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FIRE FREQUENCY AND THE VEGETATIVE MOSAIC OF A SPRUCE-FIR FOREST IN NORTHERN UTAH

Linda Wadleigh[1] and Michael J. Jenkins[2]

ABSTRACT.—Fire scar and vegetative analysis were used to construct a fire history for the Engelmann spruce/subalpine fir (*Picea engelmannii/Abies lasiocarpa*) vegetation type of the Utah State University (USU) T. W. Daniel Experimental Forest. Three distinct periods of fire frequency were established—presettlement (1700–1855), settlement (1856–1909), and suppression (1910–1990). Mean fire interval (MFI) decreased during the settlement period and greatly increased during the suppression era. The difference was attributed to the influx of ignition sources during the settlement of nearby Cache Valley, located 40 km to the west. Logging and livestock grazing appear to have led to the reduced MFI, which in turn worked as a factor to create the vegetative mosaic now observed on the study area. The increase in MFI during the suppression era permitted the advancement of shade-tolerant species in the understory of the shade-intolerant lodgepole pine (*Pinus contorta* var. *latifolia*) and quaking aspen (*Populus tremuloides*). Continued suppression of disturbance from wildfire will allow the lodgepole pine cover type, which experienced the lowest MFI during the settlement period, to be further invaded by shade-tolerant species, decreasing spatial stand diversity and increasing the risk of more intense fires.

Key words: fire frequency, subalpine spruce-fir forest, fire scar.

Absence of natural fire in wildland ecosystems, due to removal of fine fuels by livestock, reduction in Native American ignitions, and a suppression policy instituted in the early 1900s has led to extensive alterations in natural vegetative succession patterns. Human disruption of natural fire regimes in fire-dependent communities limited natural diversity and altered the long-term stability of fire-adapted plant species (Heinselman 1973, Gruell 1986, Agee 1993). Previously, natural ecosystems had evolved under episodic fires (Parsons 1981, Gruell 1983). Gruell's (1983) interpretation of paired photos from the Northern Rockies showed early stages of forest succession were more common from 1870 to 1940 than they are today; however, Gruell (1983) also found the absence of fire has contributed to a marked alteration of natural vegetation mosaics by favoring woody species such as shrubs and trees over grasses.

Lightning-ignited fires in Engelmann spruce/subalpine fir (*Picea engelmannii/Abies lasiocarpa*) forests are less frequent than fires in drier vegetation types. Arno (1980) estimated a fire return interval of 50 to 130 yr for spruce/fir habitat types. Veblen et al. (1994) found a mean fire-return interval of ca 200 yr in a Rocky Mountain subalpine forest in northwestern Colorado. In these subalpine fir forests, historic fire allowed the dominance of seral species and created a mosaic of species and age compositions. Where seral species such as lodgepole pine (*Pinus contorta*) or aspen (*Populus tremuloides*) occurred, a higher fire frequency favored their dominance (Bradley et al. 1992). In the lodgepole pine–dominated communities that occur in the lower portion of the subalpine fir forest, fire was more frequent with intensity depending on amount of precipitation received in the summer months. Abundant evidence was found in the lodgepole pine forests of northern Utah of nondestructive ground fires, more intense "thinning" fires, "stand-replacing fires, and severe double burns" (Arno 1980).

Fire history studies provide land managers with estimates of past fire frequencies, mean fire-return intervals, and effects of natural fire on stand composition and structure (Arno and Sneck 1977). Such studies help to determine the return interval of fires on a site, intensity and size of fire, effects of past fire on stand dynamics, and effects of an era of modern suppression. Managers may also use the natural fire cycle or regime of an area to determine if the present disturbance regime is within the historical range of variation. A variety of techniques are used to evaluate fire history, including

[1]USDA Forest Service, Ogden, UT.
[2]Department of Forest Resources, Utah State University, Logan, UT 84322-5215. Address correspondence to this author.

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mapping stand types, correlating fire dates from fire-scarred trees to establish a fire chronology, and determining age-class distributions, using increment cores to establish the extent of fires (Arno 1980, Tande 1979).

