▸▸▸ DRAFT ◂◂◂

Fire Return Intervals and Fire Cycles for Historic Fire Regimes in the Great Lakes Region: A Synthesis of the Literature

Donald I. Dickmann[1] and David T. Cleland[2]

Discussions and descriptions of a “fire regime” require consideration of ecological context. As such a fire regime is defined by not only by the meteorological, physical, and biological properties of an ecosystem, but also by the spatial, temporal, and behavioral characteristics of the fires that burn in it. Although wildland fires are affected by many variables, the fire regime of a particular ecosystem usually is quite distinctive when defined within a particular historic time period. The fundamental premise for this discussion is that fire has been ubiquitous in all Great Lakes ecosystems during the Holocene Epoch, although the characteristic periodicity varies by several orders of magnitude according to regional and landscape ecosystem. Sooner or later—in some cases much sooner, in others much later—every ecosystem experiences fire. While usually considered an exogenous process, the very idea of a fire regime presupposes that fire is an integral part of ecosystem functioning and, in fact, may often be governed by endogenous ecosystem properties (White 1979). The relatively short fire-return intervals and fire cycles for many Great Lakes ecosystems, and the widespread adaptability of plants and animals in this region to fires, supports this contention. As White and Pickett (1985) emphasized, the neat classification of disturbances as endogenous or exogenous is problematic.

Definition of terms

Although the concept of fire regime seems to be well understood by contemporary ecologists, certain terms descriptive of fire regimes have been used in the literature in a fairly haphazard manner, without adequate attention given to their precise meaning. This problem is especially true with terms that apply to the temporal aspects of fire regimes. For example, in a recent book published by a very well-known fire ecologist, a table is presented titled “Fire-return intervals… over the past few centuries.” Yet the pertinent columns in the table are headed “Fire cycle,” a very different variable than fire-return interval (see below). Interestingly, this author later defines these terms quite explicitly. In a somewhat older fire book a table titled “Some ecosystem types and their fire cycles” has the data column labeled—incorrectly—“Fire frequency.” Other examples could be cited. Many veteran fire ecologists, however, have been very careful to precisely define their terms and use them consistently (e.g Heinselman 1981a, Van Wagner 1978)

1. Professor, Department of Forestry, Michigan State University, East Lansing MI.
2. Research Ecologist, North Central Research Station, USDA Forest Service, Rhinelander WI.

Thus, before we go any further, certain key terms related to fire regimes need to be precisely defined. Our principal authority is the *Glossary of Wildland Fire Management Terms Used in the United States*, published by the Society of American Foresters (McPherson et al. 1990). Agee (1993) and White and Pickett (1985) also offer clear definitions of disturbance regime descriptors. The following terms relate to the temporal aspects of fire regimes:

Fire rotation—Length of time necessary for an area equal to the entire area of interest (i.e. the study area) to burn (syn. fire cycle). Size of the area of interest must be clearly specified. This definition does not imply that the entire area will burn during a cycle; some sites may burn several times and others not at all. Fire cycles usually are determined by calculating the average stand age of a forest whose age distribution fits a negative exponential or a Weibull function (Van Wagner 1978).

Fire interval—Time in years between two successive fires in a designated area; i.e. the interval between two successive fire occurrences (syn. fire-free interval).

Mean fire interval—Arithmetic average of all fire intervals determined, in years, in a designated area during a specified time period; size of the area and the time period must be specified (syn. mean fire-free interval).

Fire occurrence—Number of fires per unit time in a specified area (syn. fire frequency). The reciprocal of mean fire interval.

In the ensuing discussion fire frequency and fire occurrence will be used in a general way to refer to the temporal aspect of fire regimes.

A few more widely used terms relate to fire behavior:

Crown fire—Fire that advances from top to top of trees or shrubs more or less independently of the surface fire.

Surface fire—Fire that burns **only** surface fuels such as litter, other loose debris on the soil surface, and small vegetation. All wildland fires—except those that smolder in snags or punky trees struck by lightning—begin as surface fires.

Ground fire—Fire that burns the organic matter in the soil layer that supports glowing combustion without flame; e.g. litter and duff, punky wood, tree roots, peat, or muck. This term often is mistakenly used to refer to a surface fire, although some surface fires can become ground fires.

Stand replacing fire—Fire that kills all or most living overstory trees in a forest and initiates secondary succession or regrowth. This type of fire can be a ground, surface, or crown fire, but it is usually a combination of two or more types.

Fire intensity—A general term referring to the heat energy released in a fire.

Fireline intensity—The rate of heat energy released per unit time per unit length of fire front. Numerically it is the product of the heat of combustion, quantity of fuel consumed per unit area in the fire front, and the rate of spread of a fire. Units are Btu per second per foot of fire front or kilowatts per meter.

Temporal Characteristics of Fire Regimes

Because the frequency with which fire returns to a given ecosystem is an important component of its fire regime, much attention has been paid to the temporal aspects of fire. Like most matters ecological, however, the further one gets into this topic, the more complicated it becomes. In other words, a given fire-return interval or fire cycle must be interpreted carefully, based on the data used and the manner in which calculations were made. Several points must be considered.

The overall time frame used to calculate an interval or cycle—the calculation period—varies from a few decades to millennia and reflects the ecological, meteorological, and anthropogenic characteristics of that period. The ten regimes that this project has defined for the Upper Great Lakes (Table 1) have evolved since the retreat of the Pleistocene glaciers, and they continue to evolve. This evolution is problematic for fire historians; the fire frequency of a particular regime defined for one historical period will not necessarily apply to those preceding it or following it. Most researchers carefully segregate historic periods, whereas others integrate two or three of them together in their temporal estimates. Whatever the case, the calculation period should be clearly defined.

For any wildland ecosystem in the Great Lakes area at least four historical, or demographically and culturally defined periods, can be recognized within the last millennium, each with distinct fire regimes:

- The pre-Columbian period (AD ~1000-1500);
- The immediate post-Columbian period (AD 1500-1800);
- The European settlement-exploitation period (AD 1800-1920);
- The fire-exclusion period (AD 1920-present).

