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FIRE HISTORY OF SOUTHEASTERN GLACIER NATIONAL PARK: MISSOURI RIVER DRAINAGE

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INTRODUCTION

In 1982, Glacier National Park (GNP) initiated long-term studies to document the fire history of all forested lands in the 410,000 ha. park. To date, studies have been conducted for GNP west of the Continental Divide (Barrett et al. 1991), roughly half the total park area. These and other fire history studies in the Northern Rockies (Arno 1976, Sneck 1977, Arno 1980, Romme 1982, Romme and Despain 1989, Barrett and Arno 1991, Barrett 1993a, Barrett 1993b) have shown that fire history data can be an integral element of fire management planning, particularly when natural fire plans are being developed for parks and wilderness. The value of site specific fire history data is apparent when considering study results for lodgepole pine (Pinus contorta var. latifolia) forests. Lodgepole pine is a major subalpine type in the Northern Rockies and such stands experienced a wide range of presettlement fire patterns. On relatively warm-dry sites at lower elevations, such as in GNP's North Fork drainage (Barrett et al. 1991), short to moderately long interval (25-150 yr) fires occurred in a mixed severity pattern ranging from non-lethal underburns to total stand replacement (Arno 1976, Sneck 1977, Barrett and Arno 1991). Markedly different fire history occurred in high elevation lodgepole pine stands on highly unproductive sites, such as on Yellowstone National Park's (YNP) subalpine plateau. Romme (1982) found that, on some sites, stand replacing fires recurred after very long intervals (300-400 yr), and that non-lethal surface fires were rare. For somewhat more productive sites in the Absaroka Mountains in YNP, Barrett (1993a) estimated a 200 year mean replacement interval, in a pattern similar to that found in steep mountain terrain elsewhere, such as in the Middle Fork Flathead River drainage (Barrett et al. 1991, Sneck 1977).

Aside from post-1900 written records (Ayres 1900: fire atlas data on file, GNP Archives Div. and GNP Resources Mgt. Div.), little fire history information existed for GNP's east-side forests, which are dominated primarily by lodgepole pine. In fall 1992, the park initiated a study to determine the fire history of the Missouri River drainage portion of southeastern GNP. Given the known variation in pre-1900 fire patterns for lodgepole pine, this study was seen as a potentially important contribution to GNP's Fire Management Plan, and to the expanding data base of fire history studies in the region. Resource managers sought this information to assist their development of appropriate fire management strategies for the east-side forests, and the fire history data also would be a useful interactive component of the park's Geographic Information System (GIS). Primary objectives were to: 1) determine pre-1900 fire periodicities, severities, burning patterns, and post-fire succession for major forest types, and 2) document and map the forest age class mosaic, reflecting the history of stand replacing fires at the landscape level of analysis. Secondary objectives were to interpret the possible effects of modern fire suppression on area forests, and to determine fire regime patterns relative to other lodgepole pine ecosystems in the Northern Rockies.

STUDY AREA

The study area is approximately 32,800 ha. and ranges from 1500 m. to 2900 m. elevation in the Missouri River drainage portion of the Lewis Range, southeastern GNP (fig. 1). The study area's western edge abuts the Continental Divide, which roughly bisects GNP in a southeast to northwest axis. The southern edge of the study area adjoins the southeastern border of GNP northeast of Marias Pass, while the northern boundary is defined by the primary divide that separates the park's Missouri and Hudson Bay drainages. The park Geographic Information System (data on file, GNP Research Div.) indicates that

the area contains 10,118 ha. of coniferous forest, 2833 ha. of deciduous forest and shrubland, 5909 ha. of herbaceous communities, and 13,922 ha. of alpine rocklands and water. Accordingly, this study documents the fire history of the ~13,000 ha. of forested lands, which occupy 40% of the total area.

The study area is composed primarily of moderately steep to steep terrain dissected by 6 primary drainages and associated subdrainages in an alpine glacial and dendritic erosion pattern. This area is representative of lands comprising the front range of the Northern Rocky Mountains (Arno 1979). Specifically, a relatively narrow band of coniferous and deciduous forest between lower and upper timberlines (~1500 m., 2400 m., respectively) occupies large U-shaped canyons and associated morainal topography along the mountain front. Perhaps significant to the area's fire history, a relatively abrupt change in landform and fuels occurs near lower timberline, which generally is 4-10 km east of the GNP boundary and adjoins grasslands on the Blackfeet Indian Reservation. Here, a very narrow zone of aspen groveland occupies rolling foothills and large lateral moraines that extend east to the Northern Great Plains (Ayres 1900, Lynch 1955, Habeck 1970, Arno 1979).

Climate also is a very prominent feature influencing area ecosystems (Finklin 1986). The Rocky Mountain front experiences widely fluctuating and occasionally severe climatic conditions--a complex interaction between large scale factors, such as a transition zone between north Pacific coastal and continental weather patterns, and small scale factors such as orographic effects on local weather (Finklin 1986). For example, in winter this area is commonly subjected to widely fluctuating temperatures and strong dessicating winds that can kill many hectares of wind exposed trees in a red belt effect (Habeck 1970, Arno 1979). The study area typically has shorter and cooler growing seasons than on GNP's west side (Arno 1979, Finklin 1986). The area also contains somewhat drier, less productive forest types (Pfister et al.

1977), due to a rainshadow effect that is produced by the park's high mountains. However, decreased precipitation is not readily apparent in long-term averages, partly because of the higher elevations of east side weather stations. Weather records (Finklin 1986) indicate an annual average of 77 cm for East Glacier, MT (1465 m. elev.), versus 76 cm for West Glacier (969 m.). Precipitation east of the Contintenal Divide can fluctuate more widely year to year than on the west side, and amounts also can vary more widely over short distances (Finklin 1986). For example, mean annual precipitation declines from 77 cm at East Glacier to 38 cm at Browning, MT (1313 m.), on the plains just 19 km east of the front range. Additionally, annual precipitation can exceed 250 cm at the crest of GNP's high mountains (Finklin 1986).

Because of these complex interactions between climate and topography, vegetation patterns are somewhat more complex in the front range than on GNP's west side. For example, the study area's forests are primarily lower subalpine coniferous (Pfister et al. 1977), but the krummholz ecotone can vary widely in elevation (e.g., 1830-2100 m.), depending on slope exposure to prevailing winds. (Krummholz typically extends lower along the front's broad east-facing slopes). Additionally, the study area contains the easternmost extension of such intermountain species such as Menziesia ferruginea, Xerophyllum tenax, Luzula hitchcockii, and Clintonia uniflora--primarily intermountain species that are abundant west of the Continental Divide because of the prevailing maritime climate (Pfister et al. 1977, Arno 1979, Finklin 1986). And typically just east of the study area, in the rolling morainal topography adjacent to prairie grasslands, wind-stunted stands dominated by aspen (Populus tremuloides) along with scattered large diameter Douglas-fir (Pseudotsuga menziesii var. glauca) and limber pine (Pinus flexilis) occur in a woodland forest pattern (Ayres 1900, Lynch 1955, Arno 1979). (The southeastern corner of the study area contains a comparatively large amount of this forest type).

Lower subalpine forests consist of relatively short stature, single- and multi-storied stands dominated by even age serals lodgepole pine and whitebark pine (P. albicaulis). Here, as elsewhere in the Northern Rockies, stand replacing fires have produced a mosaic of even age classes of lodgepole pine, large numbers of which regenerate in post-fire mineral soil (Brown 1975, Pfister et al 1977). Such stands occupy excessively well drained sites of low to moderate productivity (Pfister et al 1977), and have sparse to moderately dense understories of shade tolerant subalpine fir (Abies lasiocarpa) and Engelmann spruce (Picea engelmannii). At the upper limits of the lower subalpine zone, the continuous forest is dominated by increasingly wind stunted lodgepole- and whitebark pines, then shifts to upper subalpine forest that is characterized by scattered krummholz islands of subalpine fir, whitebark pine or, rarely, subalpine larch (Larix lyallii). In the southeastern portion of the study area, along the wind-swept foothills of the front range, single layer seral stands of relatively even age aspen occur adjacent to and occasionally interspersed among coniferous stands and communities that are dominated by gramminoids or shrubs (Habeck 1970). These aspen groves generally range in size from a few ha. to several hundred ha, and represent the westernmost extension of the aspen groveland, which apparently is a climax community type at lower elvations east of the study area (Lynch 1955). The following major habitat types (Pfister et al. 1977) define potential forest vegetation in the study area: 1)A. lasiocarpa/C. uniflora (C. uniflora and X. tenax phases) in creek bottoms and moist draws. 2) A. lasiocarpa/X. tenax (V. globulare phase) on sheltered north slopes primarily at lower- to middle elevations, 3) A. lasiocarpa/ X. tenax (Vaccinium scoparium phase) on most well drained exposed slopes primarily at middle elevations, and 4) A. lasiocarpa-P. albicaulis/V. scoparium throughout the upper subalpine zone.

