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Comparing the Prescribed Natural Fire Program With Presettlement Fires in the Selway-Bitterroot Wilderness

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Abstract. The severity and extent of recent fires (1979-1990) were compared with that of presettlement fires (pre-1935) by eight major forest types in the Selway-Bitterroot Wilderness (SBW) in Idaho and Montana. Presettlement fire intervals were determined for estimating area burned. Presettlement annual area burned for the entire SBW was 4,290 ha by stand replacement fire and 4,310 ha by nonlethal understory fire. All recent period fires >4 ha were mapped using a GIS system. Area burned was determined by the fire severity classes: crowning, lethal surface, nonlethal surface, and no burning. Annual area burned averaged 2,780 ha by stand replacement and 2,270 by understory fire. Area burned during presettlement was 1.7 times that during the recent period. During the presettlement period, area burned by stand replacement and nonlethal understory fire was 1.5 and 1.9 times greater respectively than during the recent period.

Introduction

The United States Wilderness Act of 1964 set forth a goal of preserving natural conditions by allowing the forces of nature to operate. Recognizing that fire had been kept from playing a natural role in wilderness areas, the U.S. Forest Service and National Park Service began a program to reintroduce fire into some wilderness areas in about 1970. By 1979, the program had been implemented over the entire Selway-Bitterroot Wilderness (SBW) in northern Idaho and western Montana.

An important question to answer for today's land managers is how well have the objectives of restoring natural fire processes been met? To help answer the question ecologically, this paper describes results of a study that compared the severity and extent of recent fires (1979-1990) with that of presettlement fires by major forest types. In a companion paper (IJWF), production of smoke emissions and occurrence of smoke events are described for presettlement and recent periods. As used here, "presettlement" refers to the period before fire suppression became effective, which was only after about 1935 in the remote SBW (Koch 1935; Pyne 1982). Since 1979, fires have been managed as either "prescribed natural fires" caused by lightning within prescribed conditions or as "wildfires" caused by lightning outside of prescribed conditions or by humans. Wildfires have been managed primarily using a confinement strategy that employs suppression tactics on only a limited basis to keep fires from escaping wilderness boundaries or threatening property.

Study Area

The 547,370 ha SBW can be divided into two geomorphic units. The western and central portion of the area is a complex maze of high mountain ridges (2,000-2,500 m in elevation) and deeply dissected canyons (500-1,000 m). The eastern portion of the SBW consists of the prominent north-south oriented Bitterroot Range, whose crest (2,400-3,000 m) forms the Idaho-Montana border.

The climate of the SBW ranges from inland-maritime in the northwestern part to a more continental rainshadow climate in the southern and eastern parts (Finklin 1983). Average annual precipitation is about 100 cm at 600 m elevation along the Selway River in the northwest; whereas it decreases upstream to less than 65 cm near the area's southern boundary. Terrain above 1,800 m in elevation generally receives 100-200 cm of precipitation annually, and on the highest ridges snowpack lingers until July. Overall the climate is cool and moist except for a hot dry period primarily in July and August. The fire season typically runs from late June to mid-September. Thunderstorms are common during this period and cause many lightning fires.

The SBW contains a diversity of forest types (Habeck 1976). At lower elevations these range from open stands of ponderosa pine (*Pinus ponderosa* var. *pon-*

derosa) with a sparse bunchgrass undergrowth on south-facing slopes to luxuriant western redcedar (*Thuja plicata*) communities in canyon bottoms. A broad zone of mixed conifer occupies intermediate elevations, including large areas dominated by interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca*), lodgepole pine (*Pinus contorta*), grand fir (*Abies grandis*), and subalpine fir (*Abies lasiocarpa*). At the highest elevations whitebark pine (*Pinus albicaulis*) is abundant on south-facing slopes and ridgetops while alpine larch (*Larix lyallii*) and Engelmann spruce (*Picea engelmannii*) occupy the north slopes and cirque basins. Large expanses of sparsely vegetated rockland consisting of exposed bedrock and talus slopes are present, especially in the Bitterroot Range.

Methods

Fire Regime Types

Major vegetation types of the SBW were classified into fire regime types that reflect presettlement fire frequencies and severities. Previous studies in the northern Rockies (Arno 1980; Barrett 1988) and elsewhere (Heinselman 1981; Martin 1982; Kilgore 1987) have shown that major vegetation types were good indicators of fire regime characteristics. Cover types and habitat types based on potential climax plant associations (Daubenmire 1968) were used to define the vegetation/fire regime types because they had been related to elevation, aspect, and landform position in the vicinity of the SBW (Pfister et al. 1977; Arno 1979; Lackschewitz 1986; Cooper et al. 1987).

The vegetation/fire regime types were named for their diagnostic tree species—usually the principal seral species followed by its late-successional replacement (Table 1). Fire regime types will be referred to in the text by principal seral species. Lower elevation types were separated based upon the potential climax dominant tree species—Douglas-fir, grand fir, and western redcedar. The middle and upper elevation forest types were based on Pfister et al.'s (1977) classification of the subalpine fir series. This provided a basis for separating the warm-dry aspects whose principal undergrowth is pinegrass (*Calamagrostis rubescens*) and beargrass (*Xerophyllum tenax*) from the cool-moist north slope types, which have a less com-

Table 1. Area occupied by fire regime types in the SBW and their topographic and presettlement fire characteristics based on the field samples.

