Fire regimes of western larch – lodgepole pine forests in Glacier National Park, Montana

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Received December 11, 1990
Accepted May 27, 1991

BARRETT, S. W., ARNO, S. F., and KEY, C. H. 1991. Fire regimes of western larch – lodgepole pine forests in Glacier National Park, Montana. Can. J. For. Res. **21**: 1711–1720.

We conducted a detailed investigation of fire frequencies, patterns of fire spread, and the effects of fire on tree succession in the western larch – lodgepole pine (*Larix occidentalis* – *Pinus contorta* var. *latifolia*) forests west of the Continental Divide in Glacier National Park, Montana. Master fire chronologies for 1650 to the present were constructed based on tree fire scars and fire-initiated age-classes. Two kinds of primeval fire regimes were identified: (*i*) a mixed-severity regime ranging from nonlethal underburns to stand-replacing fires at mean intervals of 25–75 years and (*ii*) a regime of infrequent stand-replacing fires at mean intervals of 140–340 years. The former regime is characteristic of the North Fork Flathead valley and appears to be linked to a relatively dry climate and gentler topography compared with the McDonald Creek – Apgar Mountains and Middle Fork Flathead areas, where the latter fire regime predominates. Fire frequency in the entire North Fork study area was 20 fire years per century prior to 1935 and 2 per century after 1935. In the other two study areas it was 3–5 per century both before and after 1935. We suggest that fire suppression has altered the primeval fire regime in the North Fork, but not in the central and southern areas.

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Une étude approfondie de la fréquence des incendies forestiers, des patrons de propagation du feu et des effets des incendies sur la succession forestière a été menée dans des forêts de mélèzes occidentaux et de pins tordus (*Larix occidentalis* – *Pinus contorta* var. *latifolia*) situées à l'ouest de la ligne de partage des eaux continentales dans le parc national Glacier au Montana. Des séries chronologiques couvrant la période de l'an 1650 à ce jour ont été constituées à partir des cicatrices d'incendie et des classes d'âge des peuplements originant de feux. Deux types de régimes naturels d'incendies ont été identifiés : (*i*) un régime où les incendies sont de sévérités diverses, allant d'incendies non mortels brûlant sous couvert à des incendies entraînant le remplacement des peuplements, dont les intervalles moyens étaient de 25 à 75 ans et (*ii*) un régime où les incendies sont peu fréquents en entraînent le remplacement des peuplements à des intervalles moyens de 140 à 340 ans. Le premier type de régime est caractéristique de la vallée North Fork et est apparemment associé à un climat relativement sec et à un relief moins accentué que celui des régions de ruisseau McDonald – montagnes Apgar et de Middle Fork, où le second type de régime prédomine. La fréquence des incendies dans l'aire d'étude entière de North Fork était de 20 années d'incendies par siècle, avant 1935, et de 2 par siècle, après 1935. Dans les deux autres aires d'étude, les fréquences étaient de 3 à 5 par siècle, autant avant qu'après 1935. Les auteurs suggèrent que la lutte contre les feux a altéré les régimes naturels d'incendies de North Fork mais n'a pas eu d'influence dans les aires d'étude centrales et méridionales.

[Traduit par la rédaction]

Introduction

Western larch – lodgepole pine (*Larix occidentalis* – *Pinus contorta* var. *latifolia*) is a major forest type of the inland Pacific Northwest – northern Rocky Mountain region. Yet only limited fire history information exists for this forest type, and most studies occurred on logged terrain where it was difficult to reconstruct primeval fire patterns (Arno 1976; Gabriel 1976; Davis 1980; Freedman and Habeck 1985). Before 1900, lodgepole pine dominated forests regenerated in various fire regimes (Arno 1980; Martin 1982). These included a mixed regime of nonlethal surface fires (25- to 50-year intervals) and stand-replacing fires (100- to 150-year intervals) in moderate-elevation dry forest types. In contrast, some high-elevation lodgepole pine forests experienced primarily stand-replacing fires after long intervals (>300 years).

To determine historic fire patterns in the fire-dependent larch – lodgepole pine cover type, we conducted studies in the western half of Montana's (U.S.A.) Glacier National Park (GNP) (Barrett 1983, 1986, and 1988). Our investigation sought to answer the following questions: (*i*) Were fire regimes in GNP's larch – lodgepole pine forest similar to those of other lodgepole pine dominated forests in the region? (*ii*) Are spatial patterns of environment within GNP important factors influencing fire regimes for this cover type? (*iii*) Has fire suppression affected the primeval fire regimes?

Fire's role in shaping area forests was not greatly influenced by European Americans until at least the early 1900s. Ignitions were caused by lightning and perhaps only occasionally by Native Americans in this forest type (Barrett and Arno 1982; Gruell 1985; Masters 1990). Until the

