to oak domination (approximately 9000 years B.P.) coincided with increased charcoal abundance. In a study of Mirror Lake, New Hampshire, peak domination of white pine and oak occurred 9000–7000 years B.P., when the climate was warmer and drier and charcoal concentrations were most abundant (Davis 1985).

Marc D. Abrams is with the School of Forest Resources, Pennsylvania State University, University Park, PA 16802. © 1992 American Institute of Biological Sciences.
Table 1. Distribution of some important Quercus species on upland sites in various regions of eastern North America.

<table>
<thead>
<tr>
<th>Species</th>
<th>Northeast</th>
<th>Great Lakes</th>
<th>Central plains</th>
<th>Midwest</th>
<th>Southeast</th>
<th>Mid-Atlantic</th>
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A warming trend between 6500–3500 years B.P. in south-central Wisconsin resulted in increased fire frequency and a change from rich mesophytic forests to oak savannas (Winkler et al. 1986). The climate then became cooler and wetter, resulting in less fire and a conversion of oak savannas to closed oak forests. Similarly, a change during the Holocene from prairie to oak woodlands and then more recently to mixed-mesophytic forests in southern Minnesota was attributed to reduced fire frequency from increased precipitation and decreased temperatures (Grimm 1983). However, the global warming predicted for the next 200–500 years may increase oak importance for mixed conifer-hardwood forests of the northern Great Lakes and New England regions (Overpeck et al. 1991). Thus, the dominance of oak forests, climate, and fire are seemingly interrelated in the eastern United States.

Ecophysiological features of oak

Most upland oak species exhibit physiological adaptations that should facilitate survival on sites exposed to periodic fire and drought, as well as on sites that are nutrient poor. Relative to other hardwoods, fire should favor oaks because of their thick bark, sprouting ability, resistance to rotting after scarring, and the suitability of fire-created seedbeds for acorn germination (Lorimer 1985). Periodic fire should also check succession in oak forests, because most later successional species, such as red and sugar maple (Acer rubrum and Acer saccharum), exhibit low resistance to fire.

Drought adaptations in oak include deep roots, xeromorphic leaves, low water-potential threshold for stomatal closure, and the ability to adjust osmotically (Abrams 1990). Oak species can also maintain high rates of photosynthesis during drought, and they may possess the greater ability to survive on nutrient-poor sites relative to other tree species (Reich and Hinckley 1980). However, one type of ecological stress for which oaks are not well adapted is low light. Oak species generally have low or intermediate tolerance to shade, and therefore their seedlings do not exhibit long-term survival or growth in the conditions of a closed understory (Burns and Honkala 1990, Crow 1988).

Oak expansion in the tallgrass prairie region

Tallgrass prairie dominated by Andropogon, Sorghastrum, and Panicum once occupied a 575,000-square-kilometer, roughly triangular area bounded by central Texas, eastern North Dakota, and western Indiana (Kuchler 1964). Isolated pockets of tallgrass prairie also existed throughout the northeastern deciduous forest, including a more extensive area in west-central Ohio. Oak savannas or oak openings were also a common feature of the tallgrass prairie region, and at the time of settlement they covered 11–13 million ha of the midwest (Nuzzo 1986). Oak species usually found in savannas include Quercus macrocarpa (bur oak), Quercus velutina (blackjack oak), Quercus alba (white oak), Quercus ellipsoidalis (northern pin oak), Quercus stellata (post oak), and Quercus marilandica (blackjack oak). Typically, these savannas had a prairielike understory, and they were thought to have developed from pre-existing forests exposed to frequent burning (Curtis 1959). Presettlement prairie border forests were also dominated by oak and were maintained by recurring fire (Gleason 1913, Pallardy et al. 1988, Rodgers and Anderson 1979). However, nearly all of the original tallgrass prairie and savanna have been converted to farm land or forests.