Fire regime type	Percentage of SBW	No. transects	No. stands	Elevation (m)	Aspect	Slope (%)	Dates of earliest and latest fires		Fire intervals (yr) Stand replace		Understory and mixed		Severity [1]
							Early	Late	Mean	No.	Mean	No.	
Lower elevation													
Ponderosa pine/ Douglas-fir	11.7	5	11	366 to 1,365	SW, S, SE	30 to 60	1528	1934	—	—	22	127	Nonlethal
Shrubfield-conifer	1.7	1	1	750	W	40	1880	1934	54	1	—	—	Lethal
Douglas-fir/ grand fir	10.3	6	13	1,250 to 1,798	NE, SW, W, NW	40 to 60	1580	1919	119	13	—	—	Lethal & Mixed
Western redcedar	2.9	5	9	579 to 1,280	N, NE, E, W, NW	25 to 50	1573	1919	197	7	—	—	Lethal
Upper elevation													
Lodgepole pine/ subalpine fir	45.9	5	20	1,350 to 2,399	NE, E, SW, S, W	20 to 60	1731	1934	112	9	47	8	Lethal & Mixed
Engelmann spruce-Douglas-fir/ subalpine fir	10.9	6	13	1,481 to 1,999	N, NE, NW	20 to 65	1589	1919	166	9	—	—	Lethal
Whitebark pine/ subalpine fir	6.0	5	12	2,225 to 2,749	N, SE, S, NW	25 to 70	1766	1929	180	5	56	6	Lethal & Mixed
Alpine larch-Engelmann spruce/ subalpine fir	8.4	1	1	2,499	NE	70	1729	—	166[2]	9	—	—	Lethal
	97.8[3]												

[1] "Nonlethal" to most overstory trees, "lethal" to most overstory trees, or "mixed" mortality among the overstory.
[2] The Engelmann spruce data were assumed to represent the alpine larch type.
[3] Alpine tundra, water, and other minor types comprised the remaing 2.2% of the SBW.

bustible undergrowth of tall shrubs (e.g., *Menziesia ferruginea*, *Alnus sinuata*) and semi-succulent herbs (*Clintonia uniflora*, *Senecio triangularis*). Shrubfield vegetation was split out as a separate type from the ponderosa pine and Douglas-fir vegetation types because a history of closely repeated stand replacement fires obscured classification of fire regime types. Alpine tundra was discarded from characterization of fire history.

Field sampling was undertaken to determine the site characteristics of major forest cover types in the SBW and to define their presettlement fire histories. Numerous elevational transects were located along trails and roads in the unlogged areas immediately adjacent to all sides of the SBW. Stands representative of various forest types encountered along transects were sampled using from one to three circular macroplots (375 square m), depending on stand extent and variability (Pfister and Arno 1980) (Table 1). Tree canopy cover by species and diameter class were recorded to assist in designating cover types. Other information on cover type and habitat type distributions was applied in the western portion (Habeck 1976) and in the eastern portion (Arno 1976; Arno and Petersen 1983; Pfister et al. 1977) of the SBW. It was not possible to randomly sample stands within the SBW due to logistics and cost. But, based on a previous study within the wilderness (Habeck 1976) and National Forest records of historical fire occurrence, the vegetation and fire history at the periphery and interior of the SBW appeared similar.

To map fire regime types and determine the areas occupied by each type, terrain models were developed. Site characteristics from sampled stands and the information on distribution of habitat types were used to relate elevation, aspect, and slope position to fire regime types. Because of climatic variation within the SBW, we developed separate terrain models for three geographic sectors (Barrett and Arno 1991) (Fig.1). Terrain models were developed utilizing DEM (Digital Elevation Model). LANDSAT MSS data was used to