METHODS

The methods of Arno and Sneck (1977) and Barrett and Arno (1988) were used to document the fire history. Since impacts from chainsaw sampling were not acceptable, Barrett and Arno's (1988) increment borer method was used to sample stand initiation years and fire scars, and to estimate fire frequency when fire scars were not available for sampling. Otherwise, both Arno and Sneck (1977) and Barrett and Arno (1988) recommend analyzing post-fire tree succession and developing a forest age class map as a primary basis for interpreting fire history in areas subject to stand replacing fires.

Sample Site Selection. In the office, 1968 series aerial photographs were used to prepare a preliminary map of stand polygons that comprise the mosaic of post-fire regenerated seral age classes (Heinselman 1973, Tande 1979). This age class map (7.5 minute scale) was used to select sampling transects and any potentially important sample sites. For example, sampling near the margins of adjoining even-age classes often yields useful information because such sites enable documentation of more than one stand-replacing fire (Heinselman 1973, Tande 1979). The occurrence of major vegetation types also was noted on the age class map, to ensure that transects would cross representative forest ecosystems.

Stand Sampling. In the field, sites were evaluated for sampling by first verifying the existence of fire-initiated seral age classes or fire scarred trees. In even age stands lacking fire scarred trees, preliminary estimates of stand initiation years were made by increment boring the piths of dominant seral trees 30 cm. above ground line. When possible, preliminary ring counts were made in the field to ascertain that similar pith years had been obtained from at least 3 trees. When a stand's trees also contained datable fire scars, the scars were sampled with an increment borer (Barrett and Arno 1988).

Postfire tree succession was documented in the sample stands by sampling one

or more representative circular macroplots (375 m^2)(Arno and Sneck 1977, Barrett and Arno 1988), depending on stand extent and variability. Stand physical structure was documented by making ocular estimates of tree species canopy coverage according to 4 dbh classes (0-10 cm., 10-30 cm., 30-76 cm., 76+ cm.). To complete the sampling of stand age structure, 2 or more dominant trees within each dbh class were increment bored, augmenting the tree-age data already taken from the stands' seral trees.

Age Class/Fire Scar Analysis. In the laboratory, the increment cores were surfaced and dated by counting annual rings under magnification. First, for the age class increment cores, estimates were made of the number of additional rings to the pith for any cores that did not precisely intersect tree center. Final estimates for initiation years were derived using the following criteria if more precise evidence, such as fire atlas records, was unavailable: 1) similar pith years were required from at least 3 seral trees per age class, 2) 30 years was considered an acceptible range defining a seral age class, and 3) the earliest pith year found among similarly aged dominant trees was used to designate the initiation year. (A correction factor to estimate tree age to boring height (30 cm.) was considered unnecessary because results from the author's past studies in lodgepole pine [Barrett and Arno 1988, Barrett et al. 1991, Barrett and Arno 1991, Barrett 1993a, Barrett 1993b] suggested that estimates of age class initiation years often are within $\pm$ 1 year of known fire years).

The fire scar increment cores were dated by making several ring counts from the tree cambium to each apparent fire scar annulus. Similarly aged scars that evidently dated from the same event were adjusted to the sample with the clearest ring pattern (Barrett and Arno 1988, Arno and Sneck 1977). However, in addition to being slower and more tedious, the increment boring method often yields substantially less accurate estimates for scar years than Arno and

Sneck's (1977) chain saw sampling method. Therefore, for reasons of economy, recent fire scars were not bored when transects were well within the known perimeters of documented fires (i.e., age class sampling usually sufficed to document that fire year).

Postfire succession was interpreted by constructing stand tables based on the tree macroplot data (Arno and Sneck 1977, Barrett and Arno 1988). Bar graphs were constructed by plotting each tree species' canopy coverage (Y axis) according to the 4 dbh classes (X axis), then labelling the mean tree ages that were obtained from dominant trees in each class. If more than one plot had been sampled in a stand, a composite stand graph was constructed by averaging the canopy coverages and mean ages for each species per dbh class. Successional interpretations then were derived by examining the stands' tree structure- and age patterns relative to stand fire history.

Fire Frequency Analysis. To analyze fire frequency, all fires detected from sampling and fire atlas records were listed in a study area master fire chronology (Arno and Sneck 1977). Mean fire interval (MFI) was estimated for the entire study area by dividing the estimated number of years in the chronology by the number of fire intervals. When sample stands produced data from fire-scarred trees, stand fire chronologies also were compiled (Arno and Sneck 1977), and MFI was calculated for stands that had evidence of 2 or more fire intervals. When stands did not contain fire scars but had evidence of 2 or more fire initiated seral age classes, age class chronologies were constructed by estimating the years of the successive fires (Barrett and Arno 1988, Barrett et al. 1991, Barrett and Arno 1991, Barrett 1993a). First, the year of the most recent fire was estimated based on pith samples from the stand's youngest seral class. Likewise, pith samples from any older seral trees, or fire killed snags, were used to estimate the years of previous fires years on the site. These age class chronologies were used to estimate fire

frequency as follows. First, MFI was calculated for all sites with evidence of 3 or more fires (i.e., at least 2 complete fire intervals). However, because many lodgepole pine stands can, at best, produce evidence of only one fire interval (i.e., 2 successive fires), the alternative was to calculate a multiple-site average fire interval (MAFI)(Barrett and Arno 1988, Barrett et al. 1991, Barrett and Arno 1991, Barrett 1993a). MAFI is computed by totalling the single fire intervals that were derived from sample stands of similar habitat type, then dividing the total number of years by the number of fire intervals.

Age Class Mapping. A final version of the forest age class map was compiled using 3 data sources: 1) the samples from seral age classes and tree fire scars, 2) the aerial photographs, and 3) fire atlas records listing the years of post-1900 fires (data on file, GNP Archives Div. and GNP Resource Mgt. Div.). The sample locations and stand ages were labelled on the 7.5 minute topographic maps, then the preliminary stand margins that had been drawn prior to field sampling were rechecked and edited where appropriate. When possible, unsampled polygons were labelled by extrapolating ages from nearby sample stands with similar crown appearance. When extrapolation was not possible, for example, for very remote areas, unsampled polygons were labelled with approximate stand age labels, such as "pre-1800", by comparing canopy traits with those of the nearest sample stands. After the map editing, acetate overlays were prepared at the 7.5 minute scale, enabling future digitization for the park's Geographic Information System (data to be stored on file, GNP Research Div.).

It is important to note here that the fire size estimates that are discussed in this report are only rough approximations that were produced prior to GIS digitizing and analysis, and are included only for broad comparative purposes. The method was to utilize a clear acetate template, equal to 260 ha. at the 7.5

minute scale, to make ocular estimates of polygon sizes and then total these estimates for each post-fire age class in the chronology. While useful for this report, the estimates undoubtedly will differ somewhat from those ultimately produced by the GIS. For example, size estimates for 2 large post-1900 fires were based on mapped polygons as well as fire atlas maps. These maps typically portray only approximate fire perimeters, but also occasionally depict a substantial amount of burning in non-forest ecosystems, such as alpine grasslands. Therefore, a few estimates below might vary sustantially from any computer generated statistics. (Also note that GIS statistics often yield rough approximations because fire history maps are based on seral forest alone, some of which represents only scant remnants of past burns).

RESULTS AND DISCUSSION

Landscape Fire Patterns. Sampling at 54 sites in and adjacent to the study area (fig. 1) produced 248 age class- and fire scar increment cores, mostly from lodgepole pine and whitebark pine. Because trees with old fire scars were scarce, only 5 trees were scar bored, including one large diameter (>115 cm. dbh) Douglas-fir with 3 scars outside the study area, near the east end of Lower Two Medicine Lake (discussed later in this report; note that there are few aspen/Douglas-fir stands in southeastern GNP but this stand was sampled to estimate surface fire frequency on morainal foothills near the plains: old Douglas-firs in these areas frequently have 5 or 6 basal fire scars each). By comparison, when fire scarred pines were found in GNP, they usually had single basal fire scars that had been caused by relatively recent, well documented fires. Lack of old fire scars in stands occupying moist mountain terrain frequently attests to a general pattern of severe stand replacing fires (Romme 1982, Barrett et al. 1991, Barrett 1993a). However, one ~610 year old solitary

whitebark pine on a krummholz scree slope (Scenic Point trail) had 3 old fire scars (discussed later in this report). Such trees occasionally reflect the margins of stand replacing fires, for example, in moist bottoms and along ridgelines (Romme 1982), rather than areas where substantial underburning had occurred in lodgepole pine stands (Barrett et al. 1991).