Presettlement tallgrass prairie is thought to have developed and flourished in an environment that included recurring fire at one- to ten-year intervals (Axelrod 1985). Frequent fire in the Central Plains region was a function of lightning strikes as well as Indian activity, including cooking, heat, ceramic manufacture, communication, field preparation for cultivation, combating insects, hunting, and killing woody vegetation (Day 1953). Because precipitation in the tallgrass prairie region is adequate to sustain forest vegetation on all but the most xeric sites, it is generally assumed that frequent fires limited forest development (Abrams 1986, Gleason 1913, Howell and Kucera 1956).

After European settlement of the Central Plains, fire frequency and intensity decreased due to road construction, expansion of towns, in-
creased agriculture, intensive cattle grazing, wildfire suppression, and recommendations against burning prairie in the mid-1900s (Abrams 1986). During this period, forests rapidly expanded at the expense of prairie vegetation, and the dominant species in these newly formed forests were generally oak (Figure 1, Table 2). Examples of this expansion include the formation of blackjack oak and post oak forests in central Oklahoma; white oak, shingle oak (Quercus muehlenbergii), bur oak, and American elm (Ulmus americana) forests in central Missouri; and bur oak and chinquapin oak (Quercus muehlenbergii) forests in eastern Kansas (Abrams 1986, Howell and Kucera 1956, Rice and Penfound 1959). A reduction in fire frequency, coupled with drought adaptations in oak, facilitated oak invasion and survival after European settlement. Birds and small mammals

Figure 1. Quercus macrocarpa and Quercus muehlenbergii forest expanding in a prairie ravine in eastern Kansas since European settlement in 1840.

| Table 2. | Presettlement vegetation and current overstory and understory condition for various oak forest types in eastern North America. |
|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| Presettlement vegetation        | State  | Overstory   | Understory                          | Reference                     |
| Tallgrass prairie               | KS     | Bur oak–hackberry | Hackberry–elm                      | Abrams 1986                   |
|                                 | KS     | Chinquapin oak  | Elm–redbud–chinquapin oak           | Abrams 1986                   |
| Bur oak                         | WI     | White oak–shagbark hickory | Shagbark hickory–choke cherry      | Dorney and Dorney 1989         |
| White oak–black oak             | WI     | Blackjack oak–post oak | Blackjack oak–post oak             | Rice and Penfound 1959         |
| Prairie border forest           | MO     | White oak–sugar maple | Sugar maple                        | Pallardy et al. 1988           |
| White oak–black oak             | IL     | White oak–shagbark hickory | Sugar maple                        | Rodgers and Anderson 1979      |
| White oak–red oak               | VA     | White oak–red oak | Sugar maple–red maple              | Braun 1950, Stephenson 1986    |
| Chestnut oak                    | PA     | Chestnut oak–red oak | Black oak                          |                                  |
| Northern forest                 | MA     | Black oak–red oak–white pine | Red maple                     | Lorimer 1984, Whitney and Davis 1986 |
| White oak–black oak             | NC     | White oak         | Sugar maple–red maple–cherry      | Myers 1985                     |
| Oak–chestnut                    | NC     | Red oak–chestnut oak–white oak | Red maple                     | Myers 1985                     |
effect long-distance dispersal of oak acorns (Crow 1988).

There exist similarities between tallgrass prairie and oak savannas in their transformations to closed forests with decreased fire. For example, many of the original savannas of central Oklahoma became closed post oak–blackjack oak forests, whereas gallery oak savannas in eastern Kansas became closed oak forests during the first 50 years after European settlement (Abrams 1986, Rice and Penfound 1959). In Wisconsin, bur oak or white oak–black oak savannas gave way to black oak, white oak, and/or hickory (Carya) forests after settlement (Cottam 1949, Dorney and Dorney 1989). Understory grubs (multistemmed sprouts) of oak and hickory in these savannas, previously top-killed by recurring fire, rapidly grew after fire exclusion.