During the pre-Columbian period, Great Lakes fire regimes were characterized by both lightning-caused fires and recurrent ignitions by indigenous people, and fire frequencies were high. The infectious diseases brought by European explorers to North America devastated the indigenous population, and during the centuries following Columbian contact Indian ignitions and fire frequencies declined. European populations were initially absent, then low during this period. When settlement from Europe and the eastern seaboard of North America began in earnest in the first decades of the 19th century, fire regimes again changed. During this period most fires were set by humans—principally by locomotives and settlers clearing land—and usually fueled by logging slash. Fire frequencies during this period were much higher than those immediately before, and vast areas burned in intense conflagrations. For example, the Peshtigo and Great Michigan Fires of 1971, the Michigan Thumb Fire of 1881, the Hinckley Fire of 1894, the Baudette Fire of 1910, and the Cloquet Fire of 1918 together consumed nearly three and one-half million acres (Haines and Sando 1969). And there were many other fires that are less well known. The intensity and frequency of fires during this period were unprecedented. Finally, the evolution of effective fire prevention and suppression programs beginning in the 1920s resulted in a general decrease in fire frequency and size that continues to this day. The buildup of fuels and increase in extent of flammable, early and late-seral communities during this last period, however, may herald the return of an era of large, intense fires in some areas of the northern Great Lakes.

During the past millennium there also have been distinct climatic periods that have affected the fire frequencies within them. For example, the period A.D. 700-1,200 was a warm, dry period—presumably with a higher fire frequency—whereas the "Little Ice Age" that followed, lasting into the 19th century, was a distinctly cooler, wetter period with fewer fires (Kapp 1999). These climatic influences interact with anthropogenic factors within any historic period to determine the fire regime.

The size of the area under investigation and for which fire-return intervals or cycles are calculated also is an important factor in interpreting fire regimes. Generally, the larger the study area, the more frequently fire will occur somewhere within it—the fire-return interval for the entire planet would be measured in minutes. The well-studied Boundary Waters Canoe Area (BWCA) in northern Minnesota provides a more pertinent example. In his classic study of ecosystem fire Heinselman (1973) estimated the fire-return interval for the entire 215,000 ha BWCA to be 6 years from 1542 to 1971. In contrast, Swain's 1980 estimate of the 1580 to 1970 fire-return interval for the birch-aspen area around Hug Lake in the eastern BWCA was 65 years. Obviously, these estimates are not comparable. Large areas inevitably contain many plant communities (Heinselman distinguished 19 in the BWCA), so fire frequency data for such an area represents an integration of several fire regimes, diluting its relevance. Thus, the most meaningful comparison of fire frequencies will necessarily be restricted to spatially equivalent tracts, supporting one or several ecologically similar communities.

Because the spatial dimension is included in their calculation, fire cycles are generally more ecologically meaningful than fire-return intervals or fire frequencies. On the other hand, fire cycles are more difficult to calculate (Johnson 1992, Van Wagner 1978). The same caveats discussed above apply to fire cycle data—study area size should be relatively large to accommodate the random distribution of fires in space and time, and should be partitioned into units comprising relatively homogenous ecological conditions due to landform-soil-vegetative influences on fire regimes. In either case the size of the unit on which the calculation is based must be specified.

Fire frequencies are derived from data taken by a number of different methods (Pyne et al. 1996). Each one has its pros and cons. Examination of historical documents, journal accounts, General Land Office survey notes, and comparison of historic photographs with their contemporary equivalents provide anecdotal evidence of fire, especially those that were stand replacing. Fire occurrence records exist for many places and provide fairly precise data on which to base frequency calculations, but they rarely go back for more than a century. Other methods include analysis of lake and wetland sediments or peat for peaks in charcoal and the pollen of early seral species; analysis of tree-ring records; dating fire scars from standing live trees, snags, or stumps; and inferences made about stand-replacing fires from even-aged stands or cohorts. All of these methods can provide good quantitative data on fire frequencies, provided their limitations are understood. Obviously the farther back one attempts to go, the more scanty and equivocal the record becomes. Because pre-European settlement fire regimes seem to be the current concern of many fire historians and ecosystem managers, this limitation is troublesome. And it will only get worse. Thorough discussions of methods for fire history data collection and analysis are given by Agee (1993), Heinselman (1973), Johnson (1992), and Patterson et al. (1987).

Most methods used to calculate fire frequencies give no clue to the size or intensity of the fires detected, except in a very general way. None—save fire occurrence records—can determine whether multiple fires burned during a given year. Charcoal peaks in varved sediments usually are interpreted as indicators of large, high-intensity fires in adjacent forests (MacDonald et al. 1991, Patterson et al. 1987, Swain 1978). The assumption is that these fires produced enough charcoal to be deposited in wetlands by wind or water erosion. Peaks in the pollen of early seral species (e.g. birch) also indicate that stand-replacing fires occurred several years previous. Neither method provides a high degree of temporal resolution nor any indication of whether fires were surface or crown. On the other hand, basal fire scars—in this region mostly confined to the native pines, especially red pine—are indicative of surface fires of sufficient intensity to produce a scar. Light surface fires, however, may not be recorded in trees not previously scarred, mature white pine and red pine being more resistant to cambial damage than jack pine. Existing scars can be enlarged by a light fire because the pitch associated with them is highly flammable. Intense surface or crown fires kill trees and the fire-scar record ends. In any case, to get a complete record the more fire-scarred trees available for sampling in an area, the better. Lastly, mapping and aging even-aged cohorts provides good evidence for stand-replacing fires—and their size—but gives no clue to intervening surface fires. As time goes on this technique become less reliable because older fires are obscured by more recent burns. Obviously, if more than one line of evidence is available, fire frequency calculations become more reliable (e.g. Clark 1990, Heinselman 1973).

Temporal Regimes of Lake States Fire Regimes

A compilation of fire-interval and fire cycle (fire rotation period) data reported in existing literature is given in Tables 2 and 3. These data represent the current status of our knowledge of the temporal fire regimes of Great Lakes ecosystems. A few comments on interpretation of these tables are needed. In Table 2 an attempt was made to differentiate the interval between low- to moderate-intensity surface fires and high-intensity, stand-replacing fires. We do this with some trepidation, because the historical record is not entirely clear on this matter. Furthermore, in an ecological sense the distinction between these two types of fires often is blurred. Fires burning across a natural landscape vary in intensity and defy neat categorization. A fire may be light in one area, killing back understory plants but leaving the overstory unscathed. In other places the fire may burn hotter, or even jump into the crowns of conifers where it may run for many km, producing overstory death. In other places overstory kill may be spotty. Even high intensity conflagrations that move through tree crowns typically leave behind islands of living trees or scattered, solitary survivors (Heinselman 1981b, Simard et al. 1983).

In all cases fire sets in motion a successional response. A light surface fire results in a flush of understory regrowth, the composition of which may vary from that present pre-fire (Henning and Dickmann 1996, Methven and Murray 1974). More intense fires that create overstory gaps result in a different understory succession, which may include a new cohort of seedlings or sprouts of overstory species. Such stands may eventually become uneven-aged in structure. A fire that kills all or most trees may produce a new sere, which may be different from the pre-fire overstory or a replacement of the old overstory community. The point of this discussion is that the establishment of a new tree cohort alone is not necessarily an adequate definition of a stand-replacing fire. In Table 2, therefore, a stand-replacing fire means a high-intensity fire that kills most or all of the overstory, often resulting in the establishment of a new sere (see definition above).