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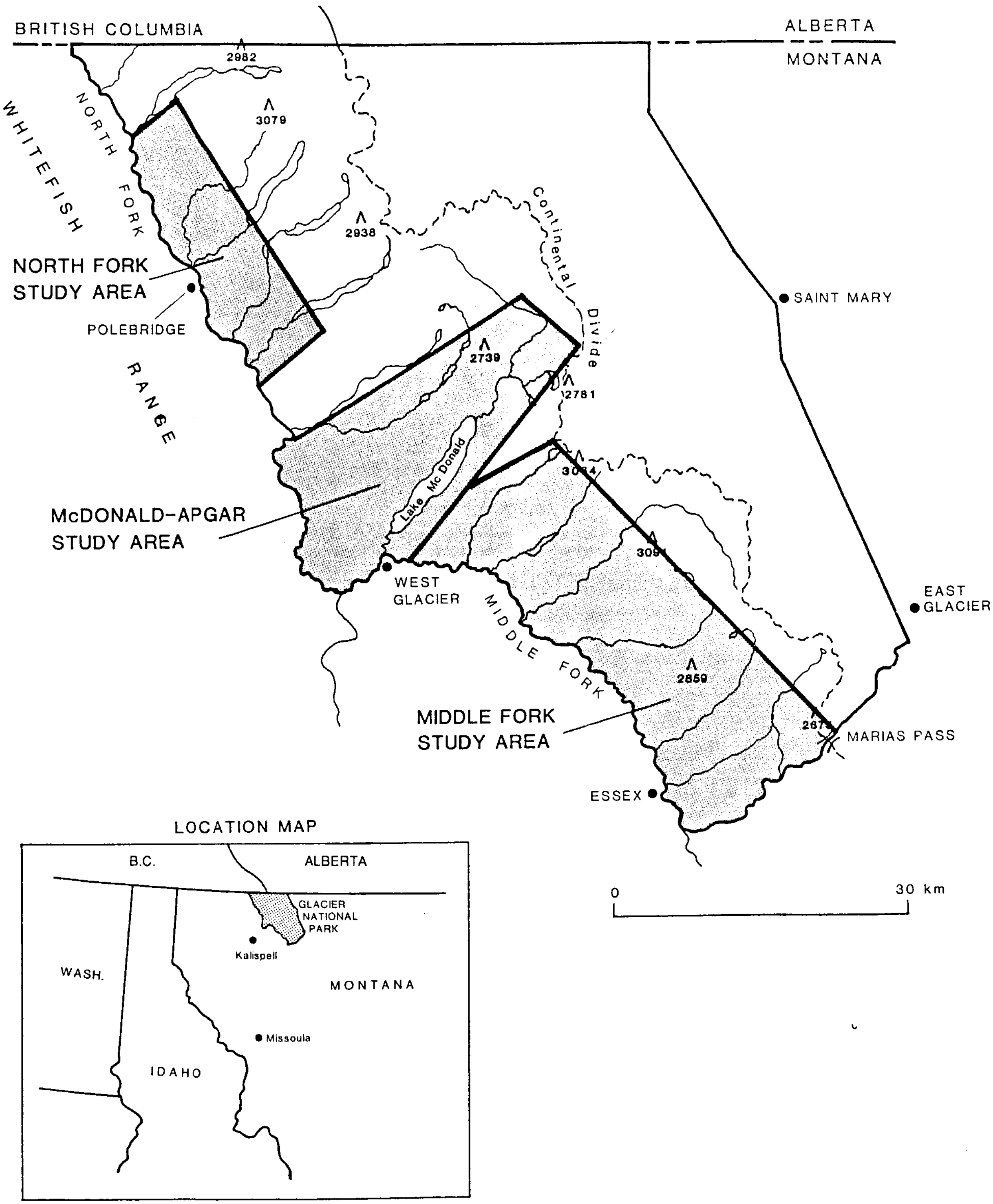

FIG. 1. Location of the three study areas in Glacier National Park (numbers on map are elevations in metres).

mid-20th century, the area remained unpopulated by European Americans, except for a few small homesteads in valley bottoms. Early records (Ayres 1900; Whitford 1905; Shoemaker 1922) indicate that forest fires occurred in and adjacent to GNP between the late 1800s and early 1900s, typically burning for weeks or months until extinguished by autumn precipitation. Large wildfires continued to occur until about the mid-1930s, after which fire suppression technology greatly improved in the region (Wellner 1970; Pyne 1982).

Study area

Roughly half of 409 961 ha GNP lies west of the Continental Divide, where alpine glacial canyons drain into the major valleys of the North Fork Flathead and Middle Fork Flathead (Fig. 1). Valley-bottom elevations range from 950 to 1150 m, and maximum elevations of 3000 m are reached at the Continental Divide. Area forests are relatively dense, productive, and rich in numbers of tre and undergrowth species for the Rocky Mountains (Habeck 1987, reflecting the influence of moist north Pacific Ocean air masses throughout most of the year (a drier continental climate prevails

TABLE 1. A comparison of some environmental characteristics in the three study areas

Environmental characteristic	Study area		
	North Fork	McDonald–Apgar	Middle Fork
Annual precipitation (cm) (valley stations shown in Fig. 1)	59 (Polebridge)	76 (W. Glacier)	102 (Essex)
Slope steepness (%) (general range from U.S. Geological Survey maps)	2–12	10–35	20–45
Major habitat type series* (potential dominant tree species, from this study)			
Dry sites			
Pseudotsuga menziesii	X		
Picea engelmannii × *P. glauca*	X		
Moist sites			
Abies lasiocarpa	X	X	X
Maritime-influence sites			
Thuja plicata and *Tsuga heterophylla*		X	

*From Pfister et al. (1977).

on the park's east side). Precipitation increases along a northwest to southeast axis in the study area (Table 1; Fig. 1) (Finklin 1986), as well as orographically toward the Continental Divide.

About 30% of GNP's west side consists of rugged alpine rock lands and depauperate upper subalpine forests dissected by numerous avalanche communities. The study area is in the continuous forest at low to middle elevations and contains a mix of seral (shade-intolerant) and potential climax (shade-tolerant) conifers. The seral species lodgepole pine and western larch dominate primarily even-aged stands that became established after stand-replacing fires (Habeck 1968; Pfister et al. 1977; Cattelino et al. 1979; Parker 1982). Western larch can persist in stands for 400–700 years and can attain large size (130 cm in diameter, 58 m in height) for a Rocky Mountain tree. These trees have thick, fire-resistant bark and can restore scorched foliage through epicormic branching, allowing some individuals to survive severe fires and release wind-dispersed seeds into the burn. Lodgepole pine is a relatively small tree in GNP (commonly 25 cm diameter and 20–25 m tall) and dominates stands for 100–180 years before succumbing to fires or attack by mountain pine beetles (*Dendroctonus ponderosae*) (Parker 1982). This thin-barked tree seldom survives intense fire, but some individuals have serotinous cones that release numerous seeds into the post-burn stand. Seral species are accompanied by various late-successional species that regenerate in stand understories during relatively long fire intervals (Pfister et al. 1977; Parker 1982; Fischer and Bradley 1987). Subalpine fir (*Abies lasiocarpa*) is a nearly ubiquitous potential climax species in GNP, and the study area's predominant forest habitat type is *A. lasiocarpa/Clintonia uniflora* (Pfister et al. 1977).