The objective of this study was to determine if the existing vegetative mosaic of the T. W. Daniel Experimental Forest is correlated with the fire history of the study area, primarily, whether fire frequency has changed between 3 distinct periods: presettlement, settlement, and suppression. Additionally, if fire frequency has changed, is that change reflected in the vegetation structure visible today.

STUDY AREA

The USU T. W. Daniel Experimental Forest, located about 40 km east of Logan, Utah, is 1036 ha in area and ranges in elevation from 2377 m to 2651 m (Fig. 1). Topography ranges from higher plateaus dissected by deep drainages to gentle slopes and small meadows. No permanent lakes or streams are within the study area (Schimpf et al. 1980); however, intermittent streams do carry runoff from the site. Winters are cold and wet, and summers are warm and dry. Mean annual precipitation is 104 cm per yr, mostly falling as snow (Hart and Lomas 1979).

The major vegetation component is the Engelmann spruce/subalpine fir type in late successional stages, with seral lodgepole pine (*Pinus contorta* var. *latifolia*) and quaking aspen stands, and small meadows distributed throughout. A young conifer understory consisting primarily of subalpine fir is often present in the aspen stands (Schimpf et al. 1980).

METHODS

Fourteen sampling transects were established along contours spaced 61 m apart based on slope distance. A continuous log of forest cover type, the predominant vegetative type, was kept along each transect to create a stand map. As the contour intervals were traversed, trees with fire scars were identified and recorded. The number of fire scars was recorded for each "catface"—an open scar resulting from fire damage. Fire scars are formed when flames near the trunk raise the temperature of the cambium to a lethal level, or actually consume bark, phloem, and xylem (McBride 1983). Trees with the largest number of sound scars were marked for further study.

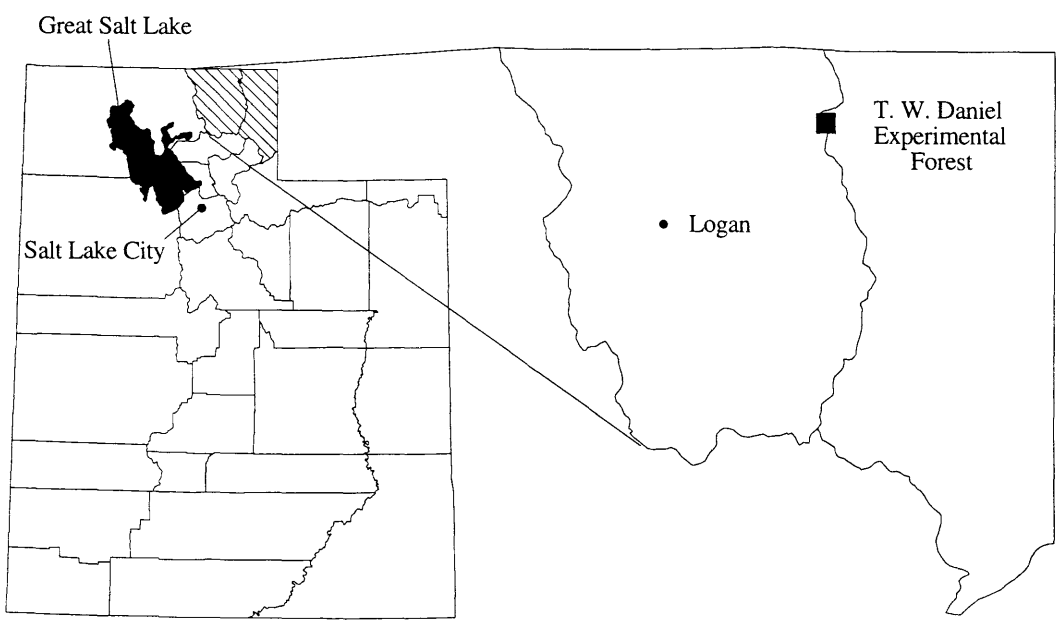

Fig. 1. Map showing approximate location of the T. W. Daniel Experimental Forest between Cache and Rich counties northeast of Logan, Utah.