Fire-return intervals and fire cycles for Great Lakes grassland and forest communities vary from annually to several thousand years (Tables 2 and 3). Most of these estimates cover the post-Columbian through the European settlement periods; a few go far back into the pre-Columbian and several include some or most of the 20th century fire-exclusion period. Furthermore, methods of estimation vary widely. Because of these confounding factors, comparisons of intervals or cycles among community types should be made with caution. Nonetheless, within a given fire regime estimates of return intervals and cycles are remarkably consistent.

True prairies (Regime CM) probably burned at intervals of less than five years—sometimes even annually or semiannually—during the pre- and post-Columbian periods (Table 2), with many of the ignitions by indigenous people. In some cases, burning of prairies may have been an annual rite. There is no agreement among ethnohistorians, however, about how widespread these Indian practices were (Dorney 1981b, Pyne 1982, Russell 1983). Fire cycles for grassland-dominated communities are impossible to calculate because most of the fire history estimates are purely anecdotal, but they must have been in the range of five to 25 years (Chandler et al. 1983). Prairies tended to occur on level or gently sloping topography and west of major river drainages where fires spread rapidly and evenly (Leitner et al. 1991, Grimm 1984). When Europeans and people from the eastern seaboard began settling the Great Lakes in large numbers, fires on the prairies all but ceased, and much of the land was converted to agriculture.

Oak savannas and oak openings (Regime SM) were a distinctive pre-European feature of the landscape of southern Michigan, Wisconsin, and Minnesota, and they clearly were fire-maintained (Dorney and Dorney 1989). Farther north in the forest-prairie ecotone in Minnesota and the prairie provinces, open savanna-like aspen woodlands also occurred that were maintained by fire. Being highly fire resistant because of their capacity to sprout vegetatively from rootstocks—and in the case of larger oak trees to resist cambial injury—oaks and aspen could persist in the presence of fires occurring at intervals of one to 15 years (Tables 2 and 3). Savannas were more common on sloping topography where fire was less frequent than on the prairies—though these open woodlands could burn annually. Thus, oak and aspen savannas represented a transition type from grassland to closed forest. Closed woodlands also occurred in the prairie-savanna matrix in areas not prone to persistent burning—on steep morainal hills and other dissected topography, on the east side of drainages and rivers, and in draws and river valleys (Anderson 1990). As with prairies, when the burning stopped woody sprouts from persistent oak grubs and other woody rootstocks, as well as new seedlings, soon converted savannas that were not cleared for farming to closed hardwood forest (Anderson 1990, Curtis 1959). Today oak savannas—and true prairies—are among the rarest communities in the Lake States.

The northern pre-European analog of the hardwood savanna was the pine barrens (Regime SM), found on sandy, xeric outwash soils throughout the upper Great Lakes Region. Fire also frequently visited the barrens—maybe even annually—with fire cycles of 15 to 60 years (Tables 2 and 3). The barrens owed their unique savanna-like structure to the serotinous fecundity of jack pine and the resistance of older red and white pines to fatal fire injury. Jack pine was the most-common tree species and probably occurred in fire-maintained even-aged stands or thickets, particularly on north-facing slopes. Large red pines—and occasionally white pines—were widely scattered, uneven-aged, fire-scarred emergents. Sprouting early seral hardwoods like northern pin oak, aspens, and paper birch also were present (Vogl 1964, 1970; Whitney 1986). The barrens could be very flat or gently rolling, and wetlands were interspersed, so fire interacted with topography to produce a spatially variable landscape. Lightning most likely was a common source of ignitions, but barrens probably were burned regularly by indigenous people to maintain their open, easily traveled structure and encourage blueberry production (Murphy 1931). Pine barrens still can be seen today in many places in the Lake States, especially where prescribed fire is used in their management, but the large red pine component is mostly missing.

The pre-European composition and structure of closed northern forests depended on an interaction of topography, soil moisture, and fire frequency (Whitney 1986), with large-scale blowdown and insect infestations integral to fuel development and subsequent conflagrations. Fires tended to burn more erratically and less frequently on ice-contact landforms than on outwash areas, while the better soils on hills and ridges supported more lush hardwood-dominated forest communities that were less prone to fire. But this picture oversimplifies the ecological heterogeneity that occurred across the northern landscape. Fires burning in closed forests could be quite variable in intensity—from light surface fires to intense crown fires raging through the forest canopy. Thus, each fire event represented a complex of fire types, introducing another variable. Therefore, our designation of separate FM and FR regimes is not meant to imply that these necessarily represented discreet temporal fire events. In a given community FM and FR really implies a single overall regime with two separate components. A single fire could represent one or the other or both of these regimes.

Excessively to very-well drained ice-contact landforms, consisting of soils with slightly higher water-holding capacity and nutrient capital than the xeric, outwash barrens supported closed-forest communities that were dominated by either white pine or red pine, with jack pine, oaks, aspen, and other early seral hardwoods minor but common associates. In the far north of the Great Lakes Region—the southern extent of the boreal forest—other conifers such as black spruce, white spruce, and balsam fir also were prevalent on the uplands. In these communities fire typically placed a dual role. On the one hand, relatively low-intensity surface fires burned at intervals of ca. 5 to 40 years (Table 2), though these intervals could be shorter or longer. These fires either left the basic structure of the overstory unaltered or created small gaps but maintained a low-growing understory (Regimes FM-1 and FM-2). After many years such a regime tended to produce a stand of uneven-aged structure. The surface-fire cycle for these communities appears to be 70 to 100 years (Table 3; Bergeron 1991). Fortunately, old, fire-scarred red pines have been fairly abundant, so fire frequencies for these communities for the past 200 to 300 years are better documented than for any other Great Lakes forest type. In the present analysis fire-occurrence data taken from basal fire-scars was interpreted to indicate non stand-replacing surface fires; i.e. a forest maintenance regime.