The master fire chronology extends back 277 years, to ca. 1715 (table 1, fig. 2), and is composed primarily of stand replacing fires that initiated the seral age class mosaic (refer to age class maps included with this report). The increment core- and fire scar data suggested 16 fires between 1715 and 1992, thus producing an area MFI of 19 years--that is, stand replacing fires of varying size occurred somewhere in the study area on an average of every 2 decades. In addition to these fires, a number of ignitions also have been suppressed in their incipient stages during this century (discussed later in this report).

The last fire of any significance in the study area occurred near Lubec Lake in 1953, a human-caused fire that was suppressed at less than 8 ha. Conversely, the last major fire activity occurred in the early 1900s, similar to results for GNP's west side (Barrett et al. 1991). In 1919, which was a severe fire year in the Northern Rockies (Wellner 1970), a large fire of unknown cause apparently entered the study area from the Blackfeet Indian Reservation. GNP has no fire report for the 1919 fire, however, the burn pattern shown on an old atlas map suggests that this fire may have originated outside the park. This fire burned ~1700 ha. in a virtually total stand replacement pattern on both sides of Lower Two Medicine Lake, but most burning occurred north of the lake on the south side of Two Medicine Ridge, and throughout most of the adjacent Dry Fork drainage. In 1918, an approximately 65 ha. fire of unknown cause burned most of the upper Fortyone Mile Creek drainage, and the atlas map suggested that this fire also had swept up GNP's

mountain front from the east. Both of these fires apparently had burned up to alpine rocklands before expiring.

Extensive stand replacement also occurred in the study area during the regionally severe 1910 fire year (Wellner 1970). Fires in 1910 had burned large areas on GNP's west side (Barrett et al. 1991) and one such burn, caused by humans near Essex, successfully crossed the Continental Divide near Firebrand Pass. The age class map suggests that this fire had spread over the Divide in 2 directions. First, one arm of the fire burned northeast, down Railroad Creek, in a virtually total stand replacement pattern, then evidently reversed direction and burned in a more patchy backing pattern of stand replacement toward Marias Pass. The age class map suggests that ~2600 ha. of krummholz, lower subalpine forest, and aspen stands were replaced in the general area between Midvale Creek and Summit Creek. The 1910 fire also had spread northwest over the top of the Continental Divide. Embers apparently blowing from the severely burned Jackstraw Lake basin on GNP's west side (upper Ole Creek drainage) ignited fires that replaced ~245 ha. of stands in upper Paradise Creek, near Buttercup Park. In total, post-1910 regenerated stands account for the largest proportion of the study area's age class mosaic, an estimated 20% of the seral forest.

In summary of this century's recorded fire history, several spreading fires before the era of efficient fire suppression (ca. 1940; Wellner 1970) had developed into major stand replacing burns. With the exception of the 1910 fire, park fire reports do not indicate fire causes or points of origin before about 1920. However, old fire atlas maps suggested that the 3 important fires had entered the study area from other locations, east and west, and that these fires had burned within all major vegetation types. Today, primarily in the middle and southern portions of the study area, an estimated 25% of the seral age class mosaic is occupied by mid-age stands that regenerated after 3 fires

between 1910 and 1919--and most of this regeneration is attributable to just one fire (1910). Similarly, Barrett et al. (1991) found that nearly 40% of the seral forest on GNP's west side had regenerated after a few large fires between 1910 and 1929, and some were caused by humans (O'Brien 1969, Key 1984).

Large fires clearly predominate the master fire chronology (table 1, fig. 2). As many as 9 of the 16 fires (56%) between 1715 and 1992 apparently exceeded 400 ha.; moreover, as many as 63% of the fires exceeded 200 ha. The 1910 burn is the largest fire in the chronology, but this might simply be a reflection of diminishing age class evidence over time. Because some drainages experienced multiple fires within the time span of the data, today's oldest age classes undoubtedly represent vignettes of the actual fire sizes (e.g., see age class map for upper Two Medicine and North Fork Cut Bank Creek drainages). The pre-1900 data are less precise than the written records, but age class sampling verified that a pattern of mid- to large size fires also occurred in the presettlement era. For example, 7 of the 9 largest fires in the chronology occurred before 1900, and initiated most of today's seral age class mosaic: ca. 1885, 1875, 1855, 1842, 1778, 1761, and 1715 (table 1, fig. 2). Overall, the data suggest that an average of 1 out of every 2 fires in the study area over the last 3 centuries became major events, and such fires recurred on an average of every 35 years. Both in terms of proportion and frequency, the master fire chronology for southeastern GNP thus suggests that large scale disturbance by fire may have been even more prevalent than on GNP's west side (Barrett et al. 1991). From a landscape perspective, these fire history data support the following interpretation: while relatively few ignitions in GNP's subalpine and alpine ecosystems have potential to spread (O'Brien 1969, Key 1984), a comparatively large percentage of forest fires can be expected to develop into significant ecological events. Clearly the largest fires occur when ignition, drought, and severe fire weather coincide (Johnson et al 1990).

(Ignition patterns and fire suppression's potential role in influencing east-side fire history will be discussed later in this report).

Fire intervals in the master chronology have been relatively evenly distributed over the last 277 years (fig. 2), rather than being closely grouped then followed by relatively long fire-free intervals. However, only a few tens of hectares have burned since 1919. Other studies in lodgepole pine (Barrett et al. 1991, Barrett and Arno 1991, Barrett 1993a, Barrett 1993b) have found highly skewed distributions, perhaps suggestive of such events as climatic shifts or mountain pine beetle infestations. Double- and triple burns also might be in evidence when fire intervals are clustered. Specifically, severe reburns sometimes occur in heavy post-fire fuels and dense post-fire regeneration within several decades of a previous stand replacing fire (Ayres 1900 and 1901, Wellner 1970, Brown 1975, Lotan et al. 1985). The mix of age classes in several areas today suggests that 2 or more fires may have occurred within a relatively short time span, and the fires might have reburned some sites (e.g., see juxtaposition of 1885 and 1910 age classes between Railroad- and Summit Creeks; also see 1778 and 1842 classes in North Fork Cut Bank Creek drainage). In fact, the area's southern mountain travel corridor, Theodore Roosevelt Pass, evidently has an unusual history of reburns, some caused by humans (Ayres 1900). Ayres' (1900) early forest survey often mentions severely burned terrain, largely between Marias Pass and the mountain front south of Midvale Creek, and in adjacent areas of the South Fork Two Medicine River drainage. Ayres (1900) felt that fires often originated from railroad construction activities, and his report contains 5 photographs of recently heavily burned terrain in and around the Railroad Creek drainage, which was nearly totally occupied by various early stages of vegetative succession. (Ayres [1900] speculated that this area had burned in the 1860s and in 1889, whereas the 1992 age class sampling suggested fires in 1867 and 1885). The

following passages describe the aftermath of these fires in and near the study area's southeastern corner:

> "... From the railroad to the lower mountain slopes [Railroad- and Midvale Creek area, ed.] the land has been repeatedly burned over. Vegetation on the burns is now varied between patches of grass, willow, and occasionally an area that is fairly restocked with lodgepole pine. The fires of about 8 years ago [ca. 1885, ed.] reached considerably into the woods left unburned by former fires. .... (Ayres 1900: 307)

> "... The land between the South Fork [S. Fk. Two Medicine River, ed.] and Elk Creek [i.e., Railroad Cr., ed.] has been most subject to fires, and is now reduced to occasional patches of dense young stock among dead and fallen trees; large areas have only scattered young trees about 10 feet high and some brush along streams and ravines, while three-forths of the surface is grassy. South of the South Fork and about its headwaters, under the dead standing trunks killed by railroad fires a dense young stock, some about 7 years old, is common. ... (Ayres 1900: 309)

Remarkably, Ayres' (1900) accounts were written only a decade before a large portion of the area reburned in 1910. This history of relatively recent severe fires during a known drought era (ca. 1850-1935; Carrara and McGimsey 1981), likely also can be attributed to a pattern of heavy use by humans (frequent ignitions) and terrain that frequently is subjected to high winds, which can both dessicate fuels and rapidly drive fires out of control (human use patterns also will be discussed later in this report).