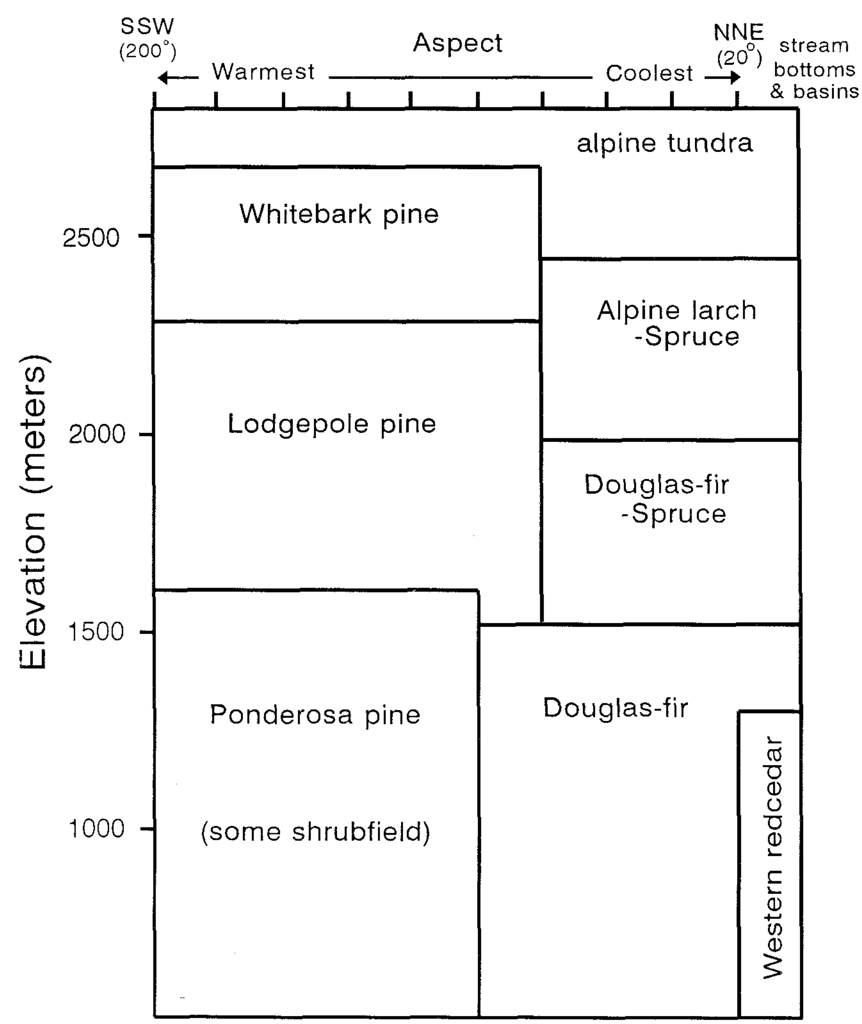

Figure 1. Model of the topographical relationships of vegetation types for the main Idaho section of the SBW. Similar models were constructed for other portions of the SBW.

derive vegetation types. Utilizing a GIS application (Bradley and Arno 1991), the vegetation and terrain models were used to classify fire regime types. Rocklands were classified when total vegetative cover of pixels was less than 40% and cover of pole sized trees less than 15%. Rockland areas were included with associated fire regime types or alpine tundra based on the classification of adjacent pixels.

Presettlement fire history was determined for stand replacement and understory fire severities using fire scars and postfire age classes. In this paper, understory fire always refers to fire that is nonlethal to most of the overstory trees even though it might be lethal to understory vegetation. Fire intervals of stand replacement fires were determined as the difference in dates between the most recent and the previous stand replacement fires. The year of the most recent fire was estimated using an increment borer to date fire scars on scattered surviving trees (Barrett and Arno 1988). When fire scars were unavailable, fire years were estimated as establishment dates of the postfire age classes (cohorts) of shade-intolerant trees, such as lodgepole pine and western larch (*Larix occidentalis*), which typically become established soon after fires (Barrett and Arno 1988). Cohort age was estimated from increment borings taken near ground line on a minimum of three shade-intolerant trees of similar age. The fire year was defined by the establishment date of the oldest tree in the cohort. The beginning date of a fire interval was based on pith age of the oldest shade-intolerant trees. Each stand yielded one presettlement fire interval except in some stands, which yielded no fire intervals because two stand replacement fire dates prior to 1935 were not found.

Average fire intervals were determined in stands experiencing nonlethal understory fires. In the ponderosa pine type, many trees had multiple fire scars. In these sample stands, the tree having the most scars was selected for fire dating. The most recent fire year and the earliest fire year in the multiple-scar sequence on a given tree were estimated by increment boring (Barrett and Arno 1988). The number of externally visible fire scars (N) was counted, yielding the number of fire intervals (N-1), which was then divided into the total number of years between the first and last fires. This produced a conservative estimate of stand mean fire interval because not all fire scars in a multiple scar sequence are visible externally (Barrett and Arno 1988).

In some stands in the lodgepole pine and whitebark pine types, single fire scars were encountered indicating a history of mixed fire severity. Fire intervals were determined as the period between a stand replacement fire indicated by the date of stand origin and the date of fire scar. Understory fire was observed in 6 of 20 stands for the lodgepole pine type; thus, 30% of the area occupied by this type was assumed to have a history of mixed fire severity. For the whitebark pine type, understory fire was observed in 5 of 10 stands; thus 50% of this type was assumed to have a history of mixed fire severity.

Mean fire intervals were calculated by averaging fire intervals from individual stands. For understory and mixed severity fire regimes, stand mean fire intervals were averaged. Average annual area burned was calculated by averaging the area of a fire regime type divided by individual stand fire intervals. This is equivalent to multiplying the average probability of fire in a stand times the area of a fire regime type (Johnson and VanWagner 1985). Annual area burned due to mixed severity fire was divided evenly between stand replacement and understory severities because the presettlement fires were nearly evenly divided that way.

Due to insufficient data in the alpine larch type (Table 1), the fire interval data from the Engelmann spruce type was assumed to characterize the alpine larch type. This assumption seemed reasonable because the alpine larch type lies just above the Engelmann spruce type on northerly exposures and probably has a similar history of fire occurrence. Fire regime types having similar fire history had dissimilar fuels and were thus treated separately to allow estimation of smoke emissions described in a companion paper (IJWF).

