Fires, Fuels, and Flora as Factors in Wilderness Management: the Pasayten Case

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INTRODUCTION

To protect a wilderness from fire or not—that was the first debate I remember within the U. S. Forest Service on entering the organization in 1938. The area in question was part of the present Selway-Bitterroot Wilderness in Idaho and Montana. Opponents of protection argued that fires, virtually 100 percent lightning-caused, were an essential part of the natural complex which the wilderness had been established to preserve. Suppression of the fires was contrary to the workings of nature and cost a lot of money besides. Proponents of protection were more concerned that fires could not be contained within the wilderness and would be an intolerable threat to resources on surrounding lands. The protectionists won out. Shortly thereafter the development of smoke-jumping and other forms of aerial fire control greatly enhanced the capability to protect remote, roadless areas.

Within about the last dozen years, concern over the proper role of fire in parks, wildernesses, and other reserves has come to the fore again. This time more cogent reasons are given for letting wild-

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fires burn or using prescribed burning as a substitute for them. The general thesis is that in the absence of fire, the flora and fauna tend to evolve into something quite different from that which the reserve was set aside to perpetuate (Leopold et al., 1963). An important mechanism of the purported change is buildup of fuels, i.e., biomass, so that fires which do occur are likely to be unnaturally intense and destructive (Cooper, 1961). A number of forest types are known to have been subject (before protection) to frequent, low-intensity surface fires that reduced dead fuel and killed low vegetation, thereby tending to prevent conflagrations and maintain a certain stage of succession. The pine types of southeastern United States are the best-known examples in the Western Hemisphere (Chapman, 1952), but a similar natural fire regime characterized certain western forest types, e.g., ponderosa pine and big-tree sequoia (Weaver, 1968; Biswell, 1961). In other types, high-intensity, catastrophic fires appear always to have accounted for most of the area burned. The fire-killed vegetation became far more hazardous than fuels in unburned stands and was a breeding place for still more conflagrations (Lyman, 1945). The successional clock was set back to near zero after every fire.

The fire/fuel relationship that characterizes an area strongly influences management practice. Where natural fires reduced fuels, forest land managers today routinely substitute prescribed burning for wildfire — upwards of 2 million acres in the southern pines, lesser but increasing areas in ponderosa pine and sequoia (USDA Forest Service, 1971; Biswell et al., 1973; Kilgore, 1970, 1973). How to manage fuels in a natural way where catastrophic fires are the rule has not been figured out yet on any practical scale. Much remains to be learned about fuel succession as it relates to fire and vegetational succession in the absence of man's interference. There is need to develop principles and measure particulars. Findings from the Pasayten Wilderness in north central Washington, U.S.A., include a little of both.

THE WILDERNESS

The Pasayten Wilderness covers 505,524 acres extending for 52 miles along the Canadian border (49° North Latitude) and as much
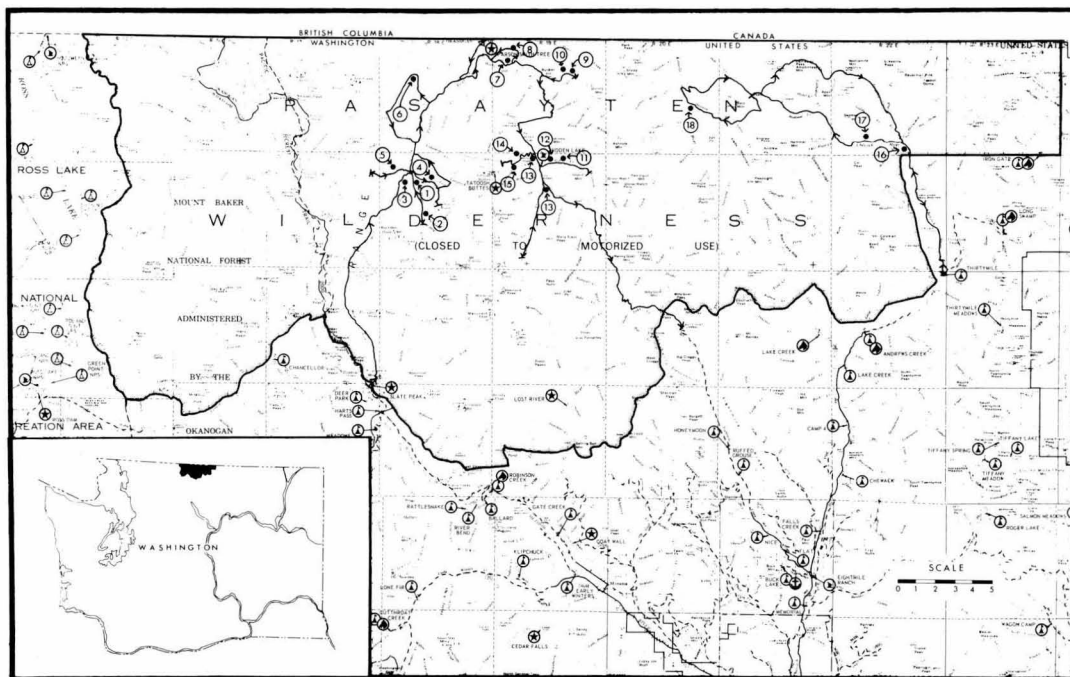
Fig. 1. The Pasayten Wilderness, with routes traveled (solid lines with arrows) and units sampled (numbered circles) by the author in 1972 and 1973.

as 22 miles southward (Fig. 1). It adjoins Ross Lake National Recrea-
tion Area on the west and ends in the hills overlooking the Okanogan
Valley on the east. About 160 square miles—everything west of the
Cascade Crest—are geographically part of the Mt. Baker Snoqualmie-
National Forest. The remainder is in the Okanogan National Forest,
which currently has responsibility for administering the entire Wil-
derness. This paper deals with the area east of the Cascade Crest.

PHYSIOGRAPHY

The Wilderness occupies most of the easternmost extension and
the widest part of the Cascade-Sierra Nevada Physiographic Pro-
vince (Hunt, 1967). Elevations exceed 4,000 ft except for two small
areas on the southern boundary along Lost River and the Chewack
River. These two streams and their tributaries drain to the south on
the east side of the Cascade Crest, alternating with the Pasayten
and Ashnola Rivers, which flow north. Pass levels in the quite wind-
ing divide between north-flowing and south-flowing streams are at
6,300-7,000+ ft, with peaks to 8,752 (Mt. Lago). Heavily dissected,
rugged topography predominates everywhere; the higher peaks and
ridges consist of bare rock. However, the ridges become gradually
less sharp from west to east; and broad, open ridges and basins are
distinctive features east of the Pasayten River drainage. Flat areas
of appreciable size below timberline occur only in the bottoms and
on terraces of major streams, notably the Pasayten River (terraces)
and Lost River (bottom). (See Staatz et al., 1971, for details on
geology.)