The North Fork valley contains a relatively narrow zone of dry forest types resulting from a rain-shadow effect caused by the Whitefish Range (Finklin 1986) (Fig. 1). Adjoining the continuous lodgepole pine forest are a few small grassland meadows bordered by dry ponderosa pine (*Pinus ponderosa* var. *ponderosa*) benches, where the indicated climax trees are inland Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) or hybrid spruce (*Picea engelmannii* × *glauca* (Habeck and Weaver 1969)) (Koterba and Habeck 1971, Lunan and Habeck 1973). Farther south, the Lake McDonald basin contains the eastern-most extension of wet Pacific coastal forest types in North America (Little 1971). Next to the lake is a narrow zone composed of mixed-aged stands of potential climax western hemlock (*Tsuga heterophylla*) and western red cedar (*Thuja plicata*), evidently in response to ample precipitation and the lake's moderating influence on local temperature (Habeck 1968).

Methods

GNP's west slope forest was divided into three geographic areas constituting a representative range of environmental gradients (Fig. 1; Table 1). The fire-year origins of 230 stands were sampled along transects (described later) in these areas. The first sample area is 24 000 ha of the approximately 69 000 ha North Fork valley in GNP. We sawed partial cross sections from 272 fire-scarred trees, many of which had been killed by mountain pine beetles (Arno and Sneck 1977; McBride 1983; Lorimer 1985). A few of the best preserved fire-scarred trees were sampled in each stand. The second and third study areas were in the Middle Fork valley (54 000 ha) and the McDonald Creek – Apgar Mountains area (hereafter referred to as McDonald–Apgar) (38 000 ha). Fire-scarred trees were comparatively rare in these areas (Habeck 1968; Parker 1982), so fire history was determined primarily from age-class sampling (Heinselman 1973). The *GNP Fire Atlas* (on file, GNP Research Office) also provided information on post-1910 fire sizes and locations.

Aerial photographs were used to develop a preliminary forest age-class (stand origin) map. Stand boundaries were transferred to topographic maps, then a system of transects was selected by using area trails and roads crossing representative terrain. In the field, stand initiation years were estimated by increment boring three or more dominant seral trees at 30 cm above the ground (Barrett and Arno 1988). No correction factor was added for the seedling to reach this height. At each stand, tree species composition and stand age structure were inventoried in a representative 375-m^2 macroplot (Pfister and Arno 1980). In these plots canopy coverage (percent) was estimated for four size classes: saplings (0–10 cm in diameter 1.3 m above ground); poles (10–30 cm); mature trees (30–76 cm); and old growth (>76 cm). Then two or more of the largest diameter shade-tolerant trees in each of the four classes were increment bored to augment the stand age-class data already obtained from dominant seral trees.

In the laboratory, the increment cores were sanded and dated with magnification. If *GNP Fire Atlas* records or fire scars were

TABLE 2. Fire frequencies for 20 sites in the North Fork (NF) sample area between 1650 and 1935

Cover types; potential climax*	Site	All fires: No. of fires	All fires: Interval range (years)	All fires: MFI (years)	PICO stand-replacing fires†: Fire interval (years)	PICO stand-replacing fires†: Current age-class (years)‡
LAOC-PICO-PIPO; PSME-PICEA	NF15	6	14-65	28	79	121
	NF1	10	4-70	29	203	129
	NF8	10	15-48	29	177; 82	61
	NF14	10	9-72	30	159	135
	NF2	7	10-55	36	172	121
	NF9	8	6-63	37	147	135
	NF3	4	32-65	46	106	187
	NF7	6	16-113	52	147	173
LAOC-PICO-ABLA; ABLA	NF5	10	12-36	24	189	143
	NF18	7	8-49	25	107	77
	NF17	11	5-129	26	211	121
	NF16	9	13-88	32	199	121
	NF4	6	6-77	41	167	135
	NF6	6	16-113	44	161	143
	NF19	4	17-78	45	nd	118
	NF13	5	13-113	52	169	135
	NF20	5	28-101	61	243	77
	NF10	5	21-147	64	197	135
	NF11	5	10-208	64	234	98
	NF12	4	21-169	76	169	135

NOTE: Site master fire chronologies include both nonlethal surface fires and stand-replacing fires. nd, no data.
*LAOC, western larch; PICO, lodgepole pine; PIPO, ponderosa pine; PSME, Douglas-fir; PICEA, hybrid spruce; ABLA, subalpine fir.
†Because of its exceptional fire resistance some western larch commonly survives fires that kill all lodgepole pine and other conifers.
‡Years, as of 1987, since last stand-replacing fire; most lodgepole pine in all stands are beetle killed.

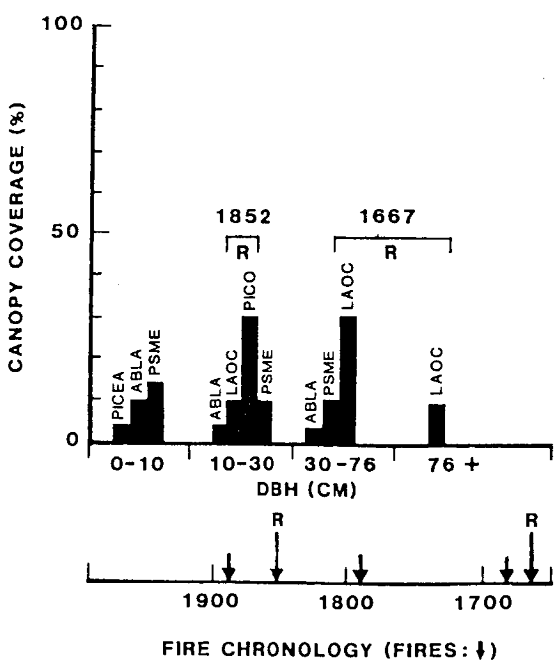

FIG. 2. A North Fork sample site (NF13, Table 1) with two-aged seral component. Stand experienced two fires that initiated seral regeneration (R) and also three low-intensity surface fires. PICEA, hybrid spruce; ABLA, subalpine fir; PSME, Douglas-fir; LAOC, western larch; PICO, lodgepole pine.