Sixty-two trees with the greatest number of visible, individual fire scars were sampled by taking a partial cross section from the pith to 1 side of the catface (Arno and Sneck 1977). The wedges were sanded and annual growth rings counted, recording the number of years back to each fire and the number between fires. Trees may be scarred in a number of ways including mechanical damage by nearby falling trees, root rot infection, lightning, or strip attacks by mountain pine beetle (*Dendroctonus ponderosae* Hopkins, Coleoptera: Scolytidae) (Johnson and Gutsell 1994); however, there were no blue stains, larval galleries, or beetle emergence holes in the scars sampled (Stuart et al. 1983), which would suggest they had resulted from causes other than fire. Because pockets of obscured rings or rot may also cause inaccurate counts, tree records were combined into a master fire chronology (Arno and Sneck 1977).

Individual tree ring counts were arranged horizontally on paper, geographically ordered so that neighboring trees were adjacent. Ten-year increments were placed on the left vertical axis, beginning with the sample year at the top, and the oldest ring year recorded at the bottom. The number of trees scarred in a year was compared to the number of trees susceptible to scarring. If a tree was consistently out of order, a number of years was added or subtracted to bring it into alignment (Arno and Sneck 1977). The maximum number of years added or subtracted equaled 3; and 16 trees were adjusted.

Variable-radius plots were laid out along the sampling transects at a spacing of 200 m. Tree species present were recorded to determine cover type, and a site tree—a dominant or codominant tree on the plot—was aged for each species. Increment cores were taken at breast height for each site tree and were adjusted for total age for each species. A 740th-ha regeneration plot was recorded, tallying seedlings and saplings by species and diameter, at the center of the variable plot to aid in determining successional patterns.

Cover type, dated scars, and stand age data collected from these plots were incorporated into a stand map to show the extent of stands that might have resulted from a fire disturbance (McBride 1983). The stand map was supplemented by remotely sensed satellite imagery obtained in 1986.

Fire frequency, "the number of fires per unit of time" (Romme 1980), on an area was calculated for 3 fire frequency periods to portray the effects of settlement, logging, grazing, and modern fire suppression on the fire regime. Mean fire intervals, "an arithmetic average of all fire intervals determined in a designated area" (Romme 1980), were calculated for each period. Determining mean fire intervals for distinct land-use periods is useful in understanding human impact on forest ecology and fire history (McBride 1983). The periods were "suppression" (1910–1990), when U.S. Forest Service fire suppression was initiated, "settlement era" (1856–1910), and "presettlement" (prior to 1856). Mormon pioneers established the first settlement by Europeans in the Cache Valley in 1856 (Bird 1964). The presettlement period began the year just prior to the age of the oldest tree sampled—1700 (Romme and Despain 1989). A fire history is limited by longevity of trees on the site and durability of wood exposed when scarred (Heinselmann 1973).

Total number of years in each period was then divided by the number of fires in that period to obtain mean fire interval. Documented evidence of historical fires was used to verify dates in the settlement-era and fire-suppression periods (Bird 1964).

A master fire chronology was developed for each stand experiencing fire in the study area as indicated by scars and the presence of even-aged stands of lodgepole pine (Romme and Despain 1989) or aspen stands (Brown and Simmerman 1986, Debyle et al. 1987). Stands were considered even-aged if deviation in the increment core age of site trees was ≤ 20% (Daniel et al. 1979).

RESULTS

Three forest cover types consisting of 15 stand types were identified. Species represented in pure stands were lodgepole pine, Engelmann spruce, subalpine fir, and quaking aspen, but the area in pure stands was relatively small compared to that of mixed stands: 280 ha in pure stands versus 580 ha in mixed stands out of a total 1036 ha.

Of the 15 delineated stand types, subalpine fir, the climax species in the habitat type present (Schimpf et al 1980), was a major secondary stand component in 9 types and the

TABLE 1. Percent of regeneration by species within stand type. Subalpine fir is the primary component in regeneration in all stands except aspen.