CLIMATE

The climate is cool and moderately moist. As is usually the case
for such remote areas, measurements are not available to support
reliable climatological means, and the following interpolations from
maps must suffice (U. S. Department of Agriculture, 1941; U. S.
Department of Commerce, 1968): average temperatures, January,
20-24°F; July, 60-62°F; average annual precipitation, 20-80 in.,
warm season (April-September), 8-16 in.; days without killing frost,
less than 120 (freezing temperatures and snow may occur during

any month). Summer rainfall, although light, is usually rather frequent, but periods of a month or more without rain do occur.[2] Both amount and frequency increase markedly with elevation. Dry summer thunderstorms are a distinctive and important weather phenomenon because they cause most forest fires in the area. Much of the year's precipitation comes as snow, and heavy snowpack is characteristic (Franklin and Dyrness, 1969, 1973).

COVER TYPES

Forest covers the land rather solidly up to about 6,500 ft elevation (Fig. 2). Higher, to about 7,000 ft, trees occur individually, in clumps, or in fairly extensive stands, reflecting site conditions and history. Of approximately 386,000 acres of land area east of the Cascade Crest, 47 percent was shown as commercial forest on the latest type map,[3] 21 percent as subalpine, 18 percent as noncommercial rocky, 8 percent as nonforest vegetation, and 6 percent as open (definitions according to USDA Forest Service, 1957). Most of the nonforest vegetation would appear to be high-elevation meadow and avalanche tracks; nearly all of the open land is talus slopes, cliffs, and high mountain peaks. Actually the entire Wilderness lies in the subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) zone (Franklin and Dyrness, 1973). Fifty-three percent of the commerical forest area was typed as Engelmann spruce (*Picea engelmannii* Parry) in 1959, 35 percent as lodgepole pine (*Pinus contorta* Dougl.), 10 percent as Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), 2 percent as true fir-mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.), and negligible percentages as ponderosa pine (*P. ponderosa* Laws.) and hardwoods. High stand density was (and is) a significant characteristic; 82 percent of the stands were at 70-100% of full stocking, only 8 percent essentially nonstocked.

Information on stand ages is not available, but size-class data indicate that in 1959, 18 percent of the area was in stands averaging

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[2]Based on fragmentary observations at Monument 83 Lookout (6,500 ft) and Pasayten Airstrip (4,200 ft) from 1947 to 1969.

[3]Forest Type Map of Okanogan County, Washington. USDA Forest Service Pacific Northwest Forest and Range Experiment Station, 1959.

Fig. 2. General views in the Pasayten Wilderness, showing continuity of forest below timberline. TOP: Looking SSW from near Bunker Hill at about 6,500 ft. The lighter colored area between the camera and the irregular line in the middleground is a 1917 burn, site of Unit 14. BOTTOM: Looking SE from Pasayten Airstrip at about 4,500 ft. A small corner of 1915 burn (site of Unit 2) shows in the extreme right middleground; the remaining forest on the slope is mostly about 300 years old. Ptarmigan Peak, the highest point in both photos reaches a little above 8,000 ft.

less than 5 in. dbh, 22 percent 5-11 in., 48 percent 11-21 in., and 12 percent larger than 21 in. By 1972 some upward shift should have occurred, probably involving mainly the lowest three classes. Lodgepole pine accounted for 92 percent of the area in stands up to 5 in. dbh, Engelmann spruce for three-fourths of the 11- to 21-in. stands and about two-thirds of the largest size-class. Subalpine fir was an important associate species (by volume) on 30 percent of the spruce acreage, lodgepole pine on 16 percent. Engelmann spruce and/or subalpine fir were associates on more than one-fourth of the lodgepole pine acreage.

Stands in the Pasayten Wilderness are even-aged, or sometimes two-aged, with minor exceptions. Fire statistics, fire scars, and other evidence of past burning make it clear that all extensive stands started after fire. (Stands in avalanche tracks are the major exception; they cover considerable area in the aggregate but are not large individually.) As the figures for size classes show, lodgepole pine tends to dominate young stands and to remain important for a rather long time. In fact, it is difficult to find even a very old stand that does not contain scattered lodgepole pine. As succession progresses, Engelmann spruce becomes dominant, but (from personal observation) subalpine fir is usually more important than the commercial-forest type map shows. The Douglas-fir type occurs almost entirely as open to moderately dense stands on dry, southerly aspects at the lower elevations. Alpine larch *(Larix Lyallii* Parl.*)* is conspicuous in the subalpine zone and along the extreme upper border of the commercial forest. Whitebark pine (*P. albicaulis* Engelm.) is abundant locally in the subalpine zone, and western white pine (*P. monticola* Dougl.), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) western redcedar (*Thuja plicata* Donn.) occur sporadically — and unpredictably — in the commercial forest. (Nomenclature follows Little, 1953.)

FOREST FIRE HISTORY

About 300 fires occurred within the Pasayten Wilderness east of the Cascade Crest in the 6 decades from 1910 to 1969 (Table 1). The precise number is uncertain because (1) fire occurrence maps included 1940 in two 10-yr periods and (2) suspiciously few light-

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TABLE 1. Number of fires, size-class distribution, and area burned in the Pasayten Wilderness east of the Cascade Crest, 1910-1969.

| Period | Number of fires by size classes[1] | | | | | Area[2] |
	A	B	C	CC	Total	Burned
Man-caused:						
1910-20	6	0	0	4	11	17,820
1921-30	4	1	1	1	7	2,601
1931-40	3	0	1	1	5	1,275
1940-49	0	0	0	0	0	0
1950-59	0	2	0	1	3	360
1960-69	11	1	0	0	12	2
Total	24	4	2	7	37	22,058
Lightning-caused						
1910-20	3	0	1	3	7	4,515
1921-30	40	8	2	6	76	67,637
1931-40	45	5	5	5	60	1,400
1940-49	48	3	0	3	54	1,585
1950-59	27	2	1	1	31	2,355
1960-69	43	2	0	0	45	9
Total	206	30	9	28	273	77,501
Grand total	230	34	11	35	310	99,559

[1]Class A,$<$¼ acre; B, ¼-10 acres; C, 11-40 acres; CC,$>$40 acres. Standard size breakdown for fires$>$10 acres not available 1931-1959.

[2]Areas from 1931 to 1949 were estimated from map for CC fires and midpoint of size class was used for B and C fires; A fires were considered to have 0 area in all periods.

ning fires were recorded before 1920. The fire atlas for this early period notes fires in more accessible country that were out when found; more must have completely escaped detection in the remote back country. Failure to detect and report man-caused fires would be less likely since they obviously occurred in places frequented by people.

Lightning caused 88 percent of the recorded fires. After 1920, number of lightning fires per decade ranged from 31 to 76, with an average of 53. The "hot" decade was 1921-1930, despite only one fire each in 1921 and 1923 and none in 1922. Even with the first

decade of record excluded, the lightning fire occurrence rate has been only about 13 fires per million acres per year. By comparison, the White Cap Wilderness Fire Study Area in the Selway-Bitterroot Wilderness of Idaho and Montana has had eight times as many fires per unit of area (Habeck and Mutch, 1973).

Seventy-five percent of the lightning fires reached a final size of less than one-quarter acre, and another 11 percent were smaller than 10 acres. Figure 3 shows the area burned, by decades. Only 8 fires in the whole 60 yr exceeded 1,000 acres in size, but these accounted for 92 percent of the acreage burned by lightning fires. Two fires, one of 20,900 acres in 1926 and one of about 25,000 acres in 1929, covered 59 percent of the total burned area. The big fires occurred in only three decades, 1910-1920, 1921-1930, and 1950-1959. Six occurred between 1921 and 1930, three of them in 1929; no other year had more than one big fire. During the period of record only one fire of any consequence (2,320 acres, 1950-1959 period) started in a recently burned area (1929).