Recent Fires

Boundaries of all recent period fires greater than 4 ha (10 acres) were mapped on U.S. Geological Survey 7-1/2 minute topographic maps by 10-day burning periods. Fire reports, interviews with fire personnel familiar with the fires, aerial photographs, and reconnaissance flights were used to determine boundaries. Burned areas by burn period were digitized using ARC INFO software package, then transferred into raster files using GRASS software to overlay with fire regime types. Area burned for each fire was computed by fire regime type and burn period.

Fire severity for each fire was estimated by fire regime type and burn period as percentage of area within each fire's perimeter that experienced crowning fire, lethal surface fire, nonlethal surface fire, and no burning. Estimates were made by an experienced fire behavior specialist who observed many of these fires in the SBW. His estimates were based on personal knowledge, reports documenting fire behavior, interviews with individuals who observed the fires, aerial photographs, aerial observation, and comparison with other fires burning at the same time in similar fuels where severity was known.

For comparison with presettlement fire severities, crowning and lethal surface fire were equated with stand replacement fire severity. Nonlethal surface fire and no burning were equated with understory fire severity. Stand replacement and understory fire severities were readily distinguishable. Nonlethal fire was mapped when less than 30% of the overstory trees appeared dead; otherwise, lethal severity was mapped. But, nearly all mapping of lethal severity was based on evidence of all trees being dead. Separation of crowning fire from lethal surface fire and nonlethal fire from no burning was more subjective. On some fires, evidence of crowning was based on foliage and fine branchwood consumption, slope, stand density, and weather during the burning period. Evidence of unburned patches was sometimes based on pattern of burning and indicies of fuel dryness.

We rated the quality of the mapped fire perimeters and fire severity data as *good* - based on observations of fire and photographs, *moderate* - based on aerial photographs and reconnaissance flights, and *poor* - based on educated judgements. As a percentage of the total area burned, the ratings were good - 76%, moderate - 18%, and poor - 6%.

Presettlement vs. Recent

The significance of differences in extent of fire between presettlement and recent periods could not be evaluated using definitive statistical methods because area burned was determined differently. Presettlement annual area burned was based on sample estimates of fire return intervals. But, recent period area burned was determined by measuring area burned by all fires during a 12-year period, and then converting it to an annual basis for comparison with the presettlement period. Recent period fire cycles (Johnson 1992) or fire rotations (Agee 1993) were computed as area of a fire regime type divided by average annual area burned for comparison with presettlement mean fire intervals. Although determined differently, they both are measures of fire frequency.

An exploratory analysis was performed to indicate significance of difference between presettlement and recent periods. Standard error confidence limits (95% probability) were computed for presettlement annual area burned and mean fire intervals to compare against confidence limits for recent period annual area burned and fire cycles. Because no area was burned during some recent period years, some fire cycle values from single year data approached infinity. To circumvent this problem, fire cycle confidence limits were approximated as area of fire regime type divided by confidence limits of annual area burned.

Results

Presettlement

At lower elevations, understory fires occurred frequently in the presettlement ponderosa pine type (Table 1), similar to that described elsewhere in the Intermountain West (Arno 1988). The lowermost branches of overstory trees were high above the ground, reflecting the pruning effects of low intensity, nonlethal fires. Old pines and scattered old Douglas-firs often had scars from numerous fires dating back to the early 1600's. Stands in the SBW probably had open understories and were dominated by mature ponderosa pines with clear boles (Leiberg 1899, 1900).

The shrubfield vegetation type occurred primarily on warm dry slopes in the northwestern SBW. It evidently resulted from repeated burns in the 1800's and early 1900's. Fire intervals were difficult to determine because of the scarcity of trees. One sample stand had a 54-year fire interval which was consistent with fire history in similar shrubfields near the SBW (Barrett 1982).

Stands in the Douglas-fir type were primarily even-aged but also retained some older Douglas-fir trees with one to two fire scars indicating that stand-replacement fires were often patchy. Five stands had mixed fire severity (evidence of both lethal and nonlethal fire) but we did not obtain nonlethal fire intervals. Sampled stands in the western redcedar type, often codominated by grand fir, were subject to long fire intervals. The average fire interval for lower elevation fire regime types determined by weighting mean fire intervals of individual types by their area was 81 yr.

At upper elevations, the lodgepole pine type was dominated primarily by even-aged lodgepole pine that regenerated soon after fires of lethal severity. But, on gently sloped dry sites, nonlethal surface fires also occurred along with lethal fires, thus severity was classed as mixed. In the eastern SBW and further east in the Rocky Mountains, mixed severity fires occurred at intervals of 25 to 60 years in a fine-grained pattern of variable severity (Arno 1980; Arno et al. 1993). Seral trees in the adjoining Englemann spruce type were generally even-aged, reflecting a history of stand replacement fires at long intervals. A few stands had mixed-aged canopies and scattered fire-scarred trees, indicative of patchy stand replacement fire.

The upper subalpine zone was a mosaic of conifer stands and sparsely vegetated rocklands. The whitebark pine type, occurring in rocky broken terrain, had a history of mixed severity fire in contrast to the alpine larch type where fire was of lethal severity but very patchy. The average fire interval for upper elevation fire regime types was 115 yr.

Recent Fire

During the 12-year recent period, fire covered nearly 61,000 ha of the SBW. During half of those years, little fire was experienced (Fig. 2). A single year, 1988, accounted for 39% of the area burned and three years accounted for nearly 73%. Almost 64% of the area burned occurred in the ponderosa pine and lodgepole pine types.