This evidently unusual history of large fires after short intervals near the southern mountain front undoubtedly helped maintain site dominance by seral aspen, gramminoids, or shrubs. For example, most of today's extensive aspen stands occupy the lower Railroad- and Summit Creek drainages, an area that burned at least 3 times in the 43 years between 1867 and 1910. This area has not experienced a significant fire in 82 years, and many of the overmature aspen stands are now decadent (Habeck 1970). Conversely, primarily old age classes occupy moist canyons in the mountain interior (e.g., upper Two Medicine- and North Fork Cut Bank Creeks), suggesting that major burning sometimes recurs in the glacial canyons after relatively long intervals (e.g.,

>150 yr.). Today a substantial amount of stand decadence, for example, crown-kill, is present in some older age classes. Habeck (1970) reported that red belt had produced widespread mortality on GNP's east side, and white pine blister rust (Chronartium ribicola) also is contributing to dead fuel loads in stands occupied by infested whitebark pine. Presumably these factors help set the stage for the recurrence of stand replacing fire in coming decades.

In terms of large fires, the chronology suggests a possible increase in activity after about 1840, closely coinciding with the end of the Little Ice Age (Carrara and McGimsey 1981)(fig. 2) and similar to results from the park's west-side studies (Barrett et al. 1991). However, the east-side fire chronology is based largely on patterns of seral age classes, as opposed to sequences of tree fire scars and seral classes. Therefore, it is difficult to detect whether there actually was an increase in large-fire activity, since the data might merely reflect diminishing evidence over time--a common finding in fire history investigations.

Because of large fires, the study area's mosaic of seral age classes displays a relatively uncomplex to only moderately complex landscape pattern. The mosaic is composed primarily of 1-age (i.e., seral component) stands of moderate- to relatively large size, for example, 20-200 ha. But compared to mosaics along portions of the mountain front, especially in the southern area, the mix of age classes in relatively narrow glacial canyons is somewhat more intricate (the canyons often range from as little as .3 to 2 km. in width). At least during the period covered by the master fire chronology, fire behavior occasionally was more complex in the study area's interior than along the front. Complex fire behavior might be expected because of the wide variation in fuel types, amounts, and moisture levels that occur on different sites. Fire behavior also would be strongly influenced by erratic mountain winds (Finklin 1986) and the highly variable terrain, which ranges

from gentle to precipitous over very short distances in the U-shaped canyons. In comparison, the Rocky Mountain front has more uniform terrain, with slopes that are relatively broad (i.e., less highly dissected) and more uniformly exposed to east winds. (Finklin [1986] also indicates prevailing west winds during the height of the fire season, in July and August). A result of large stand replacing runs, age class mosaics along the front often are uncomplex, particularly between Lower Two Medicine Lake and Railroad Creek (fig. 1). The Rocky Mountain front also contains a larger proportion of non-forest vegetation, apparently seral, and these gramminoid communities may have been maintained in part because of frequent fires sweeping off the plains (Ayres 1900, Lynch 1955, Habeck 1970).

In summary of fire patterns at the landscape level of analysis, most seral stands became initiated after 9 moderate- to large size fires between 1715 and 1992. While age classes are relatively evenly distributed within the time span of the data, large-fire activity may have increased between about 1840 and 1920, closely coinciding with a known warm-dry period following the end of the Little Ice Age (Carrara and McGimsey 1981). About 25% of the seral forest mosaic, primarily along the mountain front and including extensive deciduous stands, is composed of 70-80 year old stands that regenerated after 2 large fires, in 1910 and 1919. Conversely, today's oldest seral conifers occupy glacial canyons in the mountain interior. These stands range from about 200-280 years old and occupy an estimated 20% of the seral forest mosaic. (The study area's oldest individual trees occur in the upper subalpine zone, primarily non-seral forest, where sampled ages of dominant whitebark pines typically ranged between 300 and 600 years, and where many such trees recently have succumbed to disease).

Stand Fire Patterns. Fire history also was interpreted for the stand level of

analysis, since most management and research activities occur at that scale (e.g. prescribed fire planning). Data from 16 sites were analyzed for the lower subalpine zone, and the stands were grouped by terrain type (tables 2-3). Additionally, data from 5 sites were used to interpret fire patterns for the upper subalpine zone (table 4). Because of recurrent severe fires and subsequent decomposition, most sites today lack evidence of multiple fires. Reflecting this fact, MFIs could be calculated for only 3 of the study's 54 sample sites. Alternatively, MAFI provided useful information about stand fire patterns (tables 2-3), as it did during previous park studies in the Lake McDonald- and Middle Fork valleys (Barrett et al. 1991).

Lower subalpine zone. Fire frequencies were estimated for stands occupying different terrain, to detect any possible differences in historic fire pattern. Specifically, data were grouped according to moist canyon sites (table 3) versus sites along the mountain front, which often has drier habitat types and gentler terrain (table 2). Large stand replacing fires clearly have been the predominant severity type throughout the study area, but the data suggested somewhat different fire patterns for the 2 terrain types. For example, when compared to data from the canyon stands, substantially shorter fire intervals were suggested for lodgepole pine stands that occupy morainal foothills along the mountain front. Data were obtained from 9 such stands, 5 of which were 2-age stands near the extensive aspen groves. Two-age stands indicate that the site's most recent fire had produced only partial stand replacement (Barrett and Arno 1988, Barrett et al. 1991), and the data suggested that intervals between these secondary fires ranged from 26 years to 64 years long. However, the 2-age stands usually are small remnant islands (20-40 ha.) within relatively large past fire perimeters that today contain 1-age stands (e.g., 1910 fire). Therefore, while mixed severity fires are not highly representative of fire patterns in the coniferous forest, these data

were useful for estimating fire frequency near the aspen ecotone (as discussed below, aspen stands contain virtually no long-term fire evidence). MAFI for mixed severity fires was 42 years. This statistic is closely similar to the 3 stand MFI's in table 2 (i.e., 43, 45, and 47 years), one of which was estimated for a lower elevation aspen/Douglas-fir stand adjacent to the study area. In terms of stand replacing fires in the foothills stands, intervals determined for 6 of the 9 sites ranged from 64 to 167 years, and MAFI was 96 years--a relatively short average interval for lodgepole pine stand replacement (Sneck 1977, Hawkes 1979, Tande 1979, Romme 1982, Romme and Despain 1989, Barrett et al. 1991, Barrett and Arno 1991, Barrett 1993a, Barrett 1993b).

Data were obtained from 7 relatively moist canyon sites in the mountain interior (table 3). There was little evidence of mixed severity fires in these stands, since most stands contained just one seral age class. Moreover, because most canyon stands are old and have scant evidence of previous site age classes with which to develop age class chronologies, it was necessary to incorporate the current ages of 6 old stands in estimating mean fire frequency (as per Barrett 1993b). These currently incomplete fire intervals enabled a more comprehensive interpretation than otherwise would have been possible, since only one stand produced evidence of an actual fire interval. Only the oldest of the canyons' overmature sample stands were used in this assessment, but this method necessarily yields a conservative MAFI because the eventual fire intervals will be somewhat longer than the current ages of the old stands in table 3. The estimated intervals between stand replacing fires ranged from 114 to 277+ years ("+"=incomplete interval), and MAFI was 187 years--if conservative, still nearly twice the length estimated for sample stands along the Rocky Mountain front (table 2). Moreover, MAFI for the canyon stands probably is closely representative of actual mean frequency, since a 150-200 year average interval also has been estimated for similar habitat types on

GNP's west side (Barrett et al. 1991), and elsewhere in the Northern Rockies (Arno 1980, Barrett 1993a)(i.e., data based on complete fire intervals only).

As mentioned above, some of the data from dry-site lodgepole pine stands (table 2) were useful for estimating the frequency of stand replacing fires near the extensive aspen stands. In the West, stand replacing fires typically have recycled aspen stands by stimulating root sprouts from clones (Jones and DeByle 1985), but on unproductive sites aspen dominance rarely lasts more than 100 years before being replaced by climax conifers (Habeck 1970, Houston 1973, Loope and Gruell 1973, Jones and DeByle 1985). Lynch (1955) states that aspen groves are climax communities at lower elevations on the Blackfeet Indian Reservation, but most aspen stands in the study area are seral and occupy the ecotone between the coniferous- and woodland forest (Lynch 1955, Habeck 1970, Arno 1979, Jones and DeByle 1985). Clearly, most community types in this area have been recycled by severe stand replacing fires (Ayres 1900). Since aspen in the Northern Rockies is both a relatively short lived and highly fire sensitive species (Romme 1982), most aspen stands contain little evidence of pre-1900 fire history. Moreover, rapid decomposition of aspen snags has eliminated virtually all evidence of previous age classes on any given site.