unavailable, the stand initiation year was used to represent the approximate year of the most recent stand-replacing fire, estimated as follows: (*i*) similar initiation (pith) years were required from at least three dominant seral trees (maximum range of 20 years) and (*ii*) the earliest pith year among similarly aged seral trees indicated the stand initiation year.

When fire scars were available for sampling, master fire chronologies were compiled by estimating stand fire years based on several sample trees per stand (Arno and Sneck 1977; McBride 1983). Mean fire intervals were calculated by dividing the years between the first and last fires in a given chronology by the number of fire intervals (Romme 1980). When sites lacked fire scars but had evidence of at least one fire interval, a multiple-site average fire interval was calculated (Barrett and Arno 1988). (This is the mean of single fire intervals compiled from a number of stands in a given habitat type.) Such stands usually had a remnant larch age-class (post-fire survivors) towering above the younger larch – lodgepole pine canopy (current stand dominants), so that initiation years could be sampled for both classes. This allowed estimation of one complete fire interval.

The final forest age-class map was derived by editing the prefieldwork maps. We used the *GNP Fire Atlas* and data from age-class and fire-scar sampling to extrapolate stand initiation years to unvisited stands by comparing the canopy traits of known stands with those of nearby unsampled stands. When stand-age extrapolation was not possible, such as in distinguishing between similarly aged stands, we assigned broad age categories to the unknown classes (e.g., pre-1750, 1850–1900). This map was digitized and entered into a geographic information system for use in generating area statistics for various age-class categories. The system uses

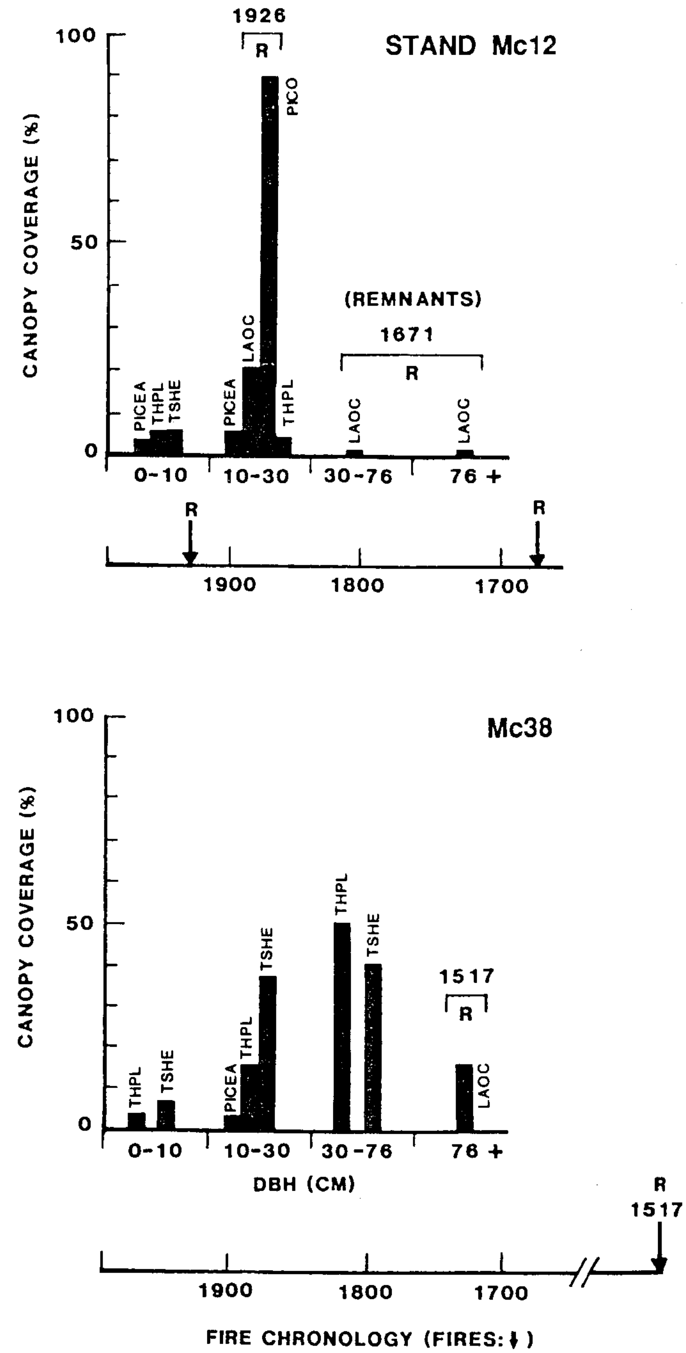

FIG. 3. Two McDonald–Apgar sample sites with primarily one-aged seral component. Mc12 is successionally young and Mc38 is near climax. THPL, western red cedar; TSHE, western hemlock. See Fig. 1 caption for additional abbreviation definitions.

GRASS software (Geographic Resource Analysis Support System, U.S. Army Corps of Engineers, 1990) installed on a Sun 386i work station.