Red oak expansion in northern hardwood forests

The northern hardwood forest biome, also known as the hemlock–white pine–northern hardwood region (Braun 1950), extends from northern Minnesota to New England, including most of New York and northern Pennsylvania. Presettlement forests of the northern hardwood region generally contained only a small oak component. The original forests of northern Wisconsin and Michigan were dominated by various combinations of hemlock (Tsuga canadensis), sugar maple, yellow birch (Betula alleghaniensis), beech (Fagus grandifolia), and mixed pine (Finley 1976, Whitney 1986). An unusually high amount of oak (5–75%) in presettlement upland forests, including an oak savanna, in northeastern Wisconsin was attributed to frequent Indian-caused fires in the area (Dorney and Dorney 1989). On the Allegheny Plateau, white oak, black oak, and red oak represented 19% of the presettlement beech-maple-hemlock forests in western New York (Seischab 1990), but less than 4% in northwestern Pennsylvania (Lutz 1930). No oak was recorded in presettlement spruce-beech-fir forests in northeastern Maine (Lorimer 1977).

There is little doubt that presettlement hemlock–northern hardwood forests containing almost no oak or pine burned infrequently. The average recurrence interval of fire in northeastern Maine was 800 years (Lorimer 1977). Only one fire occurred between 1665 and 1967 in a white pine–hemlock–spruce forest in New Hampshire (Henry and Swan 1974). In northern lower Michigan, the average return time for severe crown fires, estimated from General Land Office survey records, was approximately 80 years in jack pine, 120–240 years in mixed pine, and 1200 years for hemlock–white pine–northern hardwoods (Whitney 1986).

A particularly interesting feature of the northern hardwood forests was the postsettlement expansion of northern red oak on a variety of sites (Figure 2, Table 2). Crow (1988) reviewed literature from northern Michigan indicating that red oak dominated upland sandy soils that had been cut over and burned, soils previously dominated by white pine and red pine. In Wisconsin, current red oak stands (with red oak dominance of 37–51%) developed on former hemlock-birch-maple, maple-birch-pine, pine-oak, and mixed-pine forests that had been clearcut and burned (Nowacki et al. 1990). Between 1676 and 1750 in Massachusetts, red oak represented 7% of the woodland composition, compared to 19% in 1981 (Whitney and Davis 1986). In this area, the presettlement white oak–black oak–pine forests were cut to clear land for agriculture. Decades later, abandoned farm land was invaded by pitch pine (Pinus rigida) followed by white pine. Logging of the white pine forests promoted the dominance of red oak from the release of understory regeneration and widespread dispersal and establishment of its acorns (Crow 1988, Whitney and Davis 1986).

Mixed-oak forests of the Mid-Atlantic region

The forests between New Jersey and central Pennsylvania through Virginia were classified by Braun (1950) as oak-chestnut (Castanea dentata) and oak-pine, and they include the Ridge and Valley and northern Piedmont provinces. Oak species also dominated presettlement forests of the region (cf. Russell 1983). In precolonial northern New Jersey, white oak, black oak, chestnut, and hickory shared dominance in upland forests (Russell 1980). White oak, red oak, chestnut oak, hickory, and pine dominated the original forests in portions of Virginia and West Virginia (Orwig 1991, Spurr 1951). Presettlement forests in southwestern Pennsylvania

Figure 2. Quercus rubra forest formed after logging of Pinus strobus (note stump) in the late 1800s in north-central Pennsylvania. Hay-scented fern (Dennstaedtia punctilobula) domination of the forest floor is attributed to deer browsing of competing woody plants.
contained approximately 63% oak and hickory, of which 40% was white oak (Abrams and Downs 1990). White oak (39%), white pine (26%), hickory (14%), and black oak (11%) also dominated the original valley floor forests in central Pennsylvania (Abrams and Nowacki 1992).