Today's extensive grovelands are primarily in the southeastern portion of the study area, and most stands apparently regenerated after the large 1910 fire. (The transect sampling detected no older aspens in the study area). Eighteen increment cores were obtained from 2 sites that had burned in 1910, and the cores were taken from trees of all representative diameters to determine stand age structure. Results suggested that most trees were between 50 and 75 years old (mean: 62 yr), therefore, the stands appeared to be only broadly even age (Jones and DeByle 1985), similar to the age structures documented by Lynch (1955) at lower elevations. Jones and DeByle (1985) state that broadly even age stands might reflect effective fire suppression, because

most post-fire regenerated stands are strongly even age. (Broadly even-age stands result when gap openings occur at irregular intervals in a declining stand, giving rise to scattered root sprouts). However, the data from GNP sites also might contain significant ring-count errors. Aspen's diffuse-porous wood has a very indistinct demarcation between earlywood and latewood (Campbell 1981), and the annual rings were difficult to distinguish even after the cores were specially prepared (Mowrer and Shepperd 1987).

Jones and DeByle (1985) indicate that, while most aspen stands have comparatively low flammability, even light surface fires can kill most overstory trees and stimulate root sprouting. As mentioned above, the shorter fire intervals that were found for dry-site lodgepole pine stands adjacent to aspen groves (~25-100 yr) likely are representative of the range of stand replacement intervals that also recycled aspen. Supplementing these data from park sites, fire scars were bored on a large tripled-scarred Douglas-fir adjacent to aspen stands near the southern end of Lower Two Medicine Lake. This tree had an estimated MFI of 47 years (site 15, table 2), apparently representative of the pre-1900 frequency of surface fires (Loope and Gruell 1973, Houston 1973, Barrett 1993a) on lower elevation dry sites east of GNP. Additionally, the master fire chronology and Ayres' (1900) written accounts suggest that some sites in the Railroad Creek area may have burned as many as 3 times in the 43 years between 1867 and 1910, thus suggesting an MFI of 22 years. If this interpretation is correct, such short interval fires might have discouraged aspen regeneration on some sites and instead maintained site dominance by shrub- or gramminoid species--Jones and DeByle (1985) state that frequent fires can reduce site quality for aspen. (Ayres [1900] verified that all of these community types occupied the area in 1898). Conversely, Jones and DeByle (1985) state that seral aspen stands can persist within coniferous forest areas even when fires recurr at relatively infrequent intervals. Early-

day and modern records (Ayres 1900; fire atlas on file, GNP Archives Div.; fire reports on file, GNP Resources Mgt. Div.) suggest that most fires in this area occurred during infrequent periods of severe fire weather. Given the vagaries of this area's fire history (i.e., short- vs. longer interval fires), and the fact that aspen occupy a major ecotone in GNP, the relative coverage and vigor of seral aspen groves likely has fluctuated over time. Today, 8 decades after the area's last important fire, many aspen stands are overmature and declining, perhaps in part because of efficient fire suppression (Habeck 1970; and discussed below).

In summary of stand fire patterns in the lower subalpine zone, age class sampling appeared to confirm that relatively dry sites near the Rocky Mountain front (cf. Ayres 1900) have burned substantially more often than moist canyon sites. At least between the mid-1800s and early 1900s, severe reburns recurred along the front, generally within about 2-4 decades of one another, and these fires recycled all of the area's seral communities, including the extensive aspen groves. Overall, however, data from sites throughout the study area suggest a predominance of stand replacing fires after moderately long- to long intervals. On GNP's east side, absent an occasional reburn, apparently from 1 to 3 centuries can pass before drought, ignition, and fuels coincide to produce a stand replacing fire on any given site in the lower subalpine zone.

Upper subalpine zone. Sampling detected only limited evidence of fire history in the upper subalpine zone. Large fires that spread from lower elevation forests often are delimited by the area's extensive rocklands, and the spread and intensity of fires that originate in the upper subalpine zone is likewise hampered by the greatly diminished and discontinous fuels (Arno and Hoff 1989). Stand data from 5 sites (table 4) verified an overall pattern of highly localized fires. First, it usually was not possible to document stand replacing fires because most tree regeneration was highly uneven-aged and

comprised largely of climax species. Second, while old whitebark pines commonly had 1 or more basal fire scars, most of the relatively numerous snags of this species appear to have died from causes other than fire; the 1968-series aerial photographs indicated that many old growth whitebark pines have succumbed, apparently to blister rust, within just the last 2 decades. The maximum ages of dominant whitebark pines, including snags, ranged from 194 to 609 years (mean based on 5 oldest trees was 417 yr).

Two other observations readily attested to the patchiness of most fires. First, multiple scarred whitebark pines often are encountered as solitary individuals growing on scree slopes. These trees essentially are lightning rods, and have been scarred by resultant tiny ground fires around the bases of the trees; in addition to having been scarred by small fires over the centuries, some of these trees ultimately may have died as a result of having been struck by lightning. Second, old whitebark pines with multiple fire scars frequently are adjacent to small krummholz stands that are dominated by fire sensitive subalpine firs of widely ranging age. This regeneration pattern suggests that most fires had missed these nearby trees.

To estimate site fire frequency, fire scar- and pith samples were obtained from a solitary, triple-scarred whitebark pine snag along the upper Scenic Point trail. This snag lacked dead needles and some small branchwood, suggesting that the tree had been dead for some time, yet aerial photographs indicated that many area whitebark pines were still alive in 1968. Therefore, the snag's cambium year was estimated to be ca.1970, and the fire scar analysis would attempt to provide a better estimate after intervals had been estimated (i.e., scars occasionally reveal fire intervals similar in length to those estimated for nearby sites). This large diameter (~114 cm.) tree had lived for about 610 years, and evidently had been killed by blister rust. Numerous fire scar cores taken from this tree suggested fire intervals of ~36 and 136 years,

and yielded an estimated MFI of 86 years (table 3). Interestingly, none of the 3 fire year estimates even closely approximated the well sampled years of large fires that occurred in the continous forest below this high elevation whitebark pine. Since the sample sites were separated by as little as .4 km., either substantial sampling error had occurred for this snag, or, the fire scars had in fact been produced by highly localized fires. Both possibilities seem equally feasible, therefore, no conclusions will be drawn here.

As enumerated above, highly complex terrain and fuel types make it difficult to develop meaningful interpretations about fire frequency and other patternization for timberline stands. Because fires often involve only 1 or 2 trees in a given tree island (Arno and Hoff 1989), the concept of stand replacement frequently does not apply in the upper subalpine zone (Fischer and Clayton 1983). Still, numerous historical accounts and modern observations show that high elevation fires can range widely in severity, from light surface fires in herbaceous fuels to occasional wind-driven fires that skip across the landscape, torching individual trees and tree islands.

In summary of stand fire patterns in the study area's major forest cover type, lodgepole pine, the data suggest that GNP's east side stands have experienced nearly the full range of fire patterns previously documented in the Northern Rockies. However, relatively long interval, stand replacing fires have been the most prominent disturbance agents influencing community composition and structure. Fire patterns on relatively moist canyon sites were similar to those on comparable terrain elsewhere in the Northern Rockies. For example, non-lethal and mixed severity underburns were uncommon and intervals between stand replacing fires averaged 150 to 200 years in other areas in and adjacent to GNP (Sneck 1977, Barrett et al. 1991), in Kananaskis Provincial Park (Hawkes 1979), and in the Absaroka Mountains in Yellowstone National Park

(Barrett 1993a). Conversely, near the aspen forest ecotone (Rocky Mountain front), there was evidence of reburns and occasional mixed severity fires recurring at less than 50 year intervals, a pattern roughly similar to that found on relatively dry, gently sloped terrain in GNP's North Fork Flathead River valley (Barrett et al. 1991), in the Bob Marshall Wilderness (Gabriel 1976), in Jasper National Park (Tande 1979), on the Bitterroot National Forest (Arno 1976), and in the Selway-Bitterroot Wilderness (Barrett and Arno 1991). To date, no evidence has been found of very long fire intervals in lodgepole pine stands on GNP's east side, as would be apparent if forest mosaics contained substantial amounts of very old stands. For example, on Yellowstone National Park's subalpine plateau, highly unproductive habitat types (e.g., lodgepole pine h.t. series) often are occupied by very old and depauperate stands. Fuel accretion is extremely slow on such sites and stand replacing fires have been delayed for 400 years or more (Romme 1982, Romme and Despain 1989).

In addition to the fires that had originated in the mountains, some fires on the east side entered the mountains from adjacent prairie ecosystems (Ayres 1900). Undoubtedly for millenia, large wind-driven fires often have been ignited by lightning and humans on the Northern Great Plains. Ayres (1900) provided one of the first written accounts of area fire origins:

> "...For many years fires have crept into this valley [upper S. Fork Two Medicine River, ed.] from the prairie eastward, and others have been started probably by hunting parties, and have been swept eastward by prevailing winds. ..." (Ayres 1900: 309).