Fire played another role in pine-dominated and boreal communities. Under conditions of low fuel moisture, low humidity, high temperature, and strong wind, surface fires can quickly intensify or jump into the forest canopy, producing a stand replacing fire. Tolerant boreal conifers, particularly balsalm fir, in the understory acted as fire ladders and increased the probability of crown fires. Ultimately, every even-aged, closed pine or boreal forest owed its existence to such an event (Heinselman 1973, Spurr 1954). Stand-replacing fires were more frequent in jack pine and boreal conifer communities (Regime FR-1) than in those dominated by either red pine or white pine (Regimes FR-2 or FR-3) because their scaly bark, branchy stems, and high concentration of volatile foliar substances promote vertical fire movement. Fire intervals for jack pine and boreal conifers were fairly short—10 to 70 years (Table 2), with fire cycles of 50 to 150 years (Table 3). It is noteworthy that the two characteristic short-cycle boreal conifers—jack pine and black spruce—are serotinous, and able to produce large quantities of viable seed within one or two decades after establishment. Fire occurrence in red and white pine communities was less frequent, with return intervals of 100 to 250 years and cycles in the range of 150 to 350 years (Tables 2 and 3).

A primary source of fuel creation in jack pine and boreal forest fire regimes (FR-1 and FR-2) were—and continue to be—insect outbreaks, attending mortality, and windthrow from catastrophic storms that create conditions conducive to fires. Spruce budworm causes heavy mortality in spruce-fir communities, especially old stands with a high balsam fir component. Likewise, periodic outbreaks of jack pine budworm can devastate old stands of this species (Heinselman 1973, Heinselman 1991b, McCullough et al. 1998). Severe down-burst producing storms also are a factor in boreal communities, albeit on long return intervals (Palik and Robl 1999). The July 4, 1999 storm that tracked through the BWCA Wilderness in northeastern Minnesota, destroying to a greater or lesser extent some 72,000 ha of boreal forest, is a spectacular but by no means unusual example of this type of wind disturbance. These natural biological and meteorological events alter the abundance and arrangement of fuels and markedly increase the probability of a stand-replacing conflagration. In boreal ecosystems fire is inevitable, and the longer the interval since past events, the more inevitable it becomes.

Other northern communities with fire cycles in the 150- to 300-year range are aspen-birch and tree- or shrub-dominated wetlands (Table 3). Early seral hardwood stands burn infrequently because fuel loadings are relatively light and the canopy cannot sustain a crown fire. The major run of the 9,700 ha Mack Lake Fire in May 1980, for example, slowed considerably and could be contained by firefighters because it moved from predominantly jack pine fuels into areas dominated by aspen and other hardwoods (Simard et al. 1983). Even light surface fires can kill some thin-barked aspens, and the oily bark of paper birch is highly flammable, so these communities are quite vulnerable to mortality through fire. If the understory is dominated by tolerant boreal conifers, or if large-scale blowdown occurs, intense fires can result in the aspen-birch type, producing a classic successional stand replacement.

In normal years and in the spring wetland communities usually constitute fire breaks because of the high water content of their organic soils. However, an exceptionally dry summer and fall—such as preceded most of the infamous 19th and early 20th century wildfires in the Lake States (Haines and Sando 1969)—could produce conditions where fire would run through these communities, sustained by dry surface fuels or flammable conifer crowns. Secondary ground fires that can smolder for months or even years also were ignited by the initial surface fire in many cases (Hungerford et al. 1995). The 1977 Seney Fire in the eastern Upper Peninsula of Michigan is an example of such a fire. The landscape context of wetlands also influences fire frequency. Wetlands embedded in a larger landscape matrix composed of pyrophilic ecosystems such as jackpine-dominated outwash plains, for example, tend to burn more frequently than analogous ecosystems embedded within morainal landforms supporting fire-sensitive, mesophilic northern hardwoods. Thus historic disturbance regimes of wetlands vary spatially and temporally due to the landscape ecosystem in which they are nested, as well as long-term climatic fluctuations. As a consequence, natural disturbance regime classes attributed to specific wetlands may range from FR-2 to FR-4 depending on their surrounding or adjacent landscapes.

Well-drained, medium- to fine-texture soils, usually occurring on end, terminal, and ground moraines in the Great Lakes Region supported stands dominated by northern hardwoods—sugar maple, red maple, beech, yellow birch, white ash, and basswood, as well as hemlock. White pine, white spruce, and balsalm fir also could be locally important. These communities rarely burned (Tables 2 and 3); their recurring disturbance regime being relatively small wind-fall derived gaps (Brewer and Merritt 1978, Frelich and Lorimer 1991). In areas where topography was not highly dissected, where soils were on the low-end of productivity for northern hardwoods, and where conifers were a heavier component of the stand, fires may have been more frequent (Regime FR-3). Rich, mesic, late-successional hardwood stands were practically fireproof (Regime FR-4), representing the “asbestos” forest. Fires that did start or that moved into these stands from adjacent areas tended to smolder in the duff layer and move very slowly, eventually going out and causing little damage to the overstory (Frelich and Lorimer 1991, Stearns 1949).

In terms of fire regime, the principal cause of fuel formation leading to crown fire in northern hardwood ecosystems is broad-scale, storm-driven windthrow of catastrophic proportions (Canham and Loucks 1984, Dunn et al. 1983, Stearns 1949). The well-documented July 1977 storm in eastern Minnesota and northeastern Wisconsin, for example, broke and uprooted trees over 344,000 ha of forestland; approximately 7% of this area was completely leveled. Canham and Loucks (1984) estimated the return interval for catastrophic storms of this proportion to be about 1,200 years. Not only are these storms stand-replacing events in themselves, but after the tangled slash resulting from them cures, the probability of fire increases exponentially. Thus, the 350- to nearly 3,000-year fire cycles in northern hardwood regimes FR-4 and FR-5 likely were dependent upon rare but intense storm events. These storms did not always lead to fires, but they set a stage for fire that did not ordinarily exist.

The FR-3W and FR-4W regimes are composed of wetland forests, with white cedar-dominated swamp conifer communities having the longest fire cycles (2,000 to 6,000 years) of any Great Lakes forest type (Table 3). Blowdown is common in wetland forests, and fuel is abundant, but the moist environment often prevents fuel from curing and discourages ignitions. Furthermore, the crowns of white cedar and tamarack, as well as their associated lowland hardwoods, do not readily burn. A drought of epic proportions combined with an ignition of some kind apparently was needed to set the stage for fire in many of these communities, and such events were rare. As noted, the exception is areas of wetland forests embedded within or lying adjacent to fire-prone (FR-1 and FR-2) landscape ecosystems placed into the FR3W fire regime category. Effects of landscape heterogeneity and spatial relationships among fire-prone and fire-resistant ecosystems are being evaluated as part of the North Central Research Station's Characterizing Historical and Contemporary Fire Regime research project funded by the Joint Fire Science Program, and the Assessing Risk of Wildfire and Vulnerability of Human Populations and Development in the North Central Region funded by the National Fire Plan.