Results and discussion

ire frequencies

In the North Fork study area most age-class samples were from lodgepole pine, and the longest fire-scar sequences (three to seven per tree) dated back to the early 1600s on larch and ponderosa pine. We were able to calculate master fire chronologies for eight relatively dry sites where Douglas-fir or hybrid spruce is the potential climax tree, and 12 relatively moist sites where subalpine fir is the potential climax species (Table 2). Between about 1650 and 1935 both types of sites had roughly similar fire frequencies (grand means of 36 versus 46 years, respectively). Dry-site mean fire intervals were shortened somewhat by the recurrence of small nonlethal surface fires near ponderosa pine – grassland meadows; these stands experienced as many as seven nonlethal fires interspersed between two or more infrequent stand-replacing fires (mean interval of 141 years) (Fig. 2). Moist stands usually had evidence of only one or two nonlethal surface fires occurring between even less frequent stand-replacing fires (mean interval of 186 years).

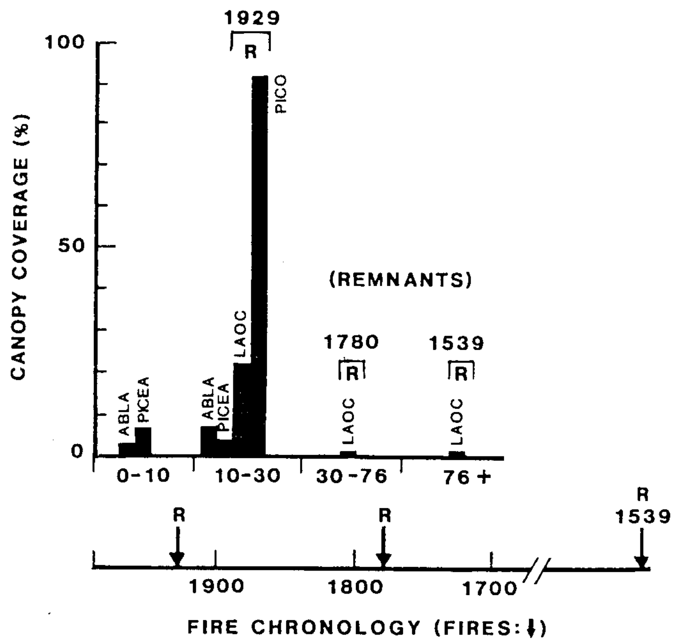

FIG. 4. A Middle Fork sample site (MF3, Table 2) dominated by a young seral component. See Fig. 1 caption for abbreviation definitions.

The McDonald–Apgar and Middle Fork sample areas generally lacked trees with multiple fire scars, suggesting a pattern of primarily stand replacing fires. Remnants of old age-classes were found on 19 of the 136 sample sites in these two study areas, enabling estimation of multiple-site average fire intervals (Figs. 3, 4; Table 3). These were 202 years (range of 131–332 years) for 13 relatively moist sites (subalpine fir potential climax) versus 261 years (range of 145–450 years) for the six wetter sites near Lake McDonald.

The forest age-class map allowed insight into age-class patterns, but constraints (described later) prevented calculation of fire cycles, i.e., the length of time it took fires to burn an area equal to the entire study area (Romme 1980). An alternate method, useful for interpreting the effects of fire suppression, was to compare pre- and post-1935 fire frequencies in each of the three study areas. The mid-1930s generally are recognized as the onset of efficient fire suppression in the region (Wellner 1970) (Fig. 5). The North Fork study area had an estimated 55 fire years (years when one or more fires occurred) between 1650 and 1935, resulting in a mean of 20 fire years per century. In contrast, only one fire occurred after 1935; thus the mean would be 2 fire years per century. At the stand level, the current intervals since

TABLE 3. Intervals between stand-replacing fires for 19 sites in the McDonald–Apgar (Mc) and Middle Fork (MF) sample areas

Cover types; potential climax*	Site	Fire interval (years)	Current age-class (years)†
LAOC-PICO-ABLA; ABLA	Mc34	131	61
	Mc35	150	58
	MF1	149; 205	58
	MF3	149; 241	58
	MF10	169	68
	MF4	187	207
	MF7	190	77
	Mc8	191	61
	Mc43	201	51
	MF8	237	77
	Mc23	252	61
	MF6	253	61
	MF5	332	93
THPL-TSHE-LAOC; TSHE-THPL	Mc25	145	107
	Mc30	164	88
	Mc40	206	74
	Mc12	255	61
	Mc39	344	126
	Mc42	450	20

*LAOC, western larch; PICO, lodgepole pine; ABLA, subalpine fir; THPL, western red cedar; TSHE, western hemlock.
†Years since last fire (as of 1987).

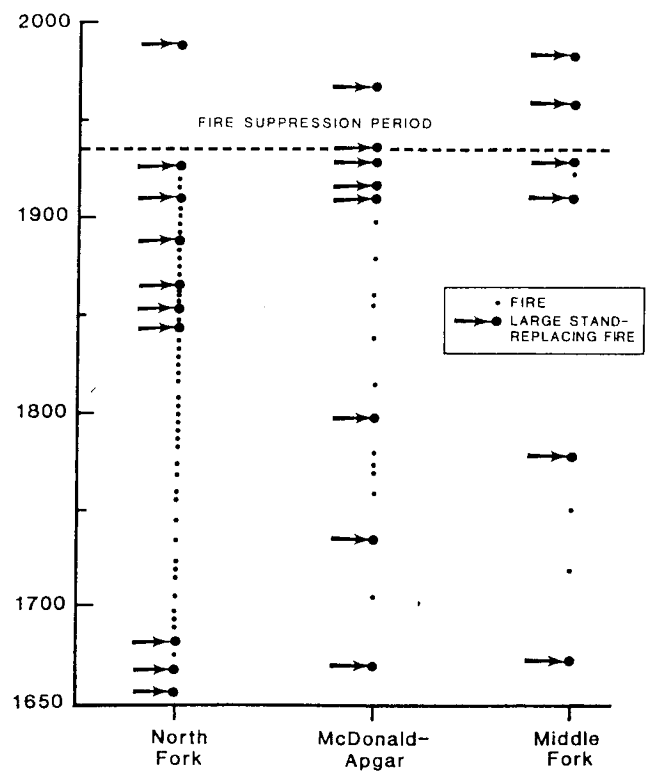

FIG. 5. Master fire chronology for the three study areas, 1650–1989.

the last fire, or until the 1988 wildfire, ranged from 62 to 155 years. These represent some of the longest fire intervals during the past 3 centuries (Table 2). Conversely, frequencies for the McDonald–Apgar study area were 5 fire years per century before 1935 and 4 per century after 1935, while the Middle Fork had averages of 3 and 4 fire years per century, respectively. Moreover, 16 of the 19 sample stands in these two study areas had current fire intervals of less than 100 years, considerably shorter than even the mean pre-1935 intervals (Table 3).