In one of the few such studies in North America, fire history was evaluated on a presettlement-origin oak from Mettler’s Woods in central New Jersey (Buell et al. 1954). Six fire scars in the tree were produced between 1641 and 1711, at a mean fire interval of 14 years. These fires were attributed to Indian activity in the area. No fire scars were recorded after 1711, representing the approximate time of European settlement. Other accounts of precocolonial fires in southern New England and the mid-Atlantic region have been reviewed by Day (1953), Russell (1983), Lorimer (1985), and Patterson and Sassaman (1988). Although this subject is controversial, eyewitness accounts and charcoal studies suggest that Indians were responsible for increasing fire frequency above the low numbers that would have been caused by lightning. Precocolonial fires were generally concentrated in, but not restricted to, areas of Indian habitation, and periodic wildfires, such as reported by early colonists, would favor oak forests (Patterson and Sassaman 1988, Russell 1983).

After European settlement, a regime of recurring logging and fire through the 1800s associated with charcoal iron production (Pearse 1876) and other activities (e.g., land clearing and producing timbers for coal mines) perpetuated or even increased oak dominance in the mid-Atlantic region (Table 2). In New Jersey, cutting trees for charcoal favored oak and birch (Russell 1980). Former white oak–white pine forests in central Pennsylvania became dominated almost exclusively by white oak and black oak after clearcutting and burning in the 1800s (Abrams and Nowacki 1992). White oak and red oak also dominated pre- and post-settlement forests near iron furnaces in central Virginia (Orwig 1991). Shrub forests of pitch pine, bear oak (Quercus ilicifolia), blackjack oak, and dwarf chestnut oak (Quercus prinoides) have been maintained by burning at frequent intervals since the presettlement era in the New Jersey pine barrens (Little 1974). However, an increase in oak dominance in the mid-Atlantic region also occurred from the loss of chestnut and the exclusion of fire from pine (e.g., Pinus strobus, Pinus pungens, Pinus virginiana, Pinus taeda, and Pinus echinata) and pine-oak forests (Little 1974, Monette and Ware 1983, Stephenson 1986).

Southeastern coastal plain and Piedmont forests

The section of the country between Mississippi and North Carolina was classified as oak-pine in the Piedmont and southeastern evergreen forest on the coastal plain (Braun 1950). Southeastern evergreen forests include bottomland hardwoods, beech-magnolia, and evergreen oak types, but these forests are mostly dominated by longleaf pine (Pinus palustris). Quarterman and Keever (1962) reviewed evidence of forest fires set by Indians, European settlers, and lightning between 1600 and 1800 on the coastal plain. Indians in the region also cleared land for agriculture by girdling and burning trees. Longleaf pine is maintained by periodic fire at a two-to-three-year interval, and without fire this forest type succeeds to oak-hickory or Southern mixed-hardwood forests (Table 2; Garren 1943, Quarterman and Keever 1962).

Unique variations of southeastern evergreen forests include sand pine scrub and sandhill vegetation (Myers 1985). Sand pine scrub occurs only in Florida and is dominated by a closed overstory of sand pine (Pinus clausa) and an understory of evergreen scrub oaks (Quercus geminata, Quercus myrtifolia, and Quercus chapmanii). This community type burns infrequently, but, when it does burn, the high fuel load results in intense, stand-replacing fires.

In contrast, sandhill vegetation extends from Florida into North Carolina; is dominated by longleaf pine, slash pine (Pinus elliottii), and turkey oak (Quercus laevis); and historically has experienced frequent, low-intensity ground fires (Myers 1985). Until the 1930s, central Florida had a long history of recurring fire from Indian burning for agriculture and hunting and from lightning. Fire exclusion from the growth of the citrus industry in both sandhill and sand pine scrub has resulted in little or no overstory recruitment of pine species and the increased dominance of turkey oak, scrub hickory (Carya floridana), and evergreen scrub oaks.