In the upper elevation fire regime types (Table 2), which occupy 71% of the SBW, stand replacement fire was responsible for 73% of the total area burned. In the lower elevation fire regime types excluding shrubfields it was responsible for 29%. Most of the understory fire occurred in the ponderosa pine type. Unburned patches within fire boundaries were included in the understory fire severity class because they are an integral part of fire patterns and are probably inherent in estimates of presettlement area burned as well.

The severe fire year of 1988 resulted in a greater proportion of stand replacement fire than in the other years. In 1988, stand replacement fire accounted for 78% of the area burned in the upper elevation fire regime types and 45% in the lower elevation types. In the lodgepole pine type, stand replacement fire was 83% of the total area burned in 1988, compared with 67% for all other years. In the ponderosa pine type, stand replacement fire was 37% in 1988 and 25% for all other years.

Rocklands in the subalpine zone, which occupied 46% of the whitebark pine type and 21% of the alpine larch type, burned at nearly the same rate as non-rocklands. But, rocklands in the lodgepole pine type, which occupied 6% of the area, burned at a greater annual rate (1.2%) than non-rocklands (0.8%). For all rocklands in these fire regime types, 54% of the area burned was by stand replacement fire and 46% by understory fire. Thus, fires in rocklands were of lower severity than in non-rocklands (Table 2). Most of the rockland area burned during the recent period occurred during the severe 1988 fire season.

The percentage of total area burned by crown fire for all fire regime types was 22% and for lethal surface fire it was 33%. Thus, less than half of the stand replacement fire was due to crown fire behavior. In the lodgepole pine type, crown fire accounted for 47% of the stand replacement fire. The percentage crown fire varied from 58% in 1988, to 33% for all other years.

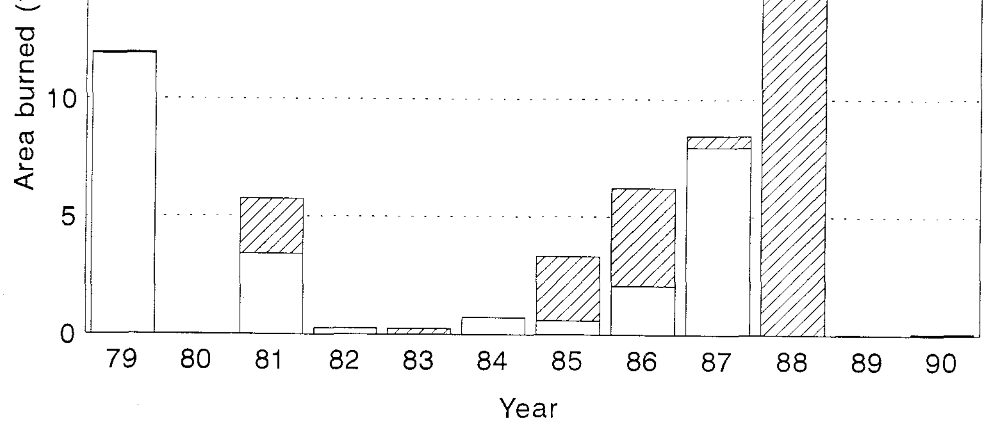

Figure 2. Area burned from 1979-1990 by prescribed fire and wildfire categories.

Table 2. Recent period total area burned (ha) and fire severity as percentage of area burned for all fires 1979-1990 by individual fire regime types. Stand replacement combines crown fire and lethal surface fire. Understory fire combines nonlethal surface fire and nonburned patches.

Fire regime type	Area burned	Crown fire	Lethal surface fire	Nonlethal surface fire	Non burned	Stand Replacement	Understory fire
Lower elevation							
Ponderosa pine	14,145	8	18	56	18	26	74
Shrubfield	1,639	0	56	13	31	56	44
Douglas-fir	7,691	11	25	39	25	36	64
Western redcedar	1,883	1	19	46	34	20	80
Upper elevation							
Lodgepole pine	24,446	35	40	11	14	75	25
Engelmann spruce	4,901	35	36	16	13	71	29
Whitebark pine	2,222	14	47	12	27	61	39
Alpine larch	3,675	22	47	11	20	69	31
TOTAL	60,602 [1]						

[1] An additional 97 ha burned in the alpine tundra.

Crown fire accounted for 32% of the stand replacement fire in the ponderosa pine type. It varied from 46% in 1988, to 30% in the other years.

The amount of stand replacement fire was greatest during late August and early September (Fig. 3). Understory fire remained about the same through August and early September. But, with 1988 excluded from the data, both stand replacement and understory fire were reduced during late August and early September probably due to a commonly occurring pulse of precipitation at that time (Finklin 1983). The seasonal occurrence of stand replacement fire (Fig. 3) reflected the seasonal occurrence of all fire severities in the high elevation fire regime types. Similarly, the seasonal occurrence of understory fire reflected the seasonal occurrence of all fire severities in the lower elevation fire regime types. Understory fire peaked earlier in the season than stand replacement fire.