Stand type	Subalpine fir	Engelmann spruce	Aspen	Lodgepole pine	Douglas-fir
DF/PF[a]	100	0	0	0	0
DF/ES/AF	100	0	0	0	0
LP	75	19	6	0	0
LP/AF/AS	67	11	22	0	0
DF/AF	67	33	0	0	0
DF/ES	67	33	0	0	0
LP/AF	65	35	0	0	0
LP/AF/ES	61	31	0	8	0
ES	60	25	15	0	0
ES/AF	57	32	11	0	0
AF	56	33	11	0	0
AF/AS	52	0	48	0	0
AS/ES/AF	46	27	27	0	0
AS	41	3	53	0	3

[a]Stand type abbreviations: AF = subalpine fir, AS = aspen, ES = Engelmann spruce, LP = lodgepole pine, DF = Douglas-fir, PF = limber pine.

principal component in 2. Regeneration surveys conducted at each plot showed subalpine fir to be the primary regeneration component in 13 of the 15 types (Table 1). Aspen regeneration was the primary component in the aspen stand type. Overstory ages ranged from 63 to 284 yr in lodgepole pine, 106 yr in aspen, 188 yr in subalpine fir, and 193 yr in Engelmann spruce.

Sixty-two fire-scar wedges were collected from fire-scarred trees, 22 from Engelmann spruce, 1 from subalpine fir, and 39 from lodgepole pines. All scar and pith dates were used in the master fire chronology, but only 6 of the spruce scars were used to indicate fire years, while 37 lodgepole pine scars were utilized. The remaining scars were not used due to rings obscured by decay.

Sixteen fire years were represented in scar and/or regeneration data. Where scars were not present, but vegetation was even-aged, e.g., stands L20, F24, L18, and L17 (Tables 2, 3), a fire year was determined from the age of dominant lodgepole pine or aspen trees present. Two of the 16 fire years, 1700 and 1860, were represented solely by age-classes on the site. Two fire years during the settlement period, 1890 and 1895, were documented by Bird (1964). Bird's account stated that numerous small fires were reported in Logan Canyon in 1890, while the 1895 fire year was substantiated by a large fire reported in Stump Hollow in Logan Canyon, an area north of the study area (Bird 1964).

Those stands where the major component was lodgepole pine exhibited 13 fire years, 4 in the presettlement fire period from 1700 to 1855, 9 in the settlement period from 1856 to 1909, and no fires in the suppression period from 1910 to the present. Ten of the 13 fires were represented by fire scars in the present stands (Table 2).

There were 7 fire years in stands in the spruce/fir cover type, which predominantly comprised spruce/fir and secondary components of lodgepole pine, aspen, Douglas-fir, and limber pine. There were no fires in the presettlement period, 6 in the settlement period, and 1 in the suppression period. Five of the 7 fires were recorded by scars and validated by age of the present stand (Table 3). There were 4 fire years in the aspen cover type. Three of those fires were validated by both fire scars and age-class analysis. One fire occurred in the presettlement period and 4 in the settlement period (Table 3). Only 1 fire year, 1903, was common to all 3 forest types. Four fire years (1860, 1890, 1902, and 1903) were shared between the spruce/fir and lodgepole pine cover types (Figs. 2, 3).

Mean fire intervals estimated for the entire study area, for each cover type, and for each fire frequency period are shown in Table 4. Mean fire interval for the entire study area was 18 yr, i.e., a fire occurred about every 18 yr somewhere within the study area. Mean fire interval was shortest in lodgepole pine and longest in aspen. During the presettlement

TABLE 2. Fire frequency in the lodgepole cover type by stand and fire year. Stands consist of a predominant lodgepole component or mixed species with the primary overstory component of lodgepole pine. (Adapted from Arno and Sneck 1977.)