Original forests of the Piedmont Region were dominated by white oak, black oak, red oak (Quercus rubra and Quercus falcata), scarlet oak, post oak, hickory, longleaf pine, and
shortleaf pine (Braun 1950, Nelson 1957). Evidence of early Indian fires on the coastal plain and Piedmont was presented by Silver (1990), who stated that fires were set to enhance soil nutrients in fields, stimulate browse species to attract birds and deer, clear land for agriculture, eliminate insects, and clear thick undergrowth in forests to facilitate woodland travel. Large, accidental wildfires were also the occasional result of Indian activity. After European settlement, virtually all of the original forests in the Piedmont region were cut, but oak and hickory still remain the dominant forest type (Table 2; Braun 1950, Keever 1953).

**Transitional status of oak forests**

In general, oaks are being successional-  ally replaced by other species, despite observations that many forests contain a substantial number of oak seedlings (Table 2). In the original tallgrass prairie region of central Missouri, sugar maple is replacing white oak forests (Pallardy et al. 1988), whereas in eastern Kansas *Celtis occidentalis* (hackberry) is replacing former bur oak forests on mesic sites (Abrams 1986). Chinquapin oak still dominates xeric sites in eastern Kansas, but it has exhibited low recruitment into the treesize class relative to that of redbud (*Cercis canadensis*) and elm. The slower replacement of chinquapin oak (Figure 3) is probably related to the greater influence of fire as well as drought on those sites (Abrams 1985).

In the northern hardwoods region, most northern red oak and mixed-oak forests currently exhibit poor recruitment of new oak individuals into the canopy due to understory domination by maple and cherry (Crow 1988, Host et al. 1987). Along edaphic gradients in northern Wisconsin and lower Michigan, sugar maple and red maple dominated oak understoreys on mesic and dry-mesic sites, respectively (Host et al. 1987, Nowacki et al. 1990). Red maple also dominated the understory of red oak and chestnut oak forests in Massachusetts and New York, and it was expected to exhibit increasing canopy importance in the absence of disturbance (Lorimer 1984).

However, it has been argued that low numbers of northern red oak regeneration do not necessarily translate to a lack of future red oak overstory dominance. After clearcutting of mixed stands in central New England, red oak may exhibit low seedling numbers and slow early growth relative to red maple and black birch (Oliver 1978). However, high mortality and decelerated height growth over time of maple and birch may allow red oak to maintain dominance in the mature forest. It is important to note that there are many examples where red oak seedlings are not expected to recruit into larger size classes in closed forests or to outgrow the competing tree species after clearcutting (see discussion in Nowacki et al. 1990).

The regeneration layer of many oak forests in the mid-Atlantic region is also dominated by later successional species (Table 2). In northern New Jersey, sugar maple, red maple, and sweet birch (*Betula lenta*) exhibited increasing importance on unburned oak sites (Little 1974). Blackgum (*Nyssa sylvatica*), sassafras (*Sassafras albidum*), and red maple dominated the understory on mesic oak sites in Virginia (Ross et al. 1982). A presettlement-origin white oak forest in southwestern Pennsylvania was in a late stage of oak replacement by beech (*F. grandifolia*), red maple, and tulip poplar (*Liriodendron tulipifera*), presumably facilitated by a long-term reduction in fire frequency (Figure 4; Abrams and Downs 1990). Selective logging during the 1930s and 1940s in that stand accelerated the speed of obtaining canopy dominance for these non-oak species. Similarly, red maple and black cherry (*Prunus serotina*) dominated the understory and subcanopy in mature white oak and black oak forests in central Pennsylvania, and they fully occupied the canopy after logging of the oak overstory (Figure 5; Abrams and Nowacki 1992).

Relative to other areas of eastern North America, studies are scarce concerning successional tendencies in oak forests of the southern Piedmont region. In one such study of a white oak–hickory forest in North Carolina, red maple increased in nearly every tree size class over a 22-year period, and those trees are expected to form a dominant part of the future overstory (Christensen 1977). Other forests in North Carolina, comprised of red oak, chestnut oak, white oak, and hickory (which dominated former oak-chestnut stands), also had a substantial number of red maple seedlings and saplings (Keever 1953).