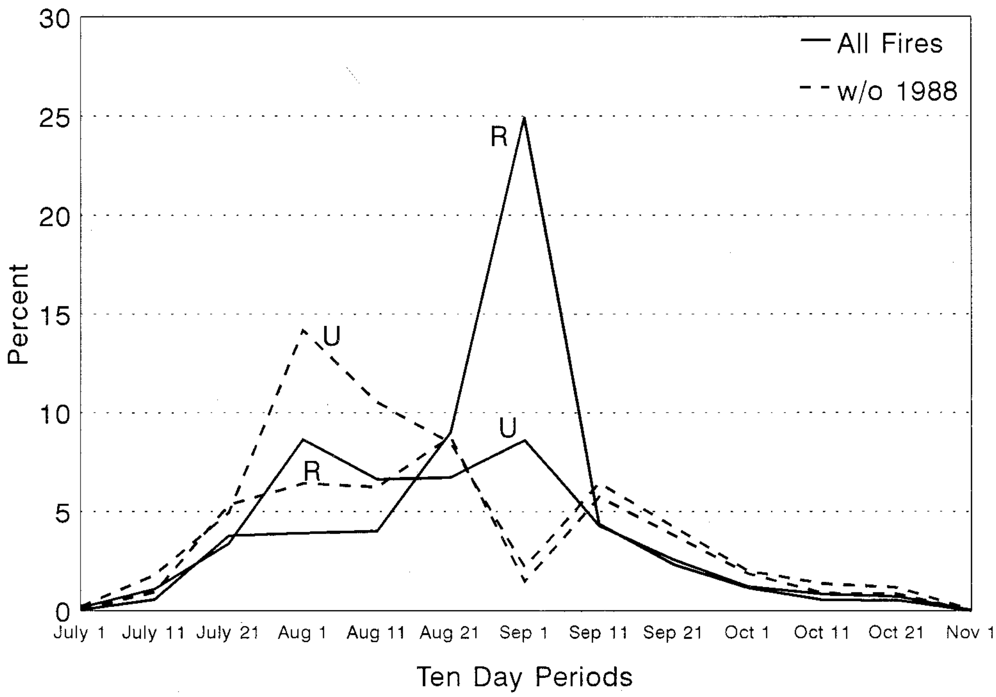

Figure 3. Recent period percentage of area burned of all fire regime types by stand replacement fire (R) and understory fire (U) with and without 1988.

Table 3. Comparison of annual area burned (ha/yr) for presettlement and recent periods and the ratio of presettlement-to-recent area burned for all fire severities by fire regime type and fire severity class.

Fire regime	Stand replacement		Understory fire		All fire		Presettle/
type	Presettle	Recent	Presettle	Recent	Presettle	Recent	recent
Lower elevation							
Ponderosa pine	0	305	3,164	874	3,164	1,179	2.7
Shrubfield	169	76	0	60	169	136	1.2
Douglas-fir	501	231	0	410	501	641	0.8
Western redcedar	87	32	0	125	87	157	0.6
SUBTOTAL	757	644	3,164	1,469	3,921	2,113	1.9
Upper elevation							
Lodgepole pine	2,585	1,527	976	510	3,561	2,037	1.7
Engelmann spruce	384	288	0	121	384	409	0.9
Whitebark pine	269	113	171	72	440	185	2.4
Alpine larch	295	212	0	94	295	306	1.0
SUBTOTAL	3,533	2,140	1,147	797	4,680	2,937	1.7
TOTAL	4,290	2,784	4,311	2,266	8,601	5,050	1.7

Presettlement vs. Recent

Presettlement annual area burned was compared with the recent period average annual area burned to indicate how closely the recent wilderness fire management program matched presettlement fire activity. For the entire SBW, area burned during presettlement was 1.7 times greater than during the recent period (Table 3). During the presettlement period, area burned by stand replacement fire was 1.5 times greater than during the recent period. Understory fire was 1.9 times more extensive during the presettlement period. The difference between presettlement and recent periods was slightly less for lower elevation fire regime types than for upper elevation types (Fig. 4).

At lower elevations, the major difference in area burned between the presettlement and recent periods was due to understory fire in the ponderosa pine type. The presettlement period annual area burned in this type was more than three times that of the recent