Before the late 1800s, in addition to lightning fires and unintentionally caused fires, it is now well known that Native Americans frequently burned grasslands to improve forage for game, to drive game during hunting, and for other purposes (Ayres 1900 and 1901, Barrett and Arno 1982, Gruell 1985). Subsequently, Euro-Americans have caused many fires, virtually all of which

have been accidently or carelessly ignited (Ayres 1900, 1901; fire reports on file, GNP Resources Mgt. Div.). For example, beyond the passages already cited above, Ayres' (1900) report contains numerous accounts of fires that had resulted from railroad and other settlement activities in the area's southern mountain travel corridor.

Fire Suppression History. Old fire atlas maps and fire reports (on file, GNP Archives Div. and GNP Resources Mgt. Div.) were examined to interpret whether post-1910 fire suppression has influenced area fire history. Occurrence data dating back to the park's inception in 1910 were examined, but the records are not considered comprehensive until at least 1915 (O'Brien 1969). Furthermore, the old fire maps and computerized fire reports had to be examined in tandem because the maps sometimes portrayed fires that were not listed in the computer files, and vice versa. These records indicated that ignitions from all sources have been relatively infrequent when compared to GNP's west side (O'Brien 1969, Key 1984), and that humans have been the primary cause of fires in the study area. There were only 47 recorded fires between 1910 and 1992 in the 33,000 ha. study area (i.e., total of forested and non-forested land)--a mean of only one ignition every 2 years. Reported ignitions were the most frequent during the 1920s, 1940s, and 1970s, specifically, 9 per decade, and were the least frequent during the 1960s and 1980s (only 2 per decade). Slightly over half (57%) of the ignitions occurred during the drought period between ca.1910 and 1940 (Carrara and McGimsey 1981), and 11 fires (23%) occurred during known severe fire seasons (1910, 1919, 1926, 1934, 1941, and 1984) (O'Brien 1969, Key 1984). Two of these 11 fires (18%) are listed as important fires in the study area master fire chronology, otherwise, most suppressed fires were tiny. For example, 89% of the fires were suppressed at less than .1 ha., and 4% were suppressed before burning 4 ha. However, as previously mentioned, just 3 fires

(1910, 1918, 1919) produced a large portion (~25%) of today's seral age class mosaic, and most of that burned area is attributable to just one fire, in 1910.

In terms of fire causes, the fire reports indicate that a large majority of reported fires have been caused by humans, specifically, 33 of the 47 fires (70%). In fact, humans apparently caused the large 1910 fire, near Essex on the west side of Continental Divide. Five of the human caused ignitions also were listed as "railroad fires" in the southern mountain travel corridor. Remarkably, only 12 lightning ignitions have been detected in this comparatively large analysis area over the last 82 years (26% of total; 2 fires were of unknown origin)--a mean of only 1 reported lightning ignition every 7 years. This finding supports previous interpretations that lightning ignitions have been infrequent on GNP's east side, at least during this century (O'Brien 1969, Key 1984). O'Brien (1969) reports that GNP east of the Continental Divide had only 10% of all recorded lightning ignitions in the park between 1910 and 1968. By way of comparison, Howe Ridge, which is the large lateral moraine bordering Lake McDonald on GNP's west side, has perhaps the highest ignition frequency of any area in the park (Key 1984). Whereas the east side study area has had only 12 recorded ignitions between 1910 and 1992, the far smaller land area around Howe Ridge occasionally may have experienced more than that number during a single storm (O'Brien 1969, Key 1984). Since early detection of small backcountry fires was inefficient before the mid-1900s (Wellner 1970), the study area likely has experienced a somewhat higher frequency of lightning ignitions than reported, but most such fires probably expired in alpine terrain without being detected. The records verified that most reported fires occurred near well used campsites, in the southern mountain travel corridor, and along the Rocky Mountain front near East Glacier.

These data suggest both the continuing importance of humans as an area ignition source and that, fire suppression notwithstanding, most ignitions have

failed to spread because they occurred during non-critical fire weather. While ignitions from all sources have been infrequent, at least 4 fires were suppressed in the southern mountain travel corridor during known drought years. (It already has been well illustrated that this area, which is occupied by extensive aspen and other seral communities, has a known history of reburns [Ayres 1900] before the advent of efficient fire suppression). Based on fire reports alone, however, it is unclear whether fire suppression has measurably influenced ecosystem functioning to date.

Fire cycles (Romme 1980) were estimated in order to further address whether modern fire suppression has been an important event in this area's fire history. The concept of fire cycle can be useful for comparative purposes, and is defined as the amount of time necessary to burn an area equivalent to the entire study area (13,000 ha.). Fire cycle estimates were produced for each of the roughly 3 centuries in the master fire chronology. First, an estimated 21% of the study area burned between 1715 and 1799, and the master fire chronology contains 2 or 3 major fires (fig. 2). At that rate 25% of the study area would have burned per century, thus fire cycle for the 1700s equals 400 years. This undoubtedly represents a very conservative estimate of fire cycle during the 16th century, because subsequent fires have progressively eliminated evidence of 1700s-regenerated age classes. Second, an estimated 28% of the area burned between 1800 and 1899, and the chronology contains as many as 4 major fires. Fire cycle therefore equals 354 years for the 1800s, again, a conservative estimate because fires after 1900 no doubt destroyed some evidence. Finally, an estimated 26% of the area burned between 1900 and 1992, and the chronology contains 2 prominent fires (1910, 1919). Therefore, fire cycle for the 1900s also equals 354 years. (Note again that these fire cycle estimates are based on a pre-GIS analysis of the data).

Another factor contributing to conservative estimates of pre-1900 fire

cycles is that the analysis included only 1-age polygons that had been labelled with specific fire years, as opposed to also including approximate stand-age groups (e.g., pre-1850) and 2-age stands. Such polygons do not represent a large proportion of the total age class mosaic, but tend to be pre-1900 regenerated stands. Therefore, when considering all of the variables described above, actual fire cycles for the 1700s and 1800s may have been substantially shorter than described above. In contrast, when the fire cycle estimates were based on the post large-fire period between 1920 to 1992, fire cycle was 7200 years. Other 7-decade long periods in the master fire chronology also may have experienced relatively few fires, but fire suppression undoubtedly plays some role in this near total lack of spreading fires over the last 7 decades. Therefore, while imprecise, the fire cycle analysis clearly suggests that a decrease in stand replacing fires has occurred during this century.

Given all of the above variables, it remains inherently difficult to detect whether fire suppression has prevented any fires from becoming prominent events in the area's fire history. Intuitively, it is generally well accepted that most ignitions in the Northern Rockes have little potential to become spreading fires (Wellner 1970), and thus are comparatively easy to extinguish. Conversely, suppression usually is relatively ineffective when wildfires occur during critical fire weather (Romme and Despain 1989). Fire suppression might have precluded some stand replacing fires, but Johnson et al. (1990) state that, in moist forests typically subject to large stand replacing fires, macroclimate (i.e., drought coinciding with severe fire weather) is the primary limiting factor influencing fire history--not ignition sources or fire suppression. While this concept undoubtedly applies to most of GNP, it likely has only limited applicability to some areas along the Rocky Mountain front. Apparently for millenia near the primary mountain travel corridor, frequent ignitions by humans have coincided with a generally severe microclimate (wind),

occasionally producing severe fires after short fire intervals.

Fire suppression evidently is promoting mosaic homogenity by preventing some stand replacing fires (Romme and Despain 1989, Barrett et al. 1991, Barrett 1993a) in the study area's forests. However, in terms of succession at the stand level, a number of studies (Romme and Despain 1989, Johnson et al. 1990, Barrett et al. 1991, Barrett 1993a, Barrett 1993b) point out that there still has been insufficient time for unnatural succession to be noticeable, even if fire intervals have been artificially lengthened in relatively old stands (Romme and Despain 1989).

Aspen would be among the first forest types to be adversely affected by fire suppression, since this species is both short lived and fire dependent (Habeck 1970). Habeck (1970) reported that GNP's east side contains few aspen stands younger than 80 years, and that these seral stands were deteriorating at least in part because of area fire suppression. However, results currently suggest that suppression's influence on these ecosystems is somewhat ambiguous. GNP's seral aspen stands occupy an ecotone between woodland and coniferous forest, and existed under a fire regime that included both relatively short and relatively long interval severe fires, primarily severe burns during critical fire weather. Therefore, despite area fire suppression and the current decline of older stands, succession in some areas still might be occurring under a primarily natural fire regime. In drier aspen grovelands just east of the study area, presettlement fire intervals and burning patterns apparently were substantially different from those along the aspen-conifer ecotone. At lower elevations near the prairie, a fire regime of short- to moderately long interval surface fires occurred before the advent of long-term overgrazing by livestock and modern fire suppression (Lynch 1955, Loope and Gruell 1973, Gruell 1980). These relatively frequent light underburns occasionally may have spread to the aspen-conifer ecotone before expiring, but the study area

generally lacks multiple fire scarred conifers and multi-age stands (Barrett et al. 1991) that would attest to such an occurrence pattern.