**Oak as a late successional forest type**

Although most recent studies indicate the transitional nature of oak, a few
studies suggest some stability in this forest type (Table 2). Blackjack oak—post oak forests derived from savannas in Oklahoma and blackjack oak—black oak forests on extremely xeric, upland sites in Illinois did not exhibit signs of being replaced by late successional species (Adams and Anderson 1980, Dooley and Collins 1984). Mixed oak forests of black oak, white oak, chestnut oak, and scarlet oak may represent a climax association on upland sites in the New Jersey pine barrens (Little 1974). Xeric ridge communities dominated by chestnut oak in southeastern Pennsylvania also exhibited no strong successional tendencies (Keever 1973), although chestnut oak stands on similar ridge sites in central Pennsylvania had a sapling class dominated by striped maple (Acer pensylvanicus), red maple, and sweet birch, with little oak (Nowacki and Abrams 1991).

Despite a regeneration layer dominated by black cherry, box elder (Acer negundo), and elm, none of these species seemed capable of being a self-replacing climax in a xeric white oak—black oak woods in Wisconsin (McCune and Cottam 1985). Similarly, second-growth white oak forests in Virginia had a scarcity of later successional species and a lack of adequate oak regeneration, leaving the ecological status of these stands unresolved (Orwig 1991). Oak-dominated forests on dry ridge sites in Kansas and Missouri have comprised substantially lower importance of later successional species compared with mesic oak forests, as do Appalachian oak forests in southwestern Virginia (Abrams 1986, Pallardy et al. 1988, Ross et al. 1982). These studies suggest that the speed of oak replacement is much slower on xeric versus mesic sites and that late successional oak forests are probably limited to certain areas at the western extreme of the eastern deciduous biome or on very xeric or nutrient-poor sites further east.

Conclusions

Paleoecological studies indicate that oak domination of eastern forests occurred during warmer and drier climatic periods at the beginning of the Holocene epoch and that these conditions are thought to have increased the incidence of fire. Indian burning practices and other disturbance factors may have elevated oak dominance in certain presettlement forests. Further increases in oak occurred after European settlement, whose activities included fire exclusion in tallgrass prairie and southeastern pine forests; logging and burning of northern pine—hemlock forests; and the charcoal iron industry, land clearing, and chestnut blight in the mid-Atlantic region. Thus, the postsettlement distribution of oak greatly exceeded that of the presettlement era in various regions of eastern North America. However, the evidence indicates that oak is not a typical dominant in late successional forests, and its stability is probably limited to sites of extreme edaphic or climatic conditions or areas that are periodically burned.

Many recently formed oak forests contain a substantial number of oak seedlings that do not recruit into larger size classes, suggesting these forests may be a one-generation phenomenon. Major oak-replacement species throughout the eastern United States include sugar maple, red maple, and black cherry. Although today's oak regeneration problems can be attributed to a suite of factors, a primary factor is the physiological limitation imposed on oak in a closed understory dominated by later successional species.

Regions of eastern North America that lacked oak domination before European settlement probably burned too frequently (tallgrass prairie) or too infrequently (hemlock—northern hardwoods) for oak to prosper. Presettlement oak forests of southern New England, the mid-Atlantic region, the midwest, and the southern Piedmont must have burned at some intermediate frequency (e.g., 50–100 year intervals) that promoted the dominance and stability of oak, including those forests at some distance from Indian settlements.

Loss of oak dominance in numerous forests in which fire has been excluded during the twentieth century, and the lack of such patterns in forests periodically burned, should be considered important indirect evidence that fire played a vital role in maintaining oak dominance before European settlement. If in the current oak forests factors antagonistic to oak regeneration, such as a lack of fire, persist into the twenty-first century, a retrenchment of oak dominance would seem inevitable.

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References cited


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