Only 36 man-caused fires have occurred in the Pasayten east of the Cascade Crest in 60 yr—about one every 2 yr on an average. Nearly two-thirds of these fires occurred in either the first decade or in the last; the 1940-1949 decade had none. Three fires larger than 1,000 acres during the period 1910-1920 accounted for 81 percent of all area burned by man-caused fires in 60 yr; only one big man-caused fire has occurred since. The record suggests that the impact of man-caused fires can be held to a negligibly low level.

All of the big fires started during long rainless periods at Omak, Washington (U. S. National Weather Service, 1910-1969), although points in the Wilderness lie 35-80 miles to the northwest and 3,000-8,000 ft higher. The average number of days in the longest period without rain annually between June 1 and September 30 has decreased from 53 in 1921-1930 to 30 in 1960-1969. The absolute maximum has declined from 98 in 1921 to 55 in 1969. Keen (1937) has shown that the drought of 1917-1931 was the most intense and prolonged in 650 yr; thus the Omak record suggests that another period as favorable for extensive burning as the 1920's may be a long time coming.

Nearly 40 percent of all fires in the Pasayten Wilderness (including
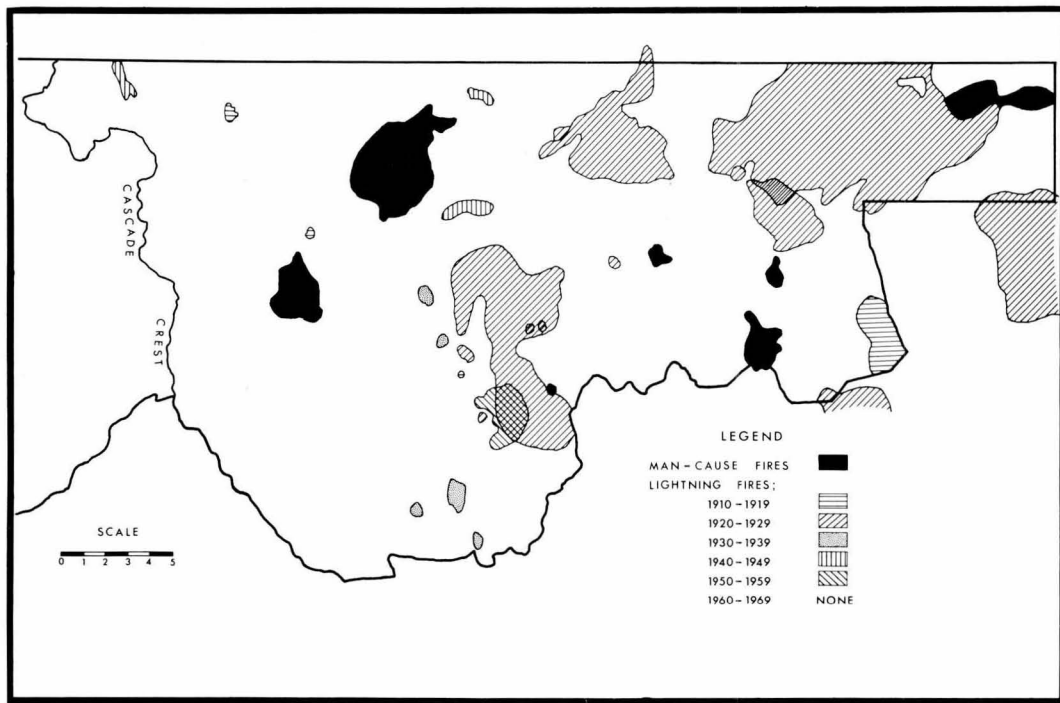
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Fig. 3. Area burned by fires larger than 40 acres in the Pasayten Wilderness east of the Cascade Crest, 1910-1969 (Does not include four fires in the 1920's found in records but not on map).

only one man-caused fire) started
because it is long in proportion to t
mostly along major divides and oth
per decade start near the Canadi;
maining boundary. From 1925 to 1!
rence maps are available) three fire
crossed into Canada, and two from C
Bunker Hill Fire of 1970 also bu
Canada.) Nowhere else did wilderne
and only one burned into the Wilde

METH(

Eighteen stands were sampled in
from 2 to about 400 years (Fig. 1).
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judgment as to typicalness strongly
Fuels were inventoried by the line-ir
in diameter along 2-chain random li:
on the final 6.6 ft of each segmer
1971). The five most important shrut
ft-wide transect centered on the last
total density (percent coverage) an
estimated. Tree reproduction (defi:
and<1.6 in. dbh) was tallied by spe
cies, density, and height of herbace
last 6.6 ft (milacre) of the transect. A
thickness of the forest floor was me
in. dbh was determined with a 10-fa
of "count" trees were estimated. Sta
weight of living crown per acre wa:
1965; Fahnestock, 1960, 1968). R;
spread, crowning potential, and resi:
by means of fuel keys and regional {
1970; USDA Forest Service, 1968).
converted to appropriate means pe
unit.

VEGETATION

TREES

Eight coniferous species occurred on sampling units: lodgepole pine, western white pine, whitebark pine, Douglas-fir, Engelmann spruce, subalpine fire, western hemlock, and western red cedar. One unit had several large black cottonwood (*Populus trichocarpa* Torr. and Gray), and another had occasional Sitka alder (*Alnus sinuata* [Reg.] Rydb.) and Scouler willow (*Salix scouleriana* Barratt) up to 7 in. dbh.

Lodgepole pine was present in all of the 16 stands that had living tree-size vegetation, and it dominated 9 in terms of basal area (Table 2). Engelmann spruce predominated in four stands, Douglas-fir in two, and subalpine fir in one. In terms of number of trees, lodgepole pine was first on eight units, Engelmann spruce on two, and subalpine fir on six. Lodgepole pine reproduction was most numerous on seven of the nine units younger than 100 yr but was almost completely missing in older stands. Subalpine fir reproduction tended in just the opposite direction, being the most numerous species on all nine units older than 100 yr and relatively inconspicuous in younger stands. The species occurred on all but two units. Engelmann spruce reproduction was nearly as ubiquitous; it was present on all but four units, although most numerous on only one. Douglas-fir reproduction was present on only nine units, only once in rather large number, without apparent relation to stand age.

SHRUBS AND HERBS

Twenty-five shrubs and 40 herbaceous plants were listed among the five most important. (Nomenclature follows Hitchcock and Cronquist, 1973.) Unidentified forbs occurred on nine units; the lateness of the season prevented identification of some. Eleven shrubs and 20 kinds of herbage occurred on at least 30 percent of the stations on one or more units (Table 3). Number of shrubs per unit ranged from 1 to 14, number of herbs from 3 to 21, and total from 7 to 32. Shrubs always appeared on at least two-thirds of the stations on every unit, and herbs on at least half. Total occupancy usually was

TABLE 2. Timber stand and reproduction on sampling unit in the Pasayten Wilderness.