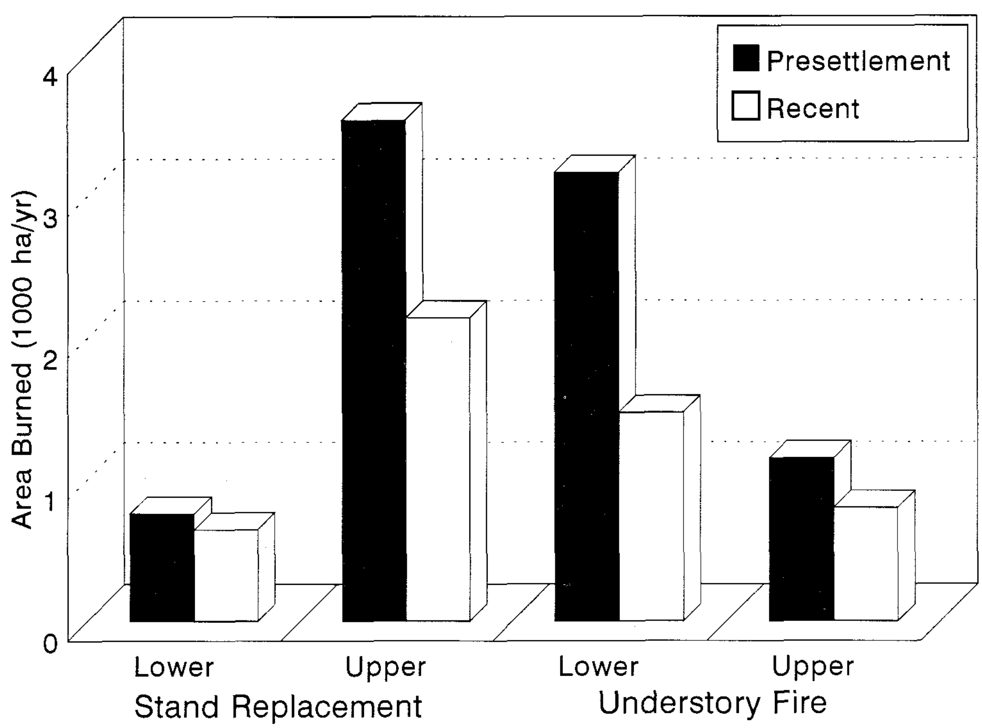

Figure 4. Area burned during presettlement and recent periods for stand replacement and understory fire by lower elevation and upper elevation fire regime types.

Table 4. Standard error 95% confidence limits for area burned (ha/yr), mean fire intervals (yr), and fire cycles by fire severity class during presettlement and recent periods.

Fire	Area burned				MFI		FC[1]	
regime	Presettle		Recent		Presettle		Recent	
type	Lower	Upper	Lower	Upper	Lower	Upper	Mean	Lower
	Understory fire							
Ponderosa pine	2,414	3,914	78	1,670	17	28	73	39
	Stand replacement fire							
Douglas-fir	422	580	0	462	103	136	245	122
Western redcedar	67	107	3	61	144	250	504	264
Engelmann spruce	297	470	0	786	132	200	207	76
Alpine larch	229	362	0	550	132	200	216	83
	All fire							
Ponderosa pine	2,414	3,914	98	2,260	17	28	54	28
Douglas-fir	422	580	28	1,254	103	136	88	45
Western redcedar	67	107	24	290	144	250	103	56
Lodgepole pine	2,120	5,002	0	4,583	66	107	123	55
Engelmann spruce	297	470	0	1,040	132	200	146	57
Whitebark pine	206	675	7	363	66	170	179	91
Alpine larch	229	362	0	788	132	200	150	58

[1] The upper limit was omitted because it usually approached infinity.

period. The differences in understory fire between periods was considered significant because the confidence intervals did not overlap (Table 4).

Although the confidence intervals may be examined for overlap between periods (Table 4), the significance of differences suggested by overlap is uncertain. The recent period confidence limits were extremely wide because annual area burned ranged from none in several of the years to very large areas in one or two years, reflecting typical fluctuations in annual fire weather patterns. Unlike the recent period, variation in presettlement annual area burned was not based on yearly fluctuations but on fire return intervals. The confidence limits for presettlement data are probably more meaningful for comparing the extent of fire over historical periods.

For the Douglas-fir and western redcedar types, understory fire activity was greater during the recent period because few fire scarred trees indicating presettlement understory fire were observed in the sampled stands. Stand replacement fire activity at lower elevations appeared significantly greater during the presettlement period in the western redcedar and Douglas-fir types (Table 4). The differences in stand replacement fire were also considered significant because the recent period fire cycles (Table 4) for the Douglas-fir type of 245 years and western redcedar type of 504 years were considerably greater than the presettlement mean fire intervals. But, fire of all severities did not appear to differ significantly. The shrubfield area burned during the presettlement period was based on scant data; thus, the significance of the comparison with the recent period was uncertain.

At upper elevations, most of the understory fire occurred in the whitebark pine type and on dry sites in the lodgepole pine type. For these types, understory fire was twice as extensive during presettlement as during the recent period.

Presettlement stand replacement fire was greater than during the recent period for all fire regime types by nearly 1.7 times (Table 3). The significance of the differences were difficult to judge because stand replacement confidence limits could not be estimated for the mixed severity fire regimes in lodgepole pine and whitebark pine types. Considering all fire severities, however, differences between presettlement and recent periods were significant for the lodgepole pine and whitebark pine types in that mean areas burned (Table 3) and fire cycles of the recent period fell outside the confidence intervals of the presettlement period (Table 4). Differences were not significant for the Engelmann spruce and Alpine larch types. The greatest presettlement-to-recent period area burned ratios were for the lodgepole pine type and whitebark pine types. The lodgepole pine type was the most important at upper elevations because it accounted for 87% of the difference between presettlement and recent periods.

Overall, the greatest and most important differences between periods occurred in the ponderosa pine, lodgepole pine, and whitebark pine types. For these types, the presettlement-to-recent period area burned ratio was 2.1. The ponderosa pine and lodgepole pine types together occupied 58% of the SBW, but accounted for 99% of difference in area burned between periods.