Fire year	Stands															
	L2[a]	L3	L4	L5	L6	L7	L22	L11	L10	L12	L15	L20	L18	L17	L9	L13
Suppression period																
1942	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Settlement period																
1909	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1903	3r[b]	2r	1r	4r	2	1	1	–r	—	—	—	—	—	—	—	—
1902	—	—	—	—	—	—	—	1r	1	1r	1	1r	1	5r	—	—
1899	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1895	–r	—	—	—	—	1	—	—	—	—	—	—	—	—	–r	—
1890	—	—	—	—	—	—	—	—	1	–r	–r	—	—	—	—	–r
1887	—	—	—	–r	—	—	—	—	—	—	—	—	—	—	—	—
1883	–r	—	—	1r	—	—	—	—	—	—	—	—	—	—	—	—
1877	–r	—	—	–r	—	1	—	—	—	—	—	—	—	—	—	—
1860	—	—	—	—	—	—	—	—	—	—	—	–r	–r	–r	—	—
1858	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—
Presettlement period																
1847	–r	–r	—	2r	—	—	—	—	—	—	—	—	—	—	—	—
1834	—	—	—	—	—	—	—	—	1r	—	—	—	—	—	—	—
1822	—	—	—	—	—	—	—	—	1r	—	—	—	—	—	—	—
1700	—	—	—	r	—	—	—	—	—	—	—	—	—	—	—	—

[a]Stand description: Lodgepole = L3, L5, L6, L22, L12, L17, L9, L13; LP/AF/AS = L2, L7, L15; LP/AF = L4, L11, L20; LP/AF/ES = L10, L18. LP = lodgepole pine, AF = subalpine fir, AS = aspen, ES = Engelmann spruce.
[b]Digit (1,2, etc ...) = number of trees in stand with fire-scar date; r = regeneration in stand, determined from increment cores.

TABLE 3. Fire frequencies in the Engelmann spruce/subalpine fir and aspen cover types. (Adapted from Arno and Sneck 1977.)

Fire year	Engelmann spruce/subalpine fir stands							Aspen stands	
	E2[a]	E4	E5	F21	F24	F7	F23	A3	A8
Supression period									
1942	1[b]	—	—	—	—	—	—	—	—
Settlement period									
1909	—	—	—	—	—	—	1	—	—
1903	1r	1r	2r	—	—	—	—	1	1r
1902	1	—	—	–r	1	—	—	—	—
1899	1	—	—	—	—	—	—	—	—
1895	—	—	—	—	—	—	—	—	—
1890	—	—	—	—	—	–r	—	—	—
1887	—	—	—	—	—	—	—	1r	—
1883	—	—	—	—	—	—	—	1	—
1877	—	—	—	—	—	—	—	1	—
1860	—	—	—	—	–r	—	—	—	—
1858	—	—	—	—	—	—	—	—	—
Presettlement period									
1847	—	—	—	—	—	—	—	–r	—
1834	—	—	—	—	—	—	—	—	—
1822	—	—	—	—	—	—	—	—	—
1700	—	—	—	—	—	—	—	—	—

[a]Stand description: ES/AF = E2, E5; AF/AS = F3, F23; DF/ES = D2; AF/LP = F5, F7; ES/AF/AS = E4, F24; AF/ES = F9; AF/LP/ES = F21; AS = A3, A8. AS = aspen, AF = subalpine fire, DF = Douglas-fir, ES = Engelmann spruce, and LP = lodgepole pine.
[b]Digit (1, 2) = number of trees in stand with fire-scar date; r = regeneration in stand determined from increment cores that correspond to fire data.