In summary, three low intensity community maintenance (CM), savanna maintenance (SM), and forest maintenance (FM), and six forest replacement/fire rotation (FR) categories have been defined based on the literature.

- CM (community maintenance) represents prairies and openlands that burned so frequently that tree species failed to establish.
- SM (savanna and barren maintenance) represents savannas and barrens that burned less frequently, with surviving individual trees and islands of trees.
- FM-1 and FM-2 (forest maintenance) represent conifer and woodland ecosystems that were typified by widely spaced trees and low understory fuel loadings due to maintenance (ground) fires.
- FR1 (forest replacement) represents xeric landscape ecosystems historically experiencing frequent, large catastrophic stand-replacing fires; the dominant pre-European settlement forest types were short-lived jack pine forests with inclusions of pine barrens.
- FR2 represents xeric to dry-mesic landscape ecosystems historically experiencing large, catastrophic stand-replacing fires at longer fire rotations than the FR1 category; the dominant pre-European forest types were white-red pine and mixed red-white-jack pine forests with minor associates of early successional deciduous species including aspen, paper birch, and oak.
- FR3 represents dry-mesic to mesic landscape ecosystems historically experiencing relatively infrequent stand-replacing fires at much longer fire rotations than the FR1 or FR2 categories. The FR3 category also includes landscape ecosystems underlain by heavier textured soils that would have succeeded to fire-sensitive northern hardwood communities in the absence of fire, however succession was impeded due to proximity to fire-prone ecosystems resulting in forest maintenance ground-fires and infrequent crown-fires. The dominant pre-European forest type for the FR3 category was long-lived mixed white pine-hemlock with minor elements of northern hardwood forests.
- FR3W represents wetland dominated landscape ecosystems historically experiencing relatively infrequent stand-replacing fires; these wetlands were embedded within or adjacent to fire-prone landscapes. The dominant pre-European forest types for the FR3W category were wetland conifers including cedar, tamarack, white pine, hemlock, aspen,

and spruce. Fire regimes were strongly influenced by fires intruding from adjacent ecosystems, and fuel formation was likely caused by interactions of insect and disease and large-scale blow-downs, as well as periods of drought.

- FR4 represents mesic northern hardwood and hardwood-hemlock landscape ecosystems historically experiencing very infrequent stand-replacing or community maintenance fires.
- FR4W represents wetland landscape ecosystems historically experiencing very infrequent stand-replacing or community maintenance (ground) fires that were embedded within or adjacent to fire-resistant, hence fire protected landscape ecosystems (FR4). The dominant pre-European forest types were wetland hardwoods and mixed hardwood-conifer forests including cedar, hemlock, tamarack, black and green ash, silver maple, elm, and cedar.

References

Agee, J.K. 1993. *Fire Ecology of Pacific Northwest Forests*. Island Press, Washington, DC.

Alexander, M.E., J.A. Mason, and B.J. Stocks. 1979. Two and a half centuries of recorded forest fire history. Great Lakes Forest Research Centre, Sault Ste. Marie, Ontario.

Anderson, R.C. 1990. The historic role of fire in the North American grassland. In *Fire in North American Tallgrass Prairies*, edited by S.L. Collins and L.L. Wallace. University of Oklahoma Press, Norman, OK. p. 8-18.

Bergeron, Y. 1991. The influence of island and mainland lakeshore landscapes on boreal forest fire regimes. Ecology 72:1980-1982.

Bergeron, Y. and J. Brisson. 1990. Fire regime in red pine stands at the northern limit of the species range. Ecology 71:1352-1364.

Bergeron, Y. and P.-R. Dansereau. 1993. Predicting the composition of Canadian southern boreal forest in different fire cycles. J. Veg. Sci. 4:827-832.

Bormann, F.H. and G.E. Likens. 1979. Catastrophic disturbance and the steady state in northern hardwood forests. Amer. Sci. 67:660-669.

Brewer, R. and P.G. Merritt. 1978. Wind throw and tree replacement in a climax beech-maple forest. Oikos 30:149-152.

Canham, C.D. and O.L. Loucks. 1984. Catastrophic windthrow in the presettlement forests of Wisconsin. Ecology 65:803-809.

Chandler, C., P. Cheney, P. Thomas, L. Trabaud, and D. Williams. 1983. *Fire in Forestry, Vol. 1: Forest Fire Behavior and Effects.* John Wiley & Sons, New York, NY.

Clark, J.S. 1990. Fire and climate change during the last 750 yr in northwestern Minnesota. Ecol. Monogr. 60:135-159.

Collins, S.L. 1990. Introduction: fire as a natural disturbance in tallgrass prairie ecosystems. In *Fire in North American Tallgrass Prairies*, edited by S.L. Collins and L.L. Wallace. University of Oklahoma Press, Norman, OK. p 3-7.

Curtis, J.T. 1959. *The Vegetation of Wisconsin*. University of Wisconsin Press, Madison, WI.

Cwynar, L.C. 1977. The recent fire history of Barron Township, Algonquin Park. Can. J. Bot. 55:1524-1538.

Cwynar, L.C. 1978. Recent history of fire and vegetation from laminated sediment of Greenleaf Lake, Algonquin Park, Ontario. Can. J. Bot. 56:10-21.

Dansereau, P.-R. and Y. Bergeron. 1993. Fire history in the southern boreal forest of northwestern Quebec. Can. J. For. Res. 23:25-32.

Davis, M.B., S. Sugita, R.R. Calcote, J.B. Ferrari, and L. Frelich. 1993. Historical development of alternate communities in a hemlock-hardwood forest in northern Michigan, USA. In *Large-Scale Ecology and Conservation Biology*, edited by P.J. Edwards, R.M. May, and N.R. Webb. Blackwell Scientific Publications, London, England. p. 19-39.

Dorney, J.R. 1981a. Presettlement vegetation of southeastern Wisconsin: edaphic relationships and disturbance. M.S. Thesis, University of Wisconsin-Milwaukee.

Dorney, J.R. 1981b. The impact of Native Americans on presettlement vegetation in southeastern Wisconsin. Trans. Wis. Acad. Sci. Arts Letters 69:26-36.

Dorney, C.H. and J.R. Dorney. 1989. An unusual oak savanna in northeastern Wisconsin: the effect of Indian-caused fire. Amer. Midl. Nat. 122:103-113.

Dunn, C.P., G.R. Guntenspergen, and J.R. Dorney. 1983. Catastrophic wind disturbance in an old-growth hemlock-hardwood forest, Wisconsin. Can. J. Bot. 61:211-217.