Discussion

Our estimates of presettlement fire history are similar to those from other studies in like vegetation types within approximately 50 km of the SBW (Table 5). Thus, the fire history characterization of the SBW seemed reasonable. But, the extent of understory fire during the presettlement period was probably underestimated due to failure of some fires to scar trees (Lorimer 1985; Agee 1993). Presettlement understory fire was not observed in five of the eight fire regime types even though it occurred in those same types during the recent period. This was particularly important in the Douglas-fir type because it occupies a substantial area and, historically, understory fire occurred frequently in this type near the SBW (Arno 1976) (Table 5).

Differences in area burned between presettlement and recent periods are likely greater than reported because of conservative presettlement understory fire estimates and the dates selected for the recent period. The period could have included two additional years, 1977 and 1978, when most of the SBW was under a prescribed natural fire policy. Less than 5 ha burned throughout the SBW those years. On this basis the ratio of presettlement to recent period area burned would have been 2.0 instead of 1.7.

The recent period was a short span of time for evaluating fire activity in fire regime types that are characterized primarily by infrequent stand replacement fire. But, the recent period did contain one year of extreme fire severity generally regarded as the most severe since 1910. Thus, the recent period should be considered as having a moderate to high degree of fire activity and not be viewed as a period of low fire activity. Regional climate trends can influence fire activity (Balling et al. 1992; Swetnam 1993). However, we were unable to evaluate variability in presettlement climate and whether the combination of recent period climate and fire activity could have occurred during the presettlement period.

Table 5. Presettlement fire regime characteristics from areas near the SBW[1].

Fire regime type	Mean fire interval (yr) Range	Mean	No. stands	No. transects
	Understory fire			
Ponderosa pine	7 to 52	20	48	9
Douglas-fir	17 to 50	30	10	3
Lodgepole pine	24 to 64	39	8	3
	Stand replacement fire			
Western redcedar	85 to 310	188	14	2
Shrubfield	37 to 85	65	4	2
Lodgepole pine	120 to 200	152	3	3

[1] From 14 published and unpublished studies in a fire history data base compiled by Stephen W. Barrett, Contract RJVA-92676, Intermountain Fire Sciences Laboratory, Missoula, MT.

Fire severity appears to have shifted from equal proportions (50%) of understory and stand replacement fire during presettlement to less understory fire (45%) and more stand replacement (55%) fire during the recent period. The change in fire severity proportions between periods is probably greater than stated because area burned by understory fire during presettlement was probably underestimated. An uncertainly in this comparison is the contribution of unburned patches to area burned by understory fire during the presettlement period. The estimates of presettlement area burned based on fire intervals certainly allows for existence of unburned patches. We assumed that fires spread by similar physical forces and would leave unburned patches during both periods. But, if unburned patches are disregarded in the recent period data, understory fire would account for 33% of the total area burned.

An important change in understory fire severity occurred in the ponderosa pine type. Here, the much greater area burned during presettlement considered with a greater amount of recent stand replacement fire (Table 3) suggests a change of fire regimes from nonlethal to mixed severities. Accumulating understory fuels in this type due to past fire control programs (Steele et al. 1986; Barrett 1988) could be partially responsible for increased fire severity in the recent period.

Stand replacement fire is sometimes considered the same as crown fire. For the SBW, however, lethal surface fire accounted for 58% of the stand replacement fire. The concept of stand replacement fire should include a recognition of crowning and lethal surface fire severities because ecological implications differ. Considering the same stand, for example, crown fire is more intense, removes all foliage resulting in minimal site protection, can kill seeds in cones (Muraro 1971), and can redistribute nutrients in the ash. Lethal surface fire is less intense, kills foliage that remains and offers site protection, may leave more undamaged seed in tree canopies, and can allow more unburned patches to be created. Generally crown fire is more severe and allows for a greater change in species composition. Lethal surface fire may be less severe and leave a wider variety of niches that offers more chance for regeneration by on-site survivors. Knowledge of the proportions of crowning and lethal surface fire may be useful for conducting prescribed fires to mimic natural processes.

The decreased amount of fire on the landscape and the reduced proportion occurring as understory fire during the recent period indicates a substantial departure from presettlement fire occurrence and its effects on the landscape. Reduced fire frequency can lead to a coarser grained landscape pattern and reduced ecological structure depending on variability in fire severity (Swetnam 1993). A reduction in diversity of forest vegetation and related biological systems can be expected in this situation (Christensen 1991; Romme 1982; Habeck and Mutch 1973).

A speculative question is how much more area would have burned if suppression actions had not been taken. Fires managed as wildfires accounted for 56% of the total area burned most of which occurred in 1988. Ninety-one percent of the area burned by wildfires occurred under a confine-and-contain strategy. Thus, the potential growth of these wildfires may have been reduced under a suppression strategy. Another unknown is the area that potentially could have burned by wildfires that were extinguished as small fires (<4 ha).

The prescribed natural fire program in the SBW has been one of the most successful programs for returning fire as a natural process. Nevertheless, this study showed a departure in fire activity between presettlement and recent periods in the SBW. This study may provide guidance to managers wishing to bring fire activity resulting from the current fire management program closer in line with fire activity during the presettlement period. Whether future management can and should reduce this departure will depend on constraints imposed by the need to prevent unwanted fire and the amplitude of fire history accepted as defining natural wilderness processes.

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