Unit	Age	Trees>2 in. dbh: Upper—basal area (ft²acre⁻¹) Lower—no. trees acre⁻¹							Reproduction, no. acre⁻¹					
		LP	ES	AF	DF	Other	All living	Dead	LP	ES	AF	DF	Other	All species
8	2	0	0	0	0	0	0	108	620	60	40	20	20	760
		0	0	0	0	0	0	321						
11	27	25	0	2	2	0	29	27	248	144	120	40	16	558
		553	0	23	41	0	617	35						
9	30	0	0	0	0	0	0	60	80	88	104	0	8	280
		0	0	0	0	0	0	113						
16	44	71	0	0	0	0	71	1	3,400	340	20	20	0	3,780
		1,890	0	0	0	0	1,890	7						
17	44	92	0	0	0	5	97	8	264	0	0	0	16	280
		1,026	0	0	0	0	1,026	18						
18	44	76	0	0	0	1	77	0	2,060	0	0	0	0	2,060
		1,978	0	0	0	46	2,024	0						
14	55	70	1	10	11	0	92	4	1,080	1,384	368	376	0	3,208
		1,344	13	152	190	0	1,689	7						
2	57	98	1	1	<1	<1	100	17	312	24	16	16	40	408
		1,175	13	5	6	5	1,203	6						
6	66	19	2	2	0	0	23	0	400	20	40	0	0	460
		83	4	5	0	0	92	0						
5	120	10	34	88	2	<1	134	22	0	32	200	0	0	232
		14	123	291	1	<1	429	75						
1	175	143	0	<1	0	0	143	16	0	0	8	0	0	8
		540	0	2	0	0	542	110						

TABLE 2. Timber stand and reproduction on sampling unit in the Pasayten Wilderness.

| | | Trees>2 in. dbh: | | | | | | | Reproduction, no. acre^{-1} | | | | | |
| | | Upper—basal area (ft²acre^{-1}) Lower—no. trees acre^{-1} | | | | | | | | | | | | |
Unit	Age	LP	ES	AF	DF	Other	All living	Dead	LP	ES	AF	DF	Other	All species
3	190	99	19	54	0	1	173	32	8	88	128	0	0	224
		99	26	174	0	6	305	55						
10	200	16	75	36	0	0	127	20	0	120	640	0	0	760
		14	70	127	0	0	211	16						
7	200+	1	78	36	0	0	115	34	0	40	760	0	20	820
		1	161	117	0	0	279	68						
15	245	11	13	38	51	0	113	5	0	0	440	20	20	480
		18	15	155	51	0	239	5						
12	277	2	42	11	74	0	129	15	0	80	1,800	40	0	1,920
		4	60	18	58	0	140	14						
4	300	3	62	44	8	2	119	26	0	8	2,680	0	144	2,832
		2	58	306	3	9	378	31						
13	400	2	63	57	55	2	179	15	0	354	1,292	138	0	1,784
		2	73	266	34	<1	375	15						

TABLE 3. Understory characteristics on sampling units in the Pasayten Wilderness.

Unit	Age (yrs)	Number of species			Stations occupied		Most frequent species[1]		Most important species[2]		Mean density		Mean maximum height[3]	
		Shrubs	Herbs	Total	Shrubs (%)	Herbs (%)	Shrubs	Herbs	Shrubs	Herbs	Shrubs (%)	Herbs (%)	Shrubs (ft)	Herbs (ft)
8	2	5	11	16	90	80	PM	EA	PM	EA	1	15	0.5	0.6
11	27	9	21	30	100	100	PM	CR,EA,Lu	PM	CR	14	48	1.2	1.3
9	30	2	13	15	100	100	VS	Lu	VS	Lu	12	62	0.5	0.9
16	44	9	8	17	100	100	SB	Lu	VS	CR	32	44	3.4	0.9
17	44	12	12	24	96	84	SB	CR	SB	CR	19	36	4.2	0.5
18	44	6	6	12	90	50	AU	Mo	PM,AU	Li	15	7	1.3	0.3
14	55	12	13	25	100	92	PM	Mo	PM	Mo	31	24	2.6	0.6
2	57	13	8	21	100	100	VS	CR	PM	CR	89	20	2.4	1.2
6	66	2	13	15	100	100	VS	Lu	VS	Lu	80	20	0.6	1.1
5	120	9	19	28	88	88	PM	Mo	PM	Mo	14	20	2.4	0.5
1	175	4	3	7	68	88	VS	Li	VS	Li	38	21	0.7	0.1
3	190	14	18	32	100	100	PM	CC	Va	CC	76	68	3.0	0.6
10	200	1	9	10	100	100	VS	Ca	VS	Ca	25	35	0.5	0.6
7	200+	10	12	22	100	100	MF	Mo	MF	Mo	57	41	6.0	0.4
15	245	9	10	19	90	90	PM	Lu	PM	Lu,CR,Py	32	10	2.9	0.4
12	277	8	10	18	90	90	SB	CR	PM	CR	13	22	1.4	0.5
4	300	11	12	23	96	100	MF	Mo	MF,PM	CC	34	52	5.4	0.3
13	400	13	17	30	100	92	RL	Mo	RL	Mo	24	23	2.5	1.0

[1]Listed for the largest number of stations. Abbreviations: Au=*Arctostaphylos uva-ursi*, Ca=*Carex* sp., CC=*Cornus canadensis*, CR=*Calamagrostis rubescens*, EA=*Epilobium angustifolium*, Li=Lichen, Lu=*Lupinus* sp., MF=*Menziesia ferruginea*, Mo=moss, PM=*Pachistima myrsinites*, Py=*Pyrola* sp. RL=*Ribes lacustre*, SB=*Spiraea betulifolia*, Va=*Vaccinium* sp., VS=*V. scoparium*.

[2]Ranked first for the largest number of stations.

[3]Based on number of stations occupied by specified vegetation.

FIRES, FUELS, FLORA IN WILDERNESS

90-100 percent; however, density exceeded 50 percent (on occupied stations) only four times for shrubs and three times for herbs. Both types of vegetation were usually short. Mean shrub heights greater than about 2 ft reliably indicated the occasional occurrence of clumps of tall species, usually alder and/or willow. All species that occurred on more than six units also occurred on 30 percent or more stations of at least one unit.