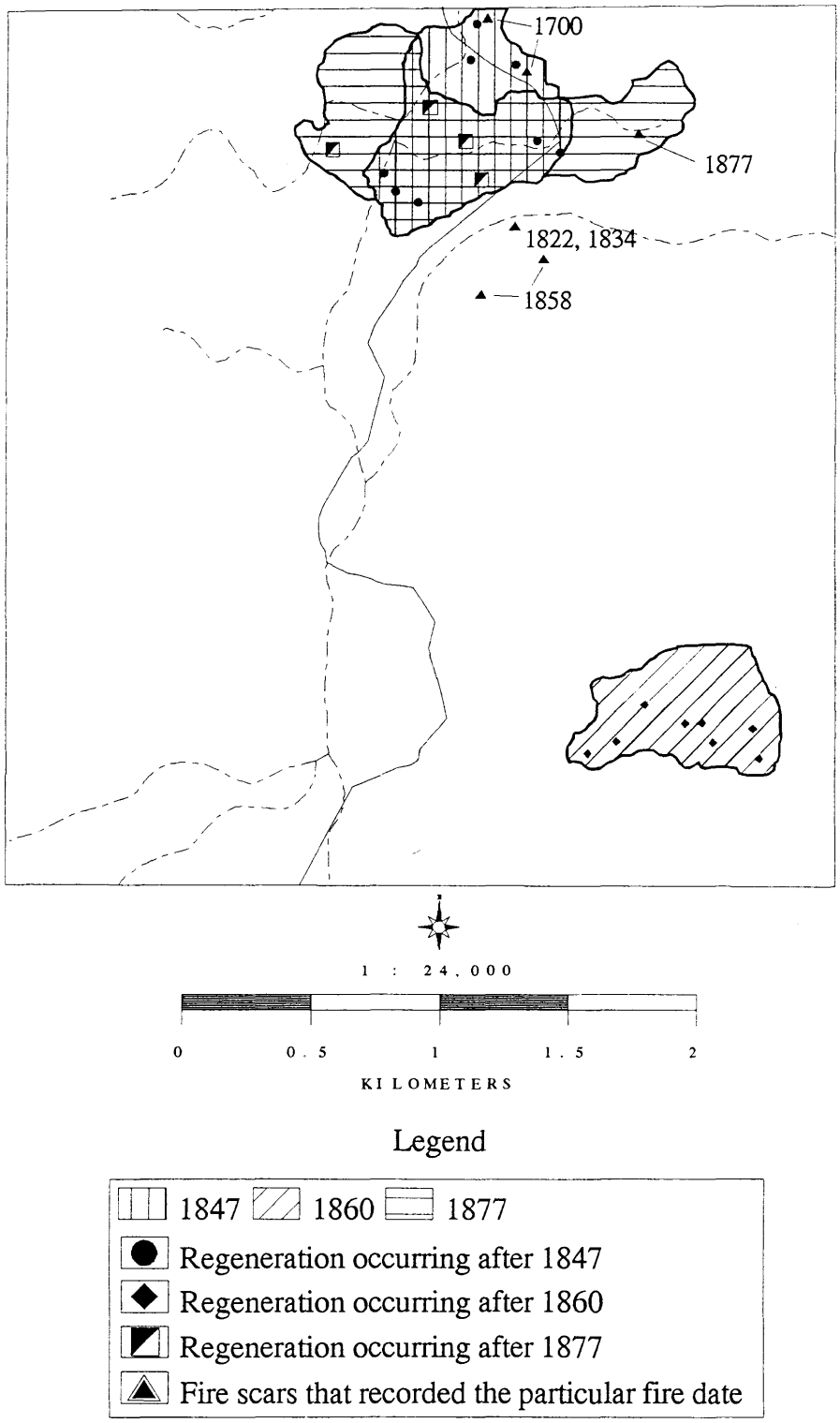

Fig. 2. GIS-produced diagram of fires in the study area from 1700 through 1877 based on stand mapping, regeneration, and fire-scar data.