Engstrom, F.B. and D.H. Mann. 1991. Fire ecology of red pine (*Pinus resinosa*) in northern Vermont. Can. J. For. Res. 21:882-889.

Frelich, L.E. and C.G. Lorimer. 1991. Natural disturbance regimes in hemlock-hardwood forests of the upper Great Lakes Region. Ecol. Monogr. 61:145-164.

Frissell, S.S. Jr. 1973. The importance of fire as a natural ecological factor in Itasca State Park, Minnesota. Quater. Res. 3:397-407.

Grimm, E.C. 1984. Fire and other factors controlling the Big Woods vegetation of Minnesota in the mid-nineteenth century. Ecol. Monogr. 54:291-311.

Guyette, R.P., D.C. Dey, and C. McDonell. 1995. Determining fire history from old white pine stumps in an oak-pine forest in Bracebridge, Ontario. Ont. For. Res. Inst., For. Res. Rep. No. 133.

Haines, D.A. and R.W. Sando. 1969. Climatic conditions preceding historically great fires in the North Central Region. U.S. For. Serv. Res. Paper NC-34.

Hansen, H.L., L.W. Krefting, and V Kurmis. 1973. The forest of Isle Royale in relation to fire history and wildlife. Univ. Minn. Agr. Exp. Sta. Tech. Bull 294, For. Series 13.

Heinselman, M.L. 1973. Fire in the virgin forests of the Boundary Waters Canoe Area, Minnesota. Quater. Res. 3:329-382.

Heinselman, M.L. 1981a. Fire intensity and frequency as factors in the distribution and structure of northern ecosystems. In *Fire Regimes and Ecosystem Properties*. U.S. For. Serv. Gen. Tech. Rep. WO-26. p. 7-57.

Heinselman, M.L. 1981b. Fire and succession in the conifer forests of northern North America. In *Forest Succession: Concepts and Application*, edited by D.C. West, H.H. Shugart, and D.B. Botkin. Springer-Verlag, New York, NY. p. 374-405.

Henning, S.J. and D.I. Dickmann. 1996. Vegetative responses to prescribed burning in a mature red pine stand. North. J. Appl. For. 13:140-146.

Henry, J.D. and J.M.A. Swan. 1974. Reconstructing forest history from live and dead plant material—an approach to the study of forest succession in southwest New Hampshire. Ecology 55:772-783.

Hungerford, R.D. 1995. Ignition and burning characteristics of organic soils. Proc. Tall Timbers Fire Ecol. Conf. 19:78-91.

Johnson, E.A. 1992. *Fire and Vegetation Dynamics: Studies from the North American Boreal Forest.* Cambridge University Press, Cambridge, England.

Kapp, R.O. 1999. Michigan late Pleistocene, Holocene, and presettlement vegetation and climate. In *Retrieving Michigan's Buried Past: The Archaeology of the Great Lakes State*, edited by J.R. Halsey. Cranbrook Institute of Science Bulletin 64, Bloomfield Hills, MI. p, 31-58.

Larson, C.P.S. and G.M. MacDonald. 1998a. An 840-year record of fire and vegetation in a boreal white spruce forest. Ecology 79:106-118.

Larson, C.P.S. and G.M. MacDonald. 1998b. Fire and vegetation dynamics in a jack pine and black spruce forest reconstructed using fossil pollen and charcoal. J. Ecol. 86:815-828.

Leitner, L.A., C.P. Dunn, G.R. Guntenspergen, F. Stearns, and D.M. Sharpe. 1991. Effects of site, landscape features, and fire regime on vegetation patterns in presettlement southern Wisconsin. Landscape Ecol. 5:203-217.

Loope, W.L. 1991. Interrelationships of fire history, land use history, and landscape pattern within Pictured Rocks National Lakeshore, Michigan. Can. Field Nat. 105:18-28.

MacDonald, G.M., C.P.S. Larsen, J.M. Szeicz, and K.A. Moser. 1991. The reconstruction of boreal forest fire history from lake sediments: a comparison of charcoal, pollen, sedimentological, and geochemical indices. Quater. Sci. Rev. 10:53-71.

McCullough, D.G., R.A. Werner, and D. Neumann. 1998. Fire and insects in northern and boreal forest ecosystems of North America. Annu. Rev. Entomol. 43:107-127.

McPherson, G.R., D.D. Wade, and C.B. Phillips (compliers). 1990. *Glossary of Wildland Fire Management Terms Used in the United States.* Society of American Foresters, Washington, DC.

Methven, I.R. and W.G. Murray. 1974. Using fire to eliminate understory balsam fir in pine management. For. Chron. 50:77-79.

Murphy, R.E. 1931. Geography of the northwest pine barrens of Wisconsin. Trans. Wis. Acad. Sci. Arts Letters 26:69-120.

Palik, B. and J. Robl. 1999. Structural legacies of catastrophic windstorm in a mature Great Lakes aspen forest. U.S. For. Serv. Res. Paper NC-337.

Patterson, W.A. III, K.J. Edwards, and D.J. Maguire. 1987. Microscopic charcoal as a fossil indicator of fire. Quater. Sci. Rev. 6:3-23.

Pyne, S.J. 1982. *Fire in America: A Cultural History of Wildland and Rural Fire.* Princeton Univ. Press, Princeton, NJ.

Pyne, S.J., P.L. Andrews, and R.D. Laven. 1996. *Introduction to Wildland Fire* (2nd edition). John Wiley & Sons, Inc., New York, NY.

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

Simard, A.J. and R.W. Blank. 1982. Fire history of a Michigan jack pine forest. Mich. Acad. 15:59-71.

Simard, A.J., D.A. Haines, R.W. Blank, and J.S. Frost. 1983. The Mack Lake Fire. U.S. For. Serv. Gen. Tech. Rep. NC-83.

Spurr, S.H. 1954. The forests of Itasca in the nineteenth century as related to fire. Ecology 35:21-25.

Stearns, F.W. 1949. Ninety years of change in a northern hardwood forest in Wisconsin. Ecology 30:350-358.

Swain, A.M. 1973. A history of fire and vegetation in northeastern Minnesota as recorded in lake sediments. Quater. Res. 3:383-396.

Swain, A.M. 1978. Environmental changes during the past 2000 years in north-central Wisconsin: analysis of pollen, charcoal, and seeds from varved lake sediments. Quater. Res. 10:55-68.

Swain, A.M. 1980. Landscape patterns and forest history in the Boundary Waters Canoe Area, Minnesota: a pollen study from Hug Lake. Ecology 61:747-754.

Vogl, R.J. 1964. Vegetational history of Crex Meadows, a prairie savanna in northwestern Wisconsin. Amer. Midl. Nat. 72:157-175.