Vaccinium scoparium was the one species that occurred on every unit. *Pachistima myrsinites* was recorded from 16 units (89%) and *Spiraea betulifolia* and *Vaccinium* sp. (probably all *V. membranaceum*) each from 12 (67%). Of the herbaceous plants, *Lupinus* sp. occurred on 15 units, followed in descending order by mosses (14), *Arnica* sp. (13), *Pyrola* sp. (11), and *Cladonia* sp. (10). Nine units had one or more forbs that were not identified for various reasons — insignificance, absence of flowers, deteriorated condition. Because of lateness in the season, numerous plants were identified only to genus on the basis of vegetative characteristics; these included *Aquilegia,* various Compositae, *Galium, Geranium, Osmorhiza,* and *Viola.* Probably some early-developing species were missed entirely and others not found everywhere they occurred. An interesting feature was the total absence of *Xerophyllum tenax.*

Habitat Types

The forest associations of the Pasayten Wilderness fit best into the *Abies lasiocarpa* series of habitat types (h.t.) defined for eastern Washington and northern Idaho (Daubenmire and Daubenmire, 1968). The type species was missing from only two recently burned sampling units and it was observed in the vicinity of these. Numerically, subalpine fir dominated the tree reproduction on all units older than 100 yr and the tree stand on all but three of these. However, all but two of these older units also had Engelmann spruce reproduction, and all but one had larger spruces. Furthermore, spruce basal area usually exceeded fir basal area. The longer pathological rotation of spruce apparently enables it to persist in a dominant or shared-dominant position for the maximum period that stands escape destruction by fire, spanning two or more generations

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of the shorter-lived fir (Boyce, 1961; Fowells, 1965). Therefore, it seems unreasonable to exclude Engelmann spruce from the climax association as has been done farther east.

The prevalence of *Pachistima myrsinites* strongly suggests that *Abies-Pachistima* is the main h.t. of the Pasayten area. Only four units had the species recorded from fewer than 30 percent of the stations. Three of these were at relatively high elevations, and had 100 percent occurrence of *Vaccinium scoparium*, to the nearly complete exclusion of all other shrub species. *V. scoparium* also was the most important species on all four units, which appear to meet the criteria for the *Abies-Vaccinium* h.t., despite the presence of *Galium* on one unit and of more than 14 understory species on two units. The relative wealth of species may reflect proximity to the West Coast flora. A fifth unit also had *V. scoparium* as the most important shrub, but the high frequency of *Pachistima* and the presence of *Spiraea betulifolia* place it in the *Abies-Pachistima* h.t. The seemingly anomalous situation appears to be the result of three or more burns at short intervals.

Menziesia ferruginea was the most important shrub or shared top importance with *Pachistima* on two units (4, 7) on north aspects at middle elevation. *Ledum glandulosum* occurred on both units, suggesting an approach to the *Abies-Menziesia* h.t. However, *Ledum* seemed to occur somewhat randomly in the Pasayten Wilderness— definitely not confined to boggy areas—and *Clintonia uniflora* was on 28 percent of the stations on Unit 4. Also, each unit had more than 20 species, not fewer than 14, as is considered characteristic of the *Abies-Menziesia* h.t. Thus the *Menziesia*-dominated units must be considered variants of the *Abies-Pachistima* h.t. In fact, nothing closely resembling the *Menziesia* union as described and pictured by Daubenmire and Daubenmire (1968) was observed during 225 miles of trail and cross-country travel in the Pasayten Wilderness.

In summation, both general observation and systematic sampling have indicated that the *Abies-Pachistima* h.t. almost exclusively covers the Pasayten Wilderness below about 6,000 ft, the *Abies-Vaccinium* h.t. above that elevation. Apparent representation of the latter h.t. occurs down to the lowest elevations as the result of frequent burning and poor site conditions, notably droughtiness. Ap-

proaches to the *Abies-Menziesia* h.t. occur on moist, north aspects at middle to upper elevations but are richer in species than is typical of this h.t., including characteristic species of the *Abies-Pachistima* h.t. *Xerophyllum tenax* is inexplicably and conspicuously absent; areas on which the *Abies-Xerophyllum* h.t. would be expected appear limited to quite high elevations and are occupied by the *Abies-Vaccinium* h.t. For the most part, understories appear to be somewhat richer in species than those of the h.t. "core area", but fewer tree species are common. Western larch, mountain hemlock, and true firs other than subalpine fir appear to be completely absent east of the Cascade Crest.

FUELS

FINE DEAD FUELS

Loading of fine dead fuels above the forest floor ranged from 0.023 to 0.419 lb ft $^{-2}$ (0.5 to 9.1 tons acre $^{-1}$); surface area, from 0.080 to 0.544 ft^2 ft $^{-2}$ (Table 4). Neither area nor loading showed any apparent effect of habitat type or stand age. Dead crown material was the main fine fuel. Occurrence was spotty; up to half the stations of a unit might yield no tally. Surface-to-volume ratio was highest when the fine-fuel segment of the line transect crossed crown material that had died recently enough to have small twigs and even some persistent foliage still intact. However, the maximum fine-fuel loading and surface area occurred on a unit with many rather long-dead small trees and crowns and one of the lowest surface-to-volume ratios.

A forest floor was nearly always present, even on the most recent burns. Mean depth was 0.71-3.41 in., and estimated loading 10.4-50.1 tons acre $^{-1}$. Depth of the forest floor increased roughly with stand age, as would be expected. The two units (12, 15) that diverged most conspicuously from the general trend were on southerly aspects dominated by Douglas-fir; there is no basis for determining whether a cause-and-effect relationship was involved. Forest floor depth would have been less if points that fell on deep rotten wood had not been averaged in and would have been greater if the full

TABLE 4. The total fuel complex in the Pasayten Wilderness.

		Fuel loading						Fuel rating[1]			
		Dead fuels				Live		Keys[4]		R-6[5]	
Unit	Age	Fine	Coarse	Duff[2]	All	crown[3]	Total	R/S	C/P	R/S	R/C
	(yrs)	($_____$ tons acre^{-1}$_____$)									
Abies-Vaccinium habitat type:											
9	30	2.9	24.2	21.5	48.6	0	48.5	1.0	2.0	1.0	1.0
6	66	2.0	31.8	24.0	57.8	1.7	59.5	1.0	0	1.0	1.0
1	175	9.1	10.8	26.2	46.1	8.9	55.1	5.7	2.0	1.0	1.0
10	200	0.7	20.3	19.1	40.1	12.4	62.5	1.8	4.0	1.0	1.0
Abies-Pachistima habitat type:											
8	2	2.8	13.9	10.4	27.1	0	27.1	1.0	5.0	1.0	1.0
11	27	3.8	98.6	13.2	115.6	1.5	117.1	11.5	0[6]	4.4	3.4
16	44	2.1	5.2	15.6	22.9	3.2	26.1	2.6	4.2	3.8	1.7
17	44	2.9	37.0	16.5	56.4	4.6	51.0	6.8	5.7	2.8	2.1
18	44	4.8	69.3	5.8	79.9	3.5	83.4	4.6	5.7	3.8	3.6
14	55	3.0	99.2	39.6	141.8	6.1	147.9	4.7	4.0	5.0	4.0
2	57	1.2	98.4	33.5	133.1	5.1	138.2	1.8	6.6	1.0	2.3
5	120	5.6	40.6	48.1	94.3	17.6	111.9	6.6	6.6	9.6	1.2
3	190	0.5	58.3	49.7	108.5	16.3	124.8	3.0	2.6	1.0	2.1
7	200+	1.6	67.1	49.9	115.6	11.3	126.9	1.0	4.0	1.0	4.0
15	245	3.4	58.1	34.6	96.1	10.3	106.4	3.4	4.0	2.2	3.8
12	277	4.0	72.0	35.4	111.4	10.5	121.9	12.1	2.7	3.4	3.4
4	300	2.3	69.0	50.1	121.4	12.7	134.1	1.0	4.2	1.0	3.7
13	400	3.5	106.0	44.3	153.8	15.8	169.6	2.9	5.0	1.0	2.9

[1]R/S = rate of spread, C/P = crowning potential, R/C = resistance to control.
[2]Duff = forest floor. Estimated on basis of 1 cm depth = 13,000 kg ha^{-1} (Wooldridge, 1970).
[3]Material $\leq$ 2 in. in diameter.
[4]On relative scale of 100 for R/S, 10 for C/P (Fahnestock, 1970).
[5]Descriptive terms and numerical equivalents are (USDA Forest Service, 1968):

	Low	Medium	High	Extreme
R/S	1	5	25	125
R/C	1	2	4	8

[6]Trees less than 20 ft tall; flammability of crowns rated by R/S.

depth of rotten wood had been measured. The system used appears to have been a reasonable approach to a gross assay of the forest floor as fuel. The most recent burn (Unit 8) still had occasional patches of rotten wood deeper than 4 in. although the rest of the forest floor was almost entirely gone.