Burning patterns

Most stands in the forest age-class mosaic are <140 years old (Fig. 6), and large portions of older age-classes were obliterated by severe fires in this century. Wildfires between 1910 and 1936 burned about 39% of the 160 000 ha constituting the three study areas (Figs. 5–7). In fact, 1910 produced the most extensive wildfires recorded in the northern Rocky Mountains (Cohen and Miller 1978), as well as in GNP (30 850 ha). The *GNP Fire Atlas* indicated that lightning has ignited most fires in this century, but humans also caused several important fires, such as in 1929 (13 000 ha). Thus, while our sampling was able to identify the major pre-1910 burns, their extent cannot be measured. The postfire stands originating before 1910 are only remnants that have been greatly depleted by later fires, and scant historical information is available for evaluating sizes of pre-1910 fires. Therefore we were unable to reconstruct long-term fire cycles (Heinselman 1973; Van Wagner 1978).

Three apparently large fires occurred in the North Fork valley between about 1655 and 1683 (Fig. 5), but today these age-classes exist as only widespread relicts (Fig. 7*a*). This overlap of multiple large fires is suggestive of a double or triple burn as described by Wellner (1970) and Lotan et al. (1985) in which fires that occurred shortly after an initial stand-replacing fire created heavy fuels such as downed snags. Evidence from fire-scarred trees indicates that maj(stand-replacing fires did not recur in the area until 160 yeaı later (Fig. 5), although frequent nonlethal surface fires occurred on dry sites (Lunan and Habeck 1973; Singer 1975). The area's current lodgepole pine age-classes became established in an intricate mosaic between 1844 and 1926 (Fig. 7*a*), suggesting that fire severites ranged from partial to total stand replacement. One-aged stands in the mosaic are 200–600 ha each, interspersed with smaller two-aged (underburned) stands <40 ha each (Figs. 2 and 7*a*).

Between 1972 and 1982 a mountain pine beetle epidemic spread across 69 000 ha of the North Fork valley and killed most of the trees in these lodgepole pine stands, producing heavy fuel loads (Armour 1982; unpublished report 87-7, Forest Insect and Disease Management, USDA Forest Service, Missoula, MT). In 1988 a wind-driven lightning fire spread into GNP and, despite aggressive fire suppression measures, burned several park buildings and 17 000 ha largely in beetle-killed stands. The Red Bench fire also killed many >350-year-old western larch and ponderosa pines that previously had survived up to seven fires each.

Age-class patterns were substantially different in the more moist study areas southeast of the North Fork valley. Whereas the North Fork study area had at least 54 fire years between the mid-1600s and 1935, the McDonald–Apgar and Middle Fork sample areas had evidence of only 18 and 7 fire years, respectively (Figs. 5 and 6). Moreover, a pattern of primarily stand replacing fires was suggested by larg((>400 ha) one-aged stands lacking fire scars (Figs. 3, 4, 7*b*).

Pre-1900 age-classes in the McDonald–Apgar area are largely between 250 and 360 years old. Most prevalent is an approximately 1735 class, which despite subsequent stand-replacing fires, still occupies 5900 ha. Nearly 2 centuries