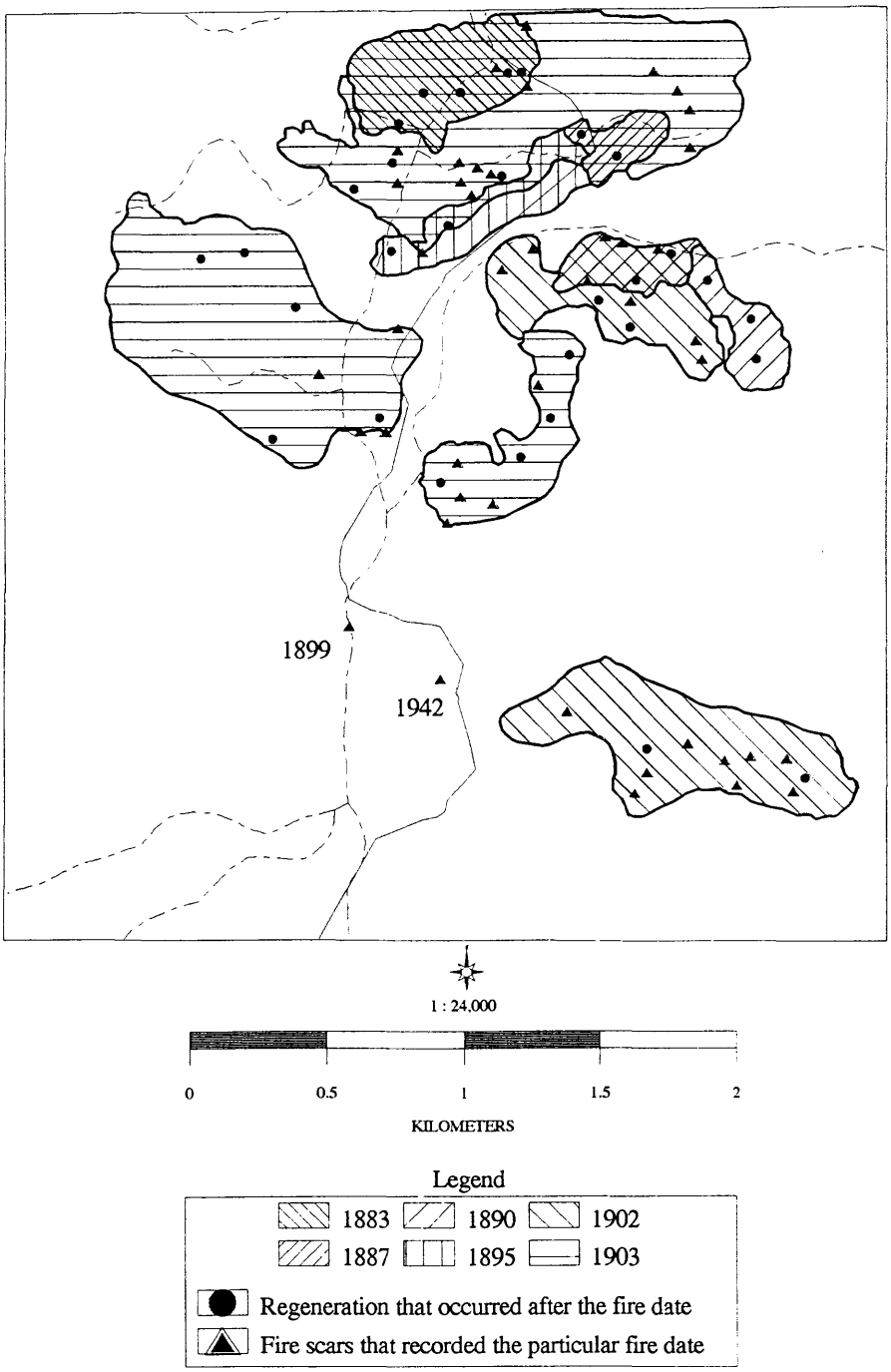

Fig. 3. GIS-produced diagram of fires in the study area from 1883 through 1942 based on stand mapping, regeneration, and fire-scar data.

TABLE 4. Mean fire interval by cover type and fire frequency period. Mean fire interval is an arithmetic average in years of the number of years in a period divided by the number of fires occurring in that period. A double hyphen denotes that no evidence of fire occurring in that period was found. Ranges of intervals are in parentheses.

	Presettlement (1700–1855)	Settlement (1856–1909)	Suppression (1910–1988)	Total (289 years)
Study area	39 (1–122)	4.9 (1–30)	79	18.1
Cover types				
ES/AF	—	9 (1–30)	79	41.3
LP	39 (12–122)	6 (1–17)	—	22.2
AS	156	13.5 (4–16)	—	57.8

and settlement periods, mean fire interval was shortest in lodgepole pine. Mean fire intervals were longest in the suppression period (e.g., spruce/fir) or no fires occurred (e.g., lodgepole pine and aspen; Table 4).

DISCUSSION

Stand Age and Regeneration

The widespread occurrence of subalpine fir in the cover types, both in the overstory component and in the regenerating understory, is associated with later stages of succession (Schimpf et al. 1980). Stands sustaining the most recent extensive fires, 1902 and 1903, have less of a subalpine fir component than those not withstanding recent fires (Figs. 2, 3). However, subalpine fir is apparent as a component of regeneration following these fires and now as a tolerant understory.