Aspen management has received widespread attention in recent years (DeByle and Winkour 1985), including in such national parks as Yellowstone and Grand Teton. Results from several fire history studies in those areas (Loope and Gruell 1973, Houston 1973, Barrett 1993a) suggested that small groves of seral aspen adjacent to Douglas-fir stands burned after comparatively short intervals ranging from about 25 to 50 years long. Fire suppression and overgrazing by ungulates (Kay 1990) apparently has severely disrupted ecosystem functioning in many stands in these intermountain valleys. However, results from this GNP study near the extensive aspen groveland (Lynch 1955) along the northern Rocky Mountain front reveal a substantially more complex mix of area fire regimes than in the Greater Yellowstone ecosystem. Complex fire regimes result from various interactions between biotic and abiotic factors, for example, terrain, climate, and fuel types all can shift abruptly over very short distances. Human use patterns also have fluctuated widely over time. Additionally, at least near the area's southern mountain travel corridor, humans have virtually supplanted infrequent lightning storms as the primary source of ignitions, apparently for millenia.

Habeck (1970) indicated that a program of scheduled prescribed fires would be an appropriate management strategy for rejuevenating aspen stands. This might be challenging from a practical standpoint because most aspen stands in GNP have been recycled primarily by large fires during severe fire weather. While human ignited fires are highly appropriate from a historical context, political considerations likely would prevent GNP managers from purposely igniting severe fires in the boundary zones where most aspen occur. And, because the aspen-conifer ecotone often occupies relatively moist, highly variable terrain, light surface fires probably would not spread sufficiently

during non-drought periods (or in the absence of dessicating winds). Such underburning also might be made difficult by aspen's typically low flammability (Jones and DeByle 1985). In the boundary zone, however, successful application of prescribed fire might help rejuevenate some stands of overmature aspen and create living firebreaks (Jones and DeByle 1985) near adjacent private properties. Of course, these considerations are somewhat academic because large wildfires doubtless will continue to recycle area forests, in spite of aggressive fire suppression measures (Habeck 1970, Johnson et al. 1990).

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Table 1. Master fire chronology for southeastern GNP, ca.1715 to 1992.

Est. Fire Year[1]	Est. Percent of Mosaic[2]
1953	<1
1919	4
1918	<1
1910	20
1885	9
1875	11
1867	<1
1866	<1
1855	3
1842	3
1829	<1
1785	2
1778	8
1761	3
1752	<1
1715	7

[1] Estimated fire years based primarily on seral age class sampling.

[2] Estimated percent of forested area occupied by fire initiated seral age classes (pre-GIS analysis). Unlisted percentage of area is occupied by approximate stand age groups and non-seral forest.

Table 2. Fire occurrence data for 9 primarily lodgepole pine-dominated stands along the Rocky Mountain front.

Stand No.[3]	Habitat Type[4]	Aspect	Fire Intervals UB[5]	SR[6]	MFI[7]	Last Fire
15*	Psme/Syal	E	36,57	-	47	1955
16	Abla/Xete	S	26,44	64	45	1855
17	Abla/Xete	S	26	64	45	1829
34	Abla/Xete	SW	-	167	-	1919
25	Abla/Vagl	S	-	88	-	1866
27	Abla/Vagl	S	64	-	-	1842
7	Abla/Vagl	S	-	125	-	1910
22	Abla/Xete	SW	-	70	-	1855
10	Abla/Vasc	W	43	-	-	1910

MAFI (stand repl. fires): 96 yr
MAFI (mixed sever. fires): 42 yr

[3] "*" denotes sites adjacent to study area, thus some fire years are not reflected in study area master fire chronology.

[4] Acronyms follow Pfister et al. (1977).

[5] Mixed severity underburns.

[6] Stand replacing fires ("+" denotes incomplete interval as of 1992).

[7] Mean fire interval based on complete intervals only.

Table 3. Fire occurrence data for 7 lodgepole pine-dominated stands on moist sites, primarily in glacial canyons.

Stand No.	Habitat Type	Aspect	Fire Intervals UB	SR	MFI	Last Fire
20	Abla/Clun	NE	-	207+	-	1785
71	Abla/Xete	N	-	277+	-	1715
72	Abla/Clun	N	-	231+	-	1761
73	Abla/Xete	NE	-	117+	-	1875
39	Abla/Xete	NE	-	114	-	1875
33	Abla/Clun	F	-	214+	-	1778
30	Abla/Xete	F	-	150+	-	1842

MAFI (stand repl. fires): 187 yr[8]

[8] MAFI based on complete intervals and incomplete intervals in overmature stands.

Table 4. Stand- and fire occurrence data for 5 whitebark pine dominated sites in the upper subalpine zone.

Stand No.[9]	Habitat Type	Aspect	Fire Intervals UB	SR[10]	MFI
41	Abla/Pial/Vasc	SW	136, 36	609	86
82	Abla/Pial/Vasc	NE	-	513	-
1K	Abla/Pial/Vasc	E	-	464	-
37	Abla/Xete/Vasc	E	115	309+	-
38	Abla/Pial/Vasc	E	-	194+	-

[9] Stand 1K data obtained from C. Key (unpub.; on file, GNP Research Div.)

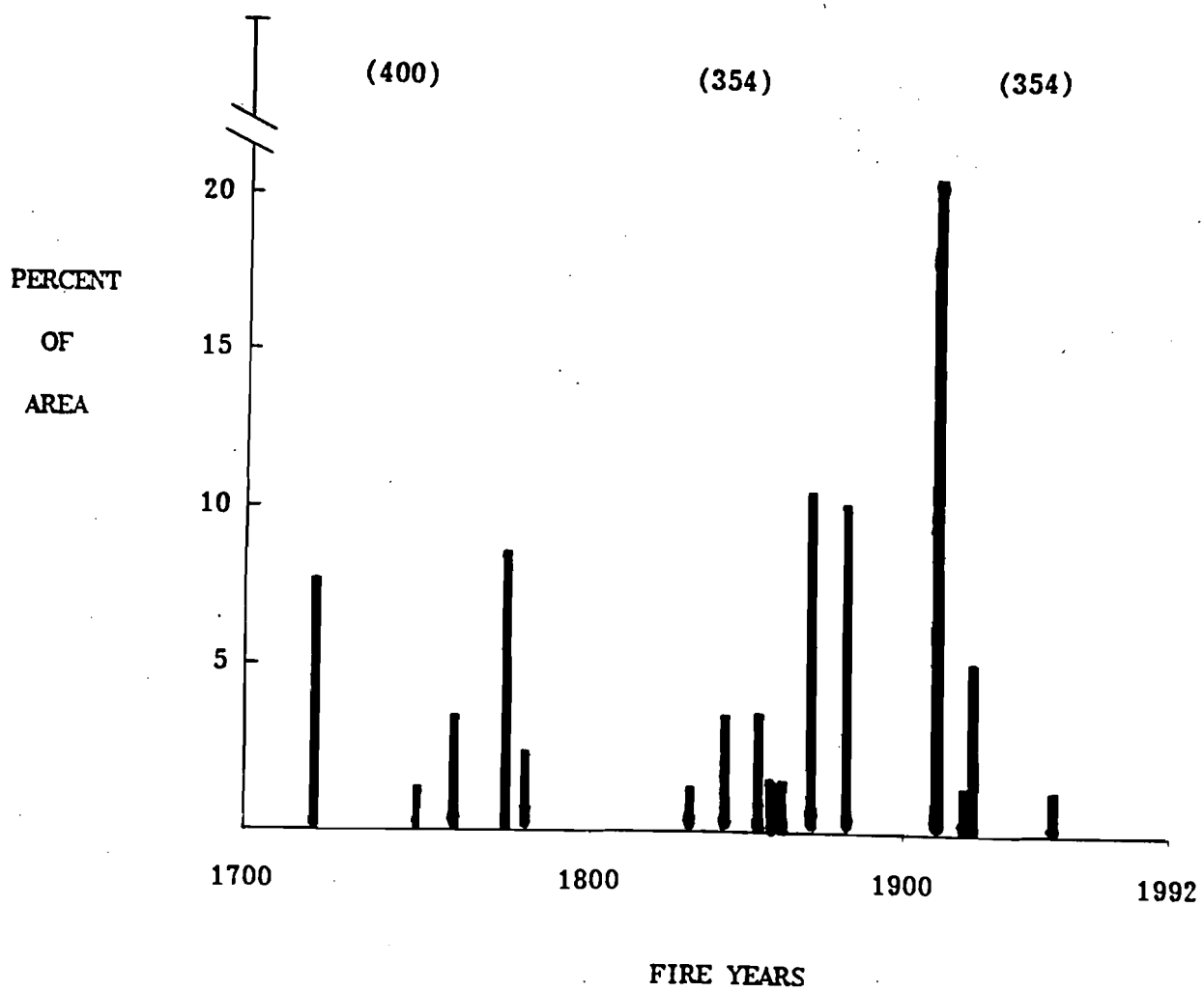
[10] "SR" indicates maximum tree age only; "+" denotes living trees.