Vogl, R.J. 1970. Fire and the northern Wisconsin pine barrens. Proc. Tall Timbers Fire Ecol. Conf. 10:175-209.

White, P.S. 1979. Pattern, process, and natural disturbance in vegetation. Bot. Rev. 45:229-299.

White, P.S. and S.T.A. Pickett. 1985. Natural disturbance and patch dynamics: An introduction. In *The Ecology of Natural Disturbance and Patch Dynamics*, edited by S.T.A. Pickett and P.S. White. Academic Press, New York, NY, p. 3-13.

Whitney, G.G. 1986. Relation of Michigan's presettlement pine forests to substrate and disturbance history. Ecology 67:1548-1559.

Zhang, Q., K.S. Pregitzer, and D.D. Reed. 1999. Catastrophic disturbance in the presettlement forests of the Upper Peninsula of Michigan. Can. J. For. Res. 29:106-114.

Table 1. Proposed Historic Fire Regimes for the Great Lakes Region.

Regime	**Function**	**Fire Intensity**	**Rotation (years)**
CM	Community Maintenance	Moderate	3-30
SM	Savanna Maintenance	Low	5-15
FM-1	Forest Maintenance	Low	5-50
FM-2	Forest Maintenance	Low	25-100
FR-1	Forest Replacement	High	30-75
FR-2	Forest Replacement	High	75-150
FR-3	Forest Replacement	High	150-350
FR-3W[1]	Forest Replacement	High	
FR-4	Forest Replacement	Moderate	350-1000
FR-4W[2]	Forest Replacement	Moderate	>1000

The FR-3W fire regime category represents wetlands embedded within pyrophilic landscapes.
The FR-4W fire regime category represents wetlands embedded within mesophilic landscapes.

Table 2. Fire Return Intervals For Historic Fire Regimes In the Great Lakes Region

Regime	Community Type	Fire Return Interval (Years)		Location	Reference	Notes
		Surface (Low-Mod Intensity)	Stand-Replacing (High Intensity)			
CM	Prairie	Annual (more or less)		S. Minnesota (Bigwoods area)	Grimm 1984	Anecodotal; highly climate dependent
	Prairie	Annual (more or less)		S. Wisconsin (Green Co.)	Leitner et al. 1991	Anecdotal
	Prairie	Annual (more or less)		S. Wisconsin	Curtis 1959	Anecdotal
	Tallgrass prairie	3-5		Michigan,Wisconsin, Minnesota	Collins 1990	Used in a conceptual model of community responses to fire
	Sedge meadows	Annual (more or less)		S. Wisconsin (Jefferson Co.)	Curtis 1959	Anecdotal; meadows maintained by adjacent prairie fires
SM	Red pine/jack pine/oak barrens		24 (range 8-41)	NW Wisconsin (Douglas Co.)	Vogl 1970	Based on 4 major wildfires since 1871 (anecdotal)
	Jack pine/oak barrens	Annual		NW Wisconsin (W Burnett Co.)	Vogl 1964	Drought period of 1930s (anecdotal)
	Pine barrens	Annual		NW Wisconsin	Murphy 1931	Anecdotal
	Jack pine barrens	15		Wisconsin-Michigan	Heinselman 1981	Estimated
	Oak savanna/open woodlands	16		S. Wisconsin (Green Co.)	Leitner et al. 1991	Estimated for areas west of Pecatonica River
	Oak savanna/open woodlands	16		SE. Wisconsin	Dorney 1981b	Areas west of major waterways
	Oak openings/barrens	Annual (more or less)		S. Wisconsin	Curtis 1959	Anecdotal
FM 1-FM 2	Red pine/jack pine	19 ± 5		N. Lower Michigan (Mack Lake)	Simard & Blank 1982	Based on fire scars, 37 fires (1824-1980)
	Red pine/jack pine/white pine	9 (range 2-32)		N. Minnesota (Itasca)	Frissell 1973	Based on fire scars, 32 fires (1650-1922)
	Red pine/white pine	26 ± 24 13 ± 8		N. Minnesota (Itasca)	Clark 1990	Fire scars (1700-1920) Charcoal analysis (1240-1440)

		9 ± 3				Charcoal analysis (1440-1600)
		13 ± 10				Charcoal analysis (1640-1920)
	Red pine/mixed hdwd conifer	37 (range 3-102)		Northern Vermont ridge	Engstrom & Mann 1991	Based on fire scars, 20 fires (1815-1987)
	Red pine	29 (range 14-46)		Sault Ste.Marie, Ontario	Alexander et al. 1979	Based on 5 fire scars (1759-1877) from 1 tree
	Red pine/mixed hdwd conifer	30 (range 11-67)		Quebec (48 28 N)	Bergeron & Brisson 1990	Based on 11 fires (1799-1971) on islands
	Red pine/jack pine	4		Lake Duparquet, Quebec	Bergeron 1991	Based on 56 fires on islands (1688-1988)
	Red pine/white pine	22 ± 12		UP Michigan (Pictured Rocks NL)	Loope 1991	Based on fire scars from living trees & stumps
	Red pine/white pine	36		N. Minnesota (BWCA)	Heinselman 1981	Revised from Heinselman 1973
	White pine/red pine/aspen	11 (range 1-62)		Ontario, Algonquin Park	Cwynar 1977	Based on fire scars, 25 fires (1696-1960)
	White pine/red oak/maple	13 (range 5-76)		S. Ontario (Bracebridge Region)	Guyette et al. 1995	Based on fire scarred stumps, 15 fires (1664-1852)
	Mixed boreal conifer/hdwd	8		Lake Duparquet, Quebec	Bergeron 1991	Based on 37 fires along lakeshore (1688-1988)
	Mixed boreal conifer/hdwd	2 (range 1-5)		Isle Royale	Hansen et al. 1973	Based on recorded lightning fires (1950-1965)
	Mixed pine/boreal conifer/hdwd	6 (range 1-53)		N. Minnesota (BWCA)	Heinselman 1973	Based on even-aged types & fires scars (1542-1971)
FR 1	Jack pine/red pine		26 (range 12-60)	N. Lower Michigan (Mack Lake)	Simard & Blank 1982	Based on 6 fire years + 2000 fire
	Jack pine/red pine/white pine		35 (range 9-89)	N. Minnesota (Itasca)	Spurr 1954	Based on 6 cohort-producing fires (1714-1886)
	Jack pine/ birch/spruce		27 (range 4-47)	S of Lake Abitibi, Quebec	Dansereau & Bergeron 1993	Based on 10 cohort-producing fires (1760-1923)
	Jack pine/black spruce		34	N. Alberta (Wood Buffalo NP)	Larsen & MacDonald 1998b	Based on 16 fires (1429-1934); charcoal & pollen analysis
	White spruce		69 (range 30-130)	N. Alberta (Wood Buffalo NP)	Larsen & MacDonald 1998a	Based on 12 fires (1185-1940); charcoal & pollen analysis
	Mixed boreal conifer/hdwd		26 (range 1-74)	Lake Duparquet, Quebec	Bergeron 1991	Based on 8 fires along lakeshore (1760-1944))
	Mixed boreal conifer/hdwd		23 (range 3-46)	Lake Abitibi, Quebec	Bergeron & Dansereau 1993	Based on 10 fires (1760-1964)