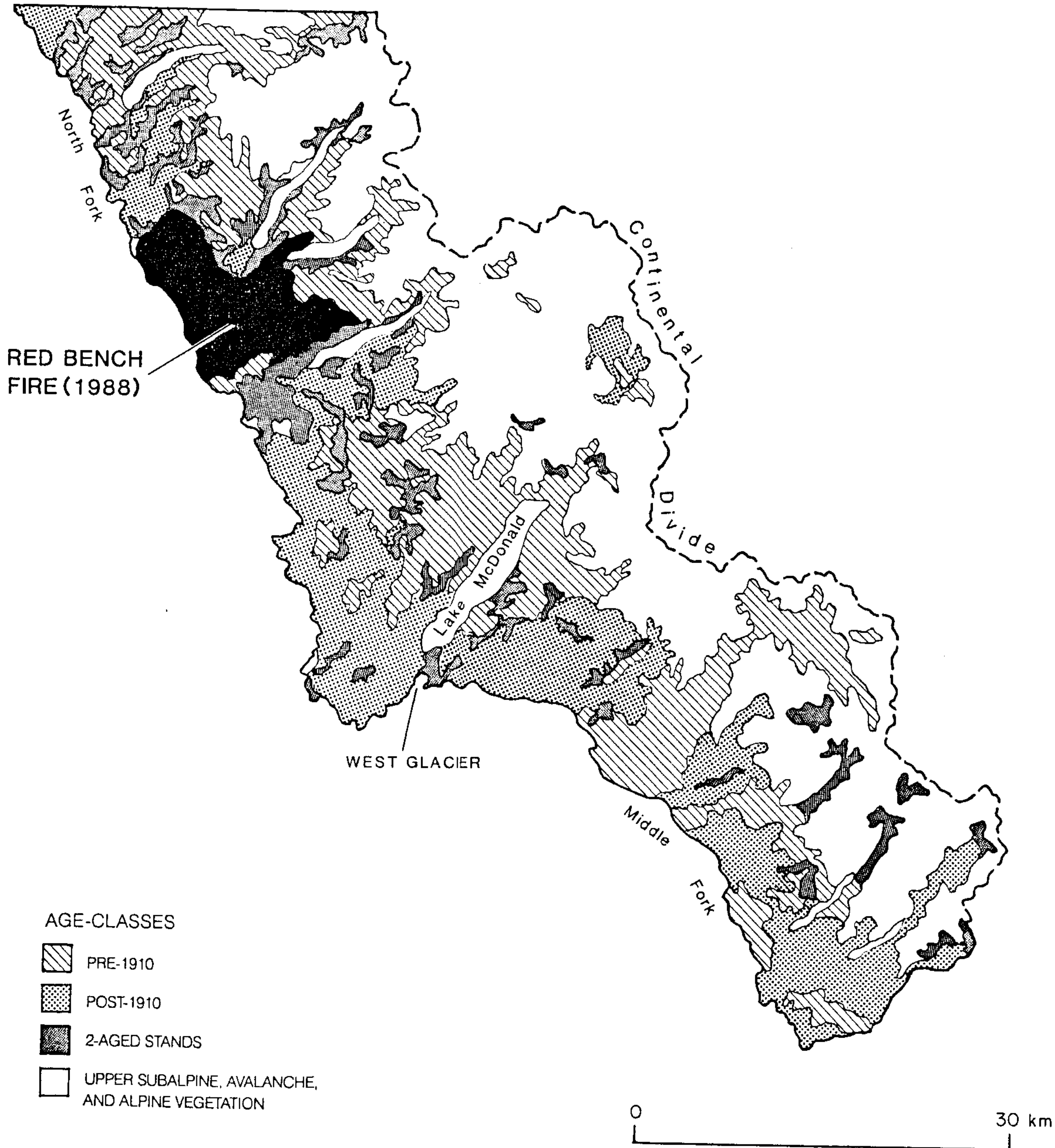

FIG. 6. Geographic information system depiction of large-scale age-class patterns (establishment dates) in Glacier National Park's lower and middle elevation west-side forests.

passed before the next major series of stand-replacement events, when six fires between 1919 and 1967 collectively burned 15 000 ha.

A relict 1670 age-class represented the earliest evidence of major fires in the Middle Fork valley, followed by a relatively fire-free period of 110 years (Fig. 5). Remnants from a 1780 age-class also are widespread in the northwestern half of the valley, but no major fires were detected for the next 149 years until 1929, when an escaped slash fire entered GNP and burned 13 000 ha, much of it in the 1780 class. This fire storm swept from valley bottom to alpine ridgetops, much like the earlier 1910 lightning fire in the southeastern half of the valley (14 700 ha). Only 1174 ha burned in the Middle Fork valley over the next 5 decades, in a 1958 lightning fire. In 1974 the GNP fire management plan was revised to allow some lightning fires to burn under prescription. Park-wide, the only significant fire allowed to burn to date has been the 1984 Crystal Creek fire (1100 ha), in central Middle Fork valley.

Fire regimes

Western larch has a narrower elevational distribution and a much smaller geographic range than lodgepole pine (Little 1971; Pfister et al. 1977). Our findings and past studies of this cover type (Gabriel 1976; Arno 1976, 1980; Arno and Davis 1980; Davis 1980; Freedman and Habeck 1985) suggest two distinct fire regimes: (*i*) variable fire severities on dry sites after relatively short fire intervals of 25–75 years and (*ii*) predominantly stand replacing fires on moist sites after long intervals of 120–350 years. Intervals between stand-replacing fires can be similar for both types of sites (> 100 years), but on moist sites some intervals are substantially longer.

The considerable environmental variation on GNP's west side undoubtedly plays a major role influencing the different fire regimes (Tables 1–3; Fig. 5). The North Fork drainage has a drier climate and areas of coarse, well-drained soils occupied by dry community types (Koterba and Habeck 1971; Lunan and Habeck 1973), and the high fire frequency