Fire frequencies declined during the last century, a trend that would favor the establishment of stands of Engelmann spruce and subalpine fir that are less resistant to fire. When a subalpine fir climax is reached, overtopping intolerant seral species, it is not easily replaced due to its tolerant reproduction, unless a disturbance interferes, such as fire, insects, disease, or logging (Eyre 1980). Aspen stands also have a component of subalpine fir present and will require a disturbance if they are not to be replaced by the tolerant subalpine fir climax (Mauk and Henderson 1984).

Fire Frequencies

Compared to the mean fire interval in the presettlement period, there was a large increase in fire frequency in the settlement period in all 3 cover types (Tables 2, 3). Both Bird (1964) and Roberts (1968) stated that ignition sources increased while settlement was occurring in Cache Valley.

Size and number of fires in the mountains surrounding Cache Valley coincided with the heaviest use period (Bird 1964). The 1880 census stated 1%–10% of the timbered area of Cache County burned, or 5000 to 50,000 acres. Heavy grazing of the period undoubtedly reduced fine fuel loads, but use by loggers and sheepherders increased ignition hazards.

Fires were largely untended until 1906, when the U.S. Forest Service arrived. An employee of the U.S. Forest Service in 1906 stated that 3/4 of the Bear River Forest Reserve (later to become part of the Wasatch-Cache National Forest) had been burned over in the last 20 yr, probably due to careless sheepherders (Bird 1964). Fires were recorded in Blacksmith Fork Canyon in 1878, as well as a "large fire" in Stump Hollow in Logan Canyon in 1881 (Bird 1964).

Compared to the settlement period, fire frequency decreased during the suppression period and there was no evidence of fire in the lodgepole pine and aspen types. Forest Service suppression techniques decreased the size and occurrence of fires, which also coincided with a large reduction in allowable grazing, lessening an ignition hazard (Bird 1964).

The lack of evidence of fire since 1910 cannot be attributed to deterioration of fire-scar evidence. A fire severe enough to scar standing trees should be recorded in the present stands. The actual fire frequency may be higher than recorded; fires may not have been severe enough to scar trees (Lorimer 1984) or were suppressed before they became extensive.

Mean fire intervals in all cover types decreased in the settlement period and increased or there were no fires during the suppression era (Table 4).

There were few if any fires found in this study in the presettlement period. The fire scars in aspen may have been lost to natural mortality and decay, and fires may not have been severe enough to produce fire-scarred trees. Evidence of additional fires in the lodgepole pine and spruce/fir cover types may also have been destroyed, and actual mean fire intervals for this period may be substantially shorter.

Fire hazard in a lodgepole pine stand is highest shortly following a fire due to standing snags and remaining ground fuels from the previous fire, and later when crowns of the tolerant understory reach into crowns of mature lodgepole pine creating ladder fuels (Brown 1975, Romme 1982). In the study area, less fire-resistant Engelmann spruce and subalpine fir have begun to reach into the crowns of the lodgepole pine and aspen stands, increasing fire hazard. Both spruce and fir are highly susceptible to fire, due to their low-branching habits and thin bark (Schimpf et al. 1980). Evidently, fuel was also available to allow several nonlethal fires to burn in lodgepole pine stands, as occurred between 1877 and 1903 in the study area. One stand apparently burned 4 times during this 26-yr period, and several areas burned more than once (Table 2).

CONCLUSIONS

The lack of disturbance by fire on the USU T. W. Daniel Experimental Forest in the last 80 yr has allowed succession to proceed towards a climax of subalpine fir. The increase in fire frequency following settlement was probably due to efforts to exploit natural resources and the concomitant increase in ignition sources.

Frequent disturbance by fires during the settlement period resulted in the present mature vegetative mosaic. These earlier frequent fires favored lodgepole pine, and the less-frequent fires of the suppression period favored more tolerant species, as demonstrated by the abundance of subalpine fir regeneration in all cover types. The continued lack of disturbance will allow the more tolerant species of subalpine fir and Engelmann spruce to overtop the intolerant lodgepole pine and aspen. Eventually the area will lose its diverse appearance and will be similar to that in the areas where fire disturbance is less frequent.

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