	Mixed pine/boreal conifer/hdwd	9 (range 1-38)	N. Minnesota (entire BWCA)	Heinselman 1973)	Based on dates of stand origin (1595-1971)
	Mixed boreal conifer/hdwd	65 (range 20-100)	N. Minnesota (Lake of the Clouds)	Swain 1973	Based on charcoal & pollen analysis past 1,000 years
	Paper birch/aspen	65	N. Minnesota (BWCA-Hug Lake)	Swain 1980	Based on 6 fires (1580-1970); charcoal & pollen analysis
FR 2-FR 3	White pine/ hemlock/ hardwoods	250+	New Hampshire (Harvard Tract)	Henry & Swan 1974	Based on fire origin of 1 stand but maybe blown down first
	White pine/mixed conifer hdwd	83	Ontario, Algonquin Park	Cwynar 1978	Based on sediment core analysis (850-1249 AD)
	Birch/white pine/hemlock	120 (range 40-230)	N. Wisconsin (Hell's Kitchen Lake)	Swain 1978	Based on 14 fires (350-1840 BP); charcoal & pollen analysis
FR 4	N. hdwds/hemlock/white pine	400+	N. Wisconsin (Forest Co.)	Stearns 1949	Virgin stands studied **may have** originated from fire in 1500s
	N. hdwds/hemlock/white pine	1700	Michigan UP (Sylvania Tract)	Davis et al. 1993	Based on 2 fires since 3500 yrs BP; charcoal & pollen analysis

Table 3. Fire Cycle (Fire Rotation Period) For Historic Fire Regimes In the Great Lakes Region

Regime	Community Type	Fire Rotation Period (Years)	Location	Reference	Notes
CM	Annual or perennial Grassland	5-25	Central North America	Chandler et al. 1983	Source unknown (from Table 6.1)
SM	Jack pine barrens	60	Wisconsin-Michigan	Heinselman 1981	Estimated
	Jack pine barrens	15-60	Great Lakes	Chandler et al. 1983	Source unknown (from Table 6.1)
	Aspen savanna/woodland	10	Minnesota	Chandler et al. 1983	Source unknown (from Table 6.1)
FM 1-FM 2	Red pine/white pine	74-112	Lake Duparquet, Quebec	Bergeron 1991	Based on 37 fires along lakeshore (1688-1988)
	Mixed boreal conifer/hardwood	63-99	Lake Duparquet, Quebec	Bergeron 1991	Based on 56 fires on islands (1688-1988)
FR 1	Jack pine	80-170	N. Lower Michigan	Whitney 1986	Based on GLO records of fires
	Jack pine	130	Michigan UP (Luce District)	Zhang et al. 1999	Based on GLO records of fires
	Jack pine/black spruce	50	N. Minnesota (BWCA)	Heinselman 1981	Revised estimate based on Van Wagner 1978
	Jack pine/black spruce	100	Quebec	Chandler et al. 1983	Source unknown (from Table 6.1)
	Jack pine/black spruce	60	Ontario	Chandler et al. 1983	Source unknown (from Table 6.1)
	Aspen/birch/fir	80	N. Minnesota (BWCA)	Heinselman 1981	Revised estimate based on Van Wagner 1978
FR 2-FR 3	Red pine/jack pine/white pine	130-260	N. Lower Michigan	Whitney 1986	Based on GLO records of fires
	Red pine/jack pinewhite pine	160	Michigan UP (Luce District)	Zhang et al. 1999	Based on GLO records of fires
	Pine/oak	170-350	N. Lower Michigan	Whitney 1986	Based on GLO records of fires
	Red pine/white pine	180	N. Minnesota (BWCA)	Heinselman 1981	Revised estimate based on Van Wagner 1978
	Red pine/white pine	150	N. Minnesota (Itasca)	Frissel 1973	
	Red pine/white pine	320	Michigan UP (Luce District)	Zhang et al. 1999	Based on GLO records of fires
FR3W	Tamarack	190	Michigan UP (Luce District)	Zhang et al. 1999	Based on GLO records of fires
	Aspen/birch	210	Michigan UP (Luce District)	Zhang et al. 1999	Based on GLO records of fires
	Black spruce peatland	150	N. Minnesota (Lake Agassiz)	Heinselman 1981	Estimated
	Black spruce	100	Ontario	Chandler et al. 1983	Source unknown (from Table 6.1)
FR 4	Sugar maple/hemlock	900	Michigan UP (Porcupine	Frelich & Lorimer 1991	Based on surface & stand replacing fires 1870-

			Mtns)		1980
	Sugar maple/hemlock	550	Michigan UP (Huron Mtns)	Frelich & Lorimer 1991	Based on surface & stand replacing fires 1870-1980
	Northern hardwoods/pine/hemlock	1400-2800	N. Lower Michigan	Whitney 1986	Based on GLO records of fires
	Northern hardwoods	2600	Michigan UP (Luce District)	Zhang et al. 1999	Based on GLO records of fires
	Northern hardwoods	1000±	New Hampshire	Bormann & Likens 1979	Estimated
	Sugar maple/hemlock	1700	Michigan UP (Sylvania Tract)	Frelich & Lorimer 1991	Based on surface & stand replacing fires 1870-1980
FR4W	Swamp conifers	3000-6000	N. Lower Michigan	Whitney 1986	Based on GLO records of fires
	White cedar	1700	Michigan UP (Luce District)	Zhang et al. 1999	Based on GLO records of fires
	Lowland hardwood/conifer	1100	Michigan UP (Luce District)	Zhang et al. 1999	Based on GLO records of fires
	Mixed lowland conifers/hdwds	580	Michigan UP (Luce District)	Zhang et al. 1999	Based on GLO records of fires
	Black spruce	890	Michigan UP (Luce District)	Zhang et al. 1999	Based on GLO records of fires
	Wetland shrub/marsh	410	Michigan UP (Luce District)	Zhang et al. 1999	Based on GLO records of fires