LIST OF FIGURES

1. Study area map and sample site distribution.

2. Master fire chronology for southeastern GNP, ca.1715 to 1992: estimated percent of forested area occupied by fire initiated seral age classes (pre-GIS analysis; estimated fire cycles [yrs] listed in parentheses above each century).

FIGURE 2.


(400)
(354)
(354)
20
15
10
5
PERCENT
OF
AREA
1700
1800
1900
1992
FIRE YEARS

MAP KEY FOR FIRE HISTORY AGE CLASSES

Fire year-specific polygons:

e.g., "1910" = 1-age stand dominated by post-1910 initiated seral trees.

e.g., "1910/1875" = 2-age stand occupied by post-1910 and post-1875 initiated seral trees (stand dominants listed first).

Approximate stand age groups (polygon boundaries indistinct):

a = 1855-1918 period regeneration.

b = 1785-1855 period regeneration.

c = 1715-1761 period regeneration.

d = 1761-1875 period regeneration.

e = 1778-1842 period regeneration.

f = 1842-1866 period regeneration.

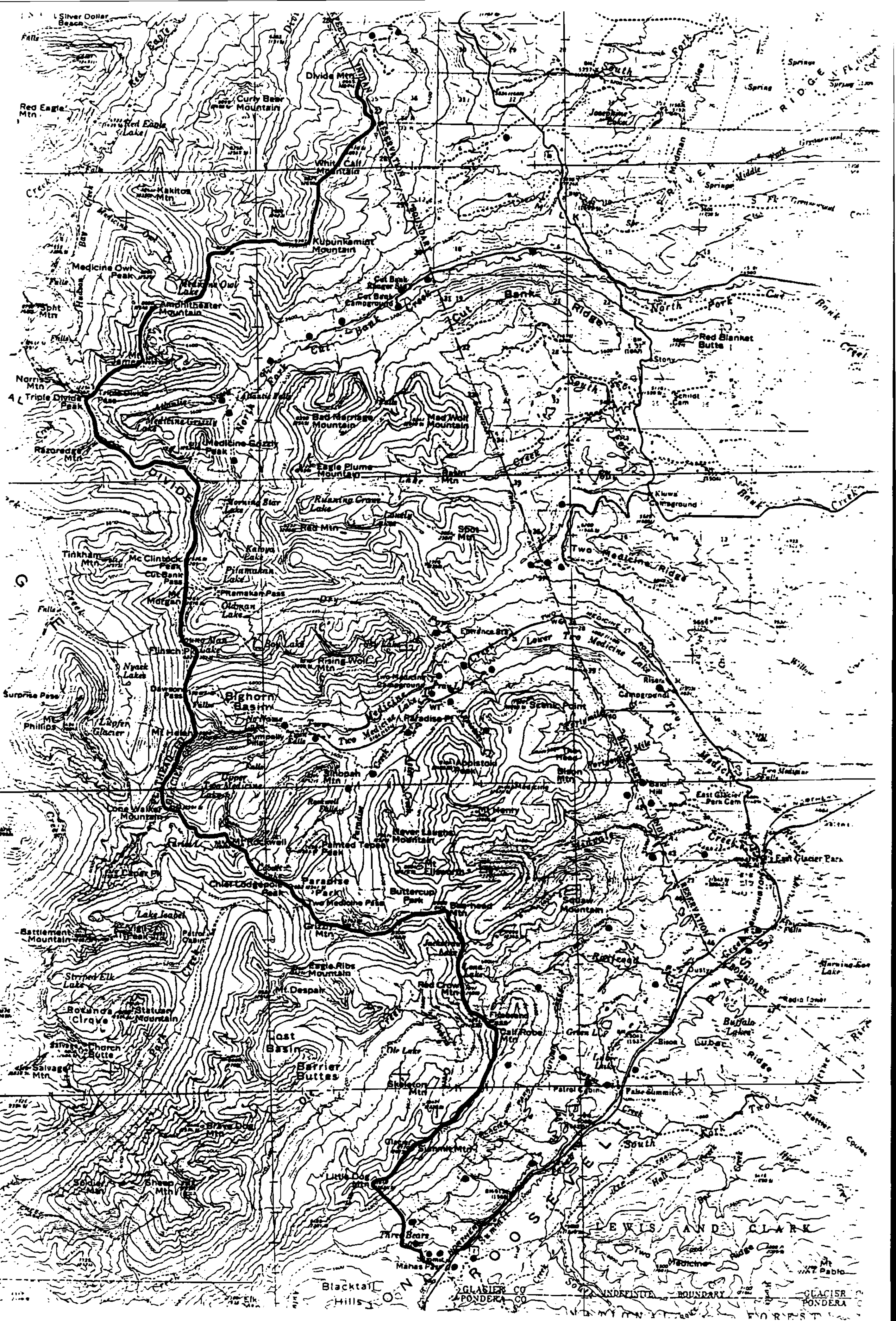
g = 1778-1866 period regeneration.

h = pre-1778 period regeneration.

i = post-1866 period regeneration.

N = unvegetated terrain or non-seral vegetation.

FIG. 1



Divide Mtn
Curly Bear Mountain
Red Eagle Mtn
Red Eagle Lake
White Calf Mountain
Kakitos Mtn
Kupunkamint Mountain
Medicine Owl Peak
Medicine Owl Lake
Amphitheater Mountain
Cut Bank Ranger Sta
Cut Bank Campground
Cut Bank Ridge
North Fork Cut Bank Creek
Red Blanket Butte
Norris Mtn
Triple Divide Peak
Triple Divide Pass
Medicine Grizzly Lake
Medicine Grizzly Peak
Bad Marriage Mountain
Mad Wolf Mountain
Razoredge Mtn
Eagle Plume Mountain
DIVIDE
Morning Star Lake
Running Crane Lake
Red Mtn
Lonely Lakes
Spot Mtn
Kiowa Campground
Tinkham Mtn
Mc Clintock Peak
Cut Bank Pass
Mt Morgan
Pitamakan Lake
Pitamakan Pass
Oldman Lake
Two Medicine Ridge
Entrance Sta
Lower Two Medicine Lake
Flinsch Pk
No Name Lake
Boy Lake
Rising Wolf Mtn
Nyack Lakes
Surprise Pass
Dawson Pass
Bighorn Basin
Two Medicine Campground
Two Medicine Lake
Paradise Pt
Scenic Point
Riser Campground
Mt Phillips
Lupfer Glacier
Mt Helen
Twin Falls
Sinopah Mtn
Appistoki Peak
Bison Mtn
Bald Hill
East Glacier Park Cam
Upper Two Medicine Lakes
Lone Walker Mountain
Mt Henry
Mt Rockwell
Painted Tepee Peak
Never Laughs Mountain
Mt Ellsworth
East Glacier Park
Chief Lodgepole Peak
Paradise Park
Two Medicine Pass
Buttercup Park
Bearhead Mtn
Squaw Mountain
Lake Isabel
Battlement Mountain
Vigil Peak
Patrol Cabin
Grizzly Mtn
Eagle Ribs Mountain
Mt. Despair
Red Crow Mtn
Striped Elk Lake
Statuary Mountain
Rocky Cirque
Firebrand Pass
Calf Robe Mtn
Buffalo Lake
Lubec
Church Butte
Lost Basin
Barrier Buttes
Ole Lake
Salvage Mtn
Skeleton Mtn
Patrol Cabin
False Summit
Brave Dog Mtn
Summit Mtn
South Fork
Soldier Mtn
Sheep Mtn
Little Dog Mtn
Three Bears
Marias Pass
LEWIS AND CLARK
Blacktail Hills
GLACIER CO
PONDERA CO
INDEFINITE BOUNDARY
GLACIER
PONDERA