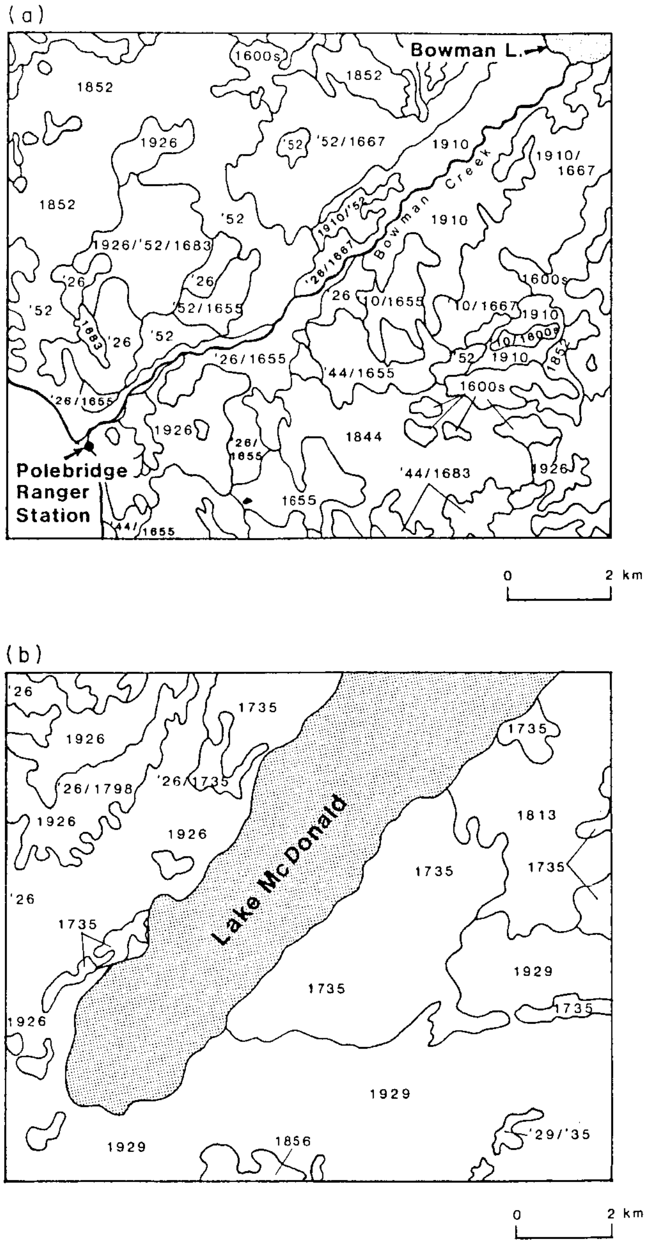

FIG. 7. (*a*) Intricate age-class mosaic as of 1987 in a portion of the North Fork study area. Establishment dates indicate one-aged or multiple-aged (underburned) stands. For this illustration some of the smallest units are not dated. (*b*) Age-class mosaic in a portion of the McDonald–Apgar study area, consisting primarily of extensive one-aged stands. '35, 1735; '44, 1844; '52, 1852; '10, 1910; '26, 1926; '29; 1929.

before 1935 suggests that fuels are receptive to spreading fire more often than moister sites to the southeast. The North Fork also has gentler topography where fuels are not so readily preheated during fires (Rothermel 1983), thus occasionally inhibiting the development of crown fires after ignition. These interpretations generally support Parker (1982), who stated that site characteristics reduce or enhance the effect of occasional summer drought, producing a wide range of fire patterns on GNP's west side.

Long- and short-term climatic patterns also have played an important role in GNP's fire history. The period of large fires between 1910 and 1936 coincided with the Pacific Northwest's most severe drought cycle in the last 3 centuries (Keen 1937; Leaphart and Stage 1968; Carrara and McGimsey 1981). Previously, major fires occurred in the North Fork during the middle to late 1600s, and Leaphart and Stage (1968) concluded that this was the region's secon' most recent long-term drought. Major fires also occurr in the North Fork during the middle to late 1800s, durin a warming trend after the end of the cool, moist Little Ice Age (Carrara and McGimsey 1981; Johnson et al. 1990). Johnson et al. (1990) state that a characteristic weather pattern produces most severe lightning fires in the region: (*i*) intense fuel drying during stationary high pressure systems followed by (*ii*) rapid change to low pressure causing lightning and high winds. The *GNP Fire Atlas* verifies this pattern for a number of the century's important fires (1910, 1936, 1967, 1974, 1988).

Effects of fire suppression

Uncontrolled variables preclude empirical testing of fire suppression's effect on area fire regimes. Fire interval length can be influenced by climatic fluctuations undetectable over the relatively short period of effective suppression (Tande 1979). However, assuming macroclimate would change uniformly across GNP's west side, the fact that there was a 10-fold reduction in post-1935 fire frequency in the North Fork versus negligible change elsewhere is strong circumstantial evidence of interrupted fire occurrence. The *GNP Fire Atlas* revealed that 95 ignitions were promptly suppressed in the North Fork study area between 1930 and 1987, some during critical fire weather in the mid-1930s, 1940, and 1967. Eliminating just a few potentially large fires would allow the forest mosaic to advance to later successional stages over a broad area, rather than a mixed pattern of young to ol' stands (Cattelino et al. 1979; Parker 1982). In the norther Rocky Mountains, mosaic homogeneity might have serious implications for productive lodgepole pine ecosystems because stands often become susceptible to mountain pine beetle epidemics after about 80 years (Amman and Cole 1983), followed by stand-replacing fires at 120–150 years (Bevins 1979; Jeske and Bevins 1979; Armour 1982; Lotan et al. 1985). Our fire history data support these lodgepole pine succession models because the chronologies for all three study areas showed a recurrent pattern of long fire-free periods (150–180 years) punctuated by major stand-replacing fires (Fig. 5). If fire suppression enhances the extent and severity of pine beetle epidemics, then more extensive fires would be expected in the resultant fuels. Indeed, the 1988 Red Bench fire might be a window to this future; the *GNP Fire Atlas* verified that a number of potentially spreading fires previously had been suppressed within that burn's 17 000 ha perimeter.

Fire suppression has not noticeably altered the primeval fire regime in moist forests south of the North Fork. First, fires in the early 1900s initiated extensive new stands whose current fire intervals are well short of pre-1900 intervals. And second, while potential stand-replacing fires might have been suppressed during the last 50–60 years, this is a short period compared with primeval fire intervals in the McDonald–Apgar and Middle Fork study areas. Johnson and Fryer (1987) and Romme and Despain (1989) made similar interpretations for more continental lodgepole pin ecosystems (lacking western larch) in Alberta and Yellowstone National Park. Johnson et al. (1990) and Masters (1990) studied moist forest types in British Columbia beyond the distributional limits of the western larch type, in western red cedar - western hemlock and lodgepole pine, respectively. They concluded that climate remains the controlling factor in the occurrence of large stand-replacing fires and that fire suppression has had little effect overall.

As an international biosphere reserve, GNP seeks to preserve naturally functioning ecosystems in the northern Rocky Mountain biogeographic region. The park contains one of North America's last expanses of unlogged larch - lodgepole pine forest, and large fires will continue to be important perturbations. Still, managers have tried to extinguish most fires to protect park visitors and facilities, evidently with varying degrees of success. Fire history reveals the inherent irony and futility of this approach, and consequently the need for new management strategies.

Acknowledgments

Reviewers' comments were very helpful in developing this paper. These were provided by James Agee and the late George Fahnestock, University of Washington; James K. Brown, USDA Forest Service; Charles Bushey, Wildland Fire Consultant, Missoula, Montana; William Romme, Fort Lewis College; Craig Lorimer, University of Wisconsin; and two anonymous reviewers. Funding was provided by Glacier National Park and the USDA Forest Service, Intermountain Research Station.

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