Coarse Dead Fuels

Coarse dead fuels aggregated 0.237-4.867 lb ft $^{-2}$ (5.2-106.0 tons acre $^{-1}$) and 0.077-0.924 ft ^{2} ft $^{-2}$ of surface area (Table 4). The *Abies-Pachistima* habitat type, except for a 2-year-old burn and a known triple-burn, consistently had much more fuel than the *Abies-Vaccinium* h.t. Also, fuel maxima appeared to occur at two general stand ages, the first between about 25 and something over 55 yr and the second at the maximum age sampled. All stations but one on all 18 units had coarse fuel.

Statistical comparisons by means of Duncan's multiple range test (Bliss, 1967) emphasized the two peaks in coarse fuel loading. Differences greater than about 1.59 lb ft $^{-2}$ (35 tons acre $^{-1}$) were found to be significant ($P<0.05$).

The early fuel peak is based on stands 27, 55, and 57 yr old. Three 44-yr-old units, other conditions being equal, should have had similarly heavy loading—but other conditions were not equal. One had burned twice in the last 80 yr, three times in 120 to 130 yr. Another probably had burned twice in the past 80 yr also, since the area apparently was a snag patch when it last burned in 1929. The third had much heavier loading than the other two but still significantly less than the three heaviest, apparently because 30 percent of the area consisted of rock or thin soil, without trees. Adjusting the 69.3 tons acre $^{-1}$ to presumed full coverage, viz., by dividing by 0.70, gives 99.0 tons acre $^{-1}$, almost identical with the mean loading of coarse fuel on the three heaviest units.

Figure 4 (bottom) shows the relations of loading to age for the three dead fuel components in the *Abies-Pachistima* h.t. The significant features are the double peak for coarse fuels, the continuous buildup to about age 100 for the forest floor, and the apparent absence of any correlation for fine fuels. Surface areas of coarse and fine fuels bear similar relations to age, but the curve is more erratic (Fig. 4 top). Figures 5-10 illustrate the sequence of fuel and vegetation development and some of its variations.

Living Fuels

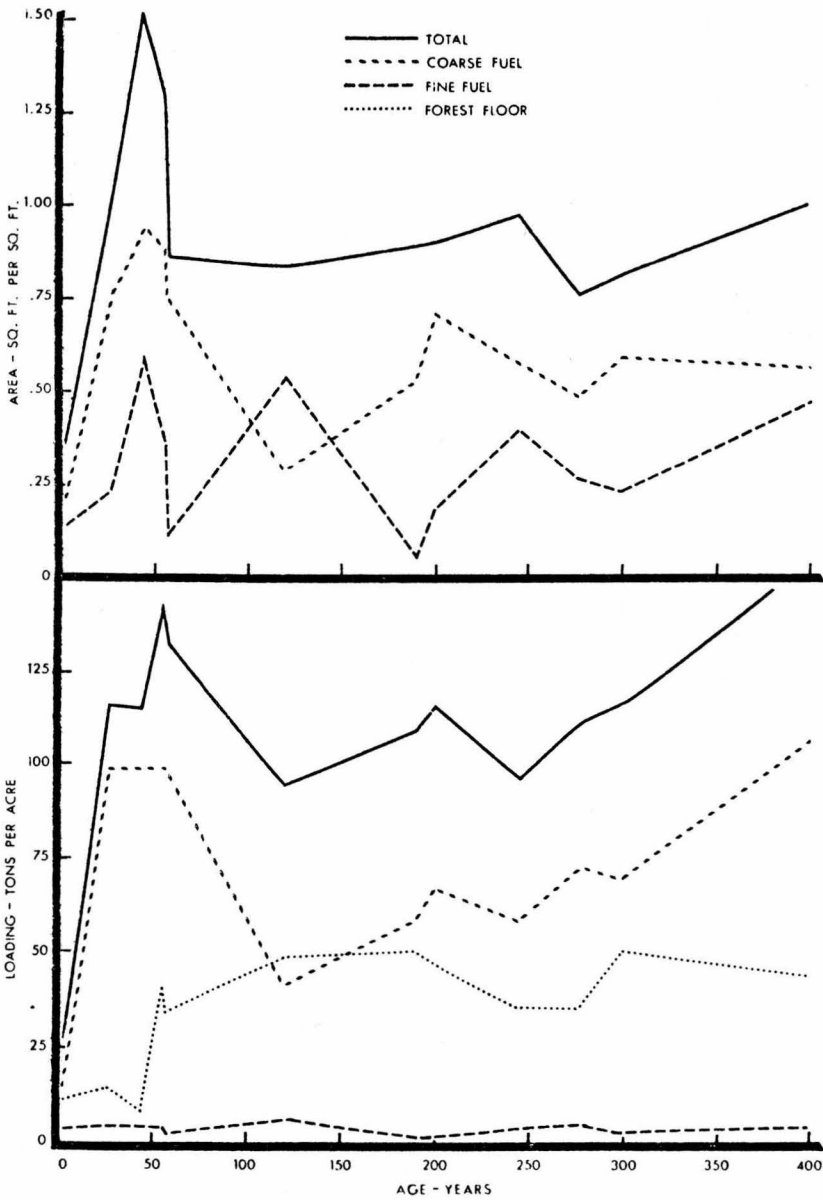Understory vegetation in the Pasayten Wilderness consists almost

Fig. 4. Loading (bottom) and surface area (top) of dead fuels as related to elapsed time since burning (age) in the *Abies-Pachistima* habitat type, Pasayten Wilderness.

exclusively of species with low flammability. Some grasses, sedges, and forbs may cure sufficiently to support rapid fire spread during particularly dry years; however, coverage by these species is usually sparse and discontinuous in the forest. The shrubs, on the whole, are even less flammable; they burn actively only when mixed with dead fuels and tend to be more of a heat sink than a heat source. Low shrubs in lodgepole pine stands — *Vaccinium scoparium, Arctostaphylos uva-ursi* — may increase flammability of the needle litter by partially supporting it in a looser, better aerated layer than it forms otherwise.

Tree crowns were estimated to contain up to nearly 18 tons of fuel per acre (Table 4). In general, crown weight increases with stand age, but stand density and composition have an important influence. Thus the two units with the greatest crown weight were only middle-aged, but each contained a large number of heavy-crowned Englemann spruce and subalpine fir. Crowns in the younger, predominantly lodgepole pine stands come to within a few feet of the ground and are more continuous at one level than those in older stands. This ready availability, coupled with the larger quantity of dead surface fuel in the young stands, represents a potential for crown fire out of proportion to the weight of fuel.

THE TOTAL FUEL COMPLEX

Total fuel loading followed the pattern already described for dead fuels (Table 4). Except for the very young and multiple-burned stands the *Abies-Pachistima* h.t. had about twice the tonnage at a given age as the *Abies-Vaccinium* h.t. The former reached 127 tons acre $^{-1}$ by 200 yr and 170 tons acre $^{-1}$ at 400 yr; the latter only 62 tons acre $^{-1}$ at 200 yr (the oldest stand sampled in the h.t.). Adding forest floor and crown weights, both of which increased with age, relatively suppressed the post-fire maximum loading and ac-

Fig. 5. Re-setting the fuel and vegetation clock to near zero. TOP: Engelmann spruce-subalpine fir stand 200+ yr old (Unit 7). Lodgepole pine occurs mainly as fallen trees (foreground). BOTTOM: Two-year-old burn (1970) in part of same stand (Unit 8). Vegetation is sparse, fine fuel is virtually absent, and coarse fuel consists of the charred remains of the fallen trees shown at top.

Fig. 6. Variation in development of fuel and vegetation due to elevation. TOP: Abundant coarse fuel consisting of trees fire-killed 27 yr earlier at 5,300 ft, with dense stand of lodgepole pine saplings (Unit 11). BOTTOM: Sparse fuel and vegetation in stand burned 30 yr earlier at 6,500 ft. Relatively few fire-killed trees have fallen because shorter, cooler summers inhibit wood decay (Unit 7).

centuated the decadence maximum but did not change the general relationship of loading to age.

FUEL RATINGS

Rate of spread ratings arrived at by using the objective key (Fahnestock, 1970) were generally rather low (Table 4). Of the two highest, the 11.5 on Unit 11 resulted from a combination of abundant dead surface fuel and dense reproduction less than 20 ft high with crowns reaching practically to the ground. Numerous dead-and-down Douglas-firs with much fine crown material still intact produced the 12.1 for Unit 12. Other ratings in the 5-7 range also represent the presence of scattered, undisintegrated tops. Virtual absence of fine surface fuel caused Units 4, 6, 7, 8, and 9 to be rated a rock-bottom 1. The ratings obviously are not closely correlated with loading.

Crowning potential averaged mainly low (<4) to medium (4-7). The low ratings signify discontinuous canopies and/or low likelihood that fire could get from the ground into the crowns. The likelihood of crowning was probably underestimated for the units with high post-fire loading because the key does not take into account fuels on the ground. Reverse effect of the same shortcoming makes the 5 rating on recently-burned Unit 8 much too high. With very little fuel on the ground, the snags would not burn.

Low to medium rate-of-spread ratings (1-5) by Region 6 standards (USDA Forest Service, 1968) were assigned to all units because of the paucity of fine fuels. Failure to parallel the two highest key ratings probably resulted from the difference in the fuels looked at when evaluating them: a specific, small area for the key and a general look at the surroundings for the Region 6 fuel type. However, the two methods produced similar results overall. Medium to high resistance-to-control (2-4) appeared appropriate for most units in the *Abies-Pachistima* habitat type. The closer approaches to high (4) reflected mainly the heavier loadings of coarse fuels; but dense brush was a factor on Units 3 and 7, and rocky soil on Unit 15. Consistently low rate of spread and resistance to control characterized the *Abies-Vaccinium* h.t.

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Fig. 7. Two views of typical surface fuel and vegetation at the peak of post-fire fuel accumulation 44 yr after a mature stand burned (Unit 18).

Fig. 8. Relatively light fuel loading following deterioration of fire-killed trees 130 yr after fire (Unit 5). The stand is composed almost entirely of Engelmann spruce and subalpine fir, apparently because the antecedent forest was so old that it contained little lodgepole pine.

DISCUSSION AND CONCLUSIONS

THE FIRE REGIME

Lightning has always been the main cause of fires and their impact in the Pasayten Wilderness. Man-caused fires burned appre-

ciable area only before 1920 and have been insignificant since the 1930's. Lightning fire incidence is relatively low but is sufficient to result in extensive burns by a few very large fires during unusually long summer drought. At other times, fires are fewer and generally small. There is currently no basis for estimating probable time between big-fire episodes; the last one occurred in the 1920's. Fires in a given forest stand are seldom much less than 50 yr apart. The average interval is about 250 yr, and the maximum at least 400 yr.

Protection probably has not greatly altered the natural fire regime. Because the effectiveness of protection began to increase significantly in the 1930's coincident with decreasing summer drought periods, it is impossible to say how much of the subsequent reduction in burned area resulted from protection and how much from favorable weather. However, experience elsewhere indicates that the size of "routine" fires can be held down, but that major conflagrations, which burn most acreage in the long run, cannot be prevented. A possible inference is that acreage saved in recent years has roughly balanced acreage burned by man-caused fires over the entire period of protection. Continued effective protection may result in a pattern made up of only very small and very large fires. In the long run — say several hundred years — variety in the age-class mosaic would decline, but too little time has elapsed to produce such a change to date.

FOREST SUCCESSION

The usual course of forest succession after fire is clear, but not without variations. Lodgepole pine seeds in aggressively and takes over the site. Because of slower initial growth, other species are inconspicuous for many years, even if numerous. If not present initially, Engelmann spruce and subalpine fir gradually invade from surviving trees in intermingled moist areas that did not burn, and Douglas-fir from dry sites where fire intensity was low. The pine reaches its peak around 150 yr; by 200 yr it is going out rapidly. However, occasional trees persist in (or reinvade) stands up to at least 400 yr old. Engelmann spruce and subalpine fir gradually dominate. The fir usually outnumbers spruce but has less volume.

Fig. 9. Successional change in dominant tree species from lodgepole pine to Engelmann spruce and subalpine fir. LEFT: Excellent stand of 190-yr-old lodgepole pine with spruce and fir becoming conspicuous (Unite 3). RIGHT: By 300 yr, spruce, fir, and Douglas-fir dominate; nearly all of the pine is dead, and much has fallen (Unit 4).

Fig. 10. Effect of multiple burns on fuel: TOP: This portion of the 1929 burn had burned twice earlier in the previous 120-130 yr (Unit 16). Little woody fuel remains, and grass is unusually abundant. BOTTOM: This area was a snag patch from an earlier fire when it burned in 1929 (Unit 17). Coarse surface fuel is plentiful, but charred above the roots.

Similarly, fir reproduction usually outnumbers spruce, but the latter is seldom completely absent. To be realistic, one must consider spruce a member of the climax, along with subalpine fir, since old stands without the species are rare to the point of nonexistence. The same thing might be said of Douglas-fir but for its spotty occurrence and known subclimax status elsewhere.

An early lodgepole pine stage is not necessary. Climax species may predominate from the start if fire occurs in a good seed year and only scattered lodgepole pines are present in the antecedent stand. At high elevations and on other severe sites establishment of a new stand, regardless of species, may take place gradually over many decades. However, the scarcity of poorly stocked young stands suggests that quick regeneration is the rule. Also on severe sites, subclimax vegetation may persist longer than is normal elsewhere; e.g., the pure lodgepole pine of Unit 1 on a particularly droughty soil and the Douglas-fir of Unit 12 on a steep, southerly aspect. Finally, repeated fires at relatively short intervals may perpetuate lodgepole pine indefinitely because it fruits early and seeds aggressively on denuded sites.

FUEL SUCCESSION

Fires that cover appreciable area in forests like those of the Pasayten Wilderness Area generate sufficient heat to kill practically all thin-barked trees and a fair share of those with thick bark. A heavy accumulation of big fuel results if the antecedent stand was reasonably well-stocked with pole-size and larger trees. Few fire-killed trees fall during the first 10 yr, and 20 or 30 yr may elapse before appreciable downfall occurs. Typically, most of the trees fall within 25 to 40 yr, and the mass of material remains essentially intact to at least 60 yr after the fire. In the absence of opportunity to follow in full the decline of the post-fire hazard, it is estimated that fire-caused fuels become unimportant to fire spread and intensity in about 100 to 125 yr, but rotten wood and occasional big, sound trunks may continue to hinder control. Flammability should be highest during about the second decade after the fire while fallen branches and twigs are present, but stands of the right age for checking this

deduction empirically were not available.[4]. Competition adds considerable fine- to medium-sized dead fuel during the first 50-100 yr after fire if the new stand is dense, and natural mortality of mature trees of short-lived species may add big material later on.

More than 25 percent of the Pasayten Wilderness east of the Cascade Crest has burned since 1910; eleven fires from 1914 to 1929 accounted for nine-tenths of the burn. Since 40 percent of the commercial forest was classed in 1959 as being less than 11 in. in diameter, it can be assumed that about that percentage of the total area has burned in the last 100 yr. Some of this was double or triple burn like that along the Chewack River, but most observed during travel was single burn. Thus the implication is that fuels on a significant proportion of the Wilderness are near the peak of and on the decline from post-fire maximum loading. To this extent, hazard is decreasing. Measurements and observations in the current study suggest that the middle-aged fuel minimum is short-lived in the Pasayten, largely because the almost ubiquitous lodgepole pine starts to die and fall increasingly by about age 200. The logical inference is that fuel loading is increasing on most of the area that burned more than about 150 yr ago.

In general, both number of fires and area burned increase with area of hazardous fuels and recent burn (Barrows, 1951; Lyman, 1945; Davis and Cooper, 1963). Recent experience in the Pasayten Wilderness appears to have been a contradiction: since the fires of the 1910's and 1920's created large expanses of heavy fuel accumulation, occurrence rate has declined, and burned area rate has dropped by 95 percent. Only one fire of any consequence (1950-1959, 2,320 acres) has started in a recently burned (1929) area, and no evidence was found that very old stands had been especially fire-prone because of abundant fuel. The apparent anomaly is best explained by (1) low occurrence rate, which minimizes the likelihood of fire starts in dangerous fuels, and (2) the relatively unfavorable weather for conflagrations since the fire-created fuels became available. Earlier burns within the 25,000-acre 1929 fire suggest that post-fire fuels may have influenced its spread.

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[4] The author has observed the condition 10-20 yr after fire in stands containing the same species in the northern Rocky Mountains.

There is little reason to believe that protection since the early 1900's has had appreciable effect on fuels in the Pasayten Wilderness. The area lies in a forest zone characterized by rather long periods between extensive burns. Stands in the Wilderness are mostly young in terms of their potential maximum age. The last major fire outbreak was only 45 yr ago. The time under protection since then has not been longer than periods without extensive burning that could occur naturally.

If earlier conclusions are correct, continued protection will have relatively little quantitative effect on the historic cycle of fuel accumulation and decline. Heavy concentrations will continue to occupy big areas burned by conflagrations up to about 75 yr earlier. Scattered smaller patches of intermediate age may be scarce, but total area will not be greatly reduced thereby. The general result will be to concentrate the worst fuels in a few large areas and slightly reduce hazard elsewhere.

IMPLICATIONS FOR MANAGEMENT

The Pasayten Wilderness affords an excellent opportunity for lighthanded management of lightning fires coupled with unabated effort to exclude man-caused fires. The lightning fire regime maintains a pattern of vegetative cover that is pleasingly varied as to kind, density, and age. Rapid regeneration after burning ensures that burned areas soon lose their initial unsightliness and that possible adverse environmental effects are short-lived. The Wilderness is large enough that even quite big fires burn only a small fraction of the total area or the area of any given vegetation type. Topography severely limits the likelihood of fire excursions and invasions except along the Canadian border. The area is so remote from population centers that air pollution from forest fire smoke is unlikely to cause adverse public reaction.

The foregoing discussion strongly suggests that the general characteristics of the Pasayten Wilderness today do not differ significantly from what they would be if protection had never been instituted. The area can be regarded as essentially pristine, altered only locally by trails and structural improvements and somewhat more widely by limited grazing.

On the principle that in wilderness the less management the better, the best fire management in the Pasayten Wilderness would be to let all lightning fires burn and prevent man-caused fires. Some modifications to the ideal are necessary because certain lightning fires will prove unacceptable and not all man-caused fires can be prevented. The trick is to detect and suppress the fires that are defined as unwanted. Existing methods appear to be effective for man-caused fires. Lightning fires that threaten to run outside the Wilderness, especially into Canada, would constitute the other main unacceptable category. Provision for peripheral detection and surveillance and for suppression of threatening runs would be necessary. Fuel reduction outside some stretches of the Wilderness boundary (probably not feasible in Canada) could be a valuable supplement to or even a substitute for suppression within the Wilderness. Conceivably fire deep within the Wilderness could threaten people or property (most likely administrative improvements) and so require extraordinary action. Generally it should be simpler to keep users out of dangerous areas or to rescue them than to suppress a threatening fire. Even in heavily used areas, forest fires rarely kill today, and the few victims usually are fire fighters. The cost of protecting property in the Wilderness is likely to be many times greater than the replacement cost.

The suggested change in fire management policy should have little or no physical and biological effect, but a significant decrease in cost of administration should result. Obviously, direct savings would accompany cessation of detection and suppression of fires well within the wilderness boundary — more than 60 percent of all fires — and the further withholding of suppression from all except threatened fire excursions. An immediate benefit to wilderness values would result from termination of frequent, low-level, detection-suppression patrols by multi-engined aircraft, which are irritating to many wilderness users (including the author and the president of The Wilderness Society). Ultimately the cost of maintaining improvements should go down. Fire control has always been a major reason for building and maintaining trails to high standards. Back-country cabins are used largely by fire guards and trail crews. Forest Service policy

calls for elimination of cabins in wilderness; reduction in utility would favor their removal.

In summary, fire management in the Pasayten Wilderness as opposed to fire control appears scientifically sound, environmentally safe, and economically attractive. The question of political—i.e., public—acceptance can only be determined by testing, but experience in Sequoia-Kings Canyon National Park suggests a favorable response, given proper publicity (Kilgore, 1973).

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