

S. G. Pickford

College of Forest Resources
University of Washington
Seattle, Washington 98195

G. R. Fahnestock

Forest Fire Consultant
16310 North Ashworth Avenue
Seattle, Washington 98133

and

R. Ottmar

Forestry Technician
Pacific Northwest Forest
and Range Experiment Station
Seattle, Washington 98115

Weather, Fuel, and Lightning Fires in Olympic National Park

Abstract

Seven hundred forty-seven forest fires burned 2502 ha in Olympic National Park, Washington (exclusive of the coastal strip), from 1916 to 1975. The 274 lightning fires accounted for 81 percent of the area burned; 37 fires larger than 4 ha accounted for 96 percent of the area burned by lightning fires. Lightning started fires in only 22 of the 60 years, although 3-50 thunderstorms per year occurred during the summers of a 19-year sample period. Probability of one or more fires resulting from a thunderstorm depended on the number of days without 2.5 mm of rain preceding the storm. Eighty-seven percent of the fires and all but one of the fires larger than 40 ha burned in the northeasterly half of the Park, presumably because of lower precipitation. More than half of the fires started above 1220 m elevation, and four-fifths above 915 m. Differences in fuel types and quantities had little influence on fire occurrence or behavior. Most fires started and most areas burned in the subalpine zone, which has the lightest, least continuous fuels.

Introduction

Water, not fire, is the ancient element that comes first to mind upon mention of Olympic National Park. The west side of the Olympic Peninsula in Washington is the wettest spot in the contiguous 48 states of the U.S.A. and seems, therefore, an unlikely place to study the natural role of fire. However, available weather and fire statistics reveal extensive lightning activity.

In 1976, the Pacific Northwest Region of the National Park Service contracted for a preliminary study of the fire potential within Olympic National Park.¹ This paper reports the major findings of that study.

The Park comprises about 323,890 ha of land, most of which lies as a solid block in the heart of the Olympic Mountains (Fig. 1). Elevations range from a few tens of meters above sea level to 2428 m at the crest of Mt. Olympus. Precipitation at peripheral

¹Contract #CX-9000-6-0116. Detailed report on file at Olympic National Park Headquarters, Port Angeles, Washington, and College of Forest Resources, University of Washington, Seattle.

stations averages 2550-3680 mm annually except in the northeastern rain-shadow area, which receives as little as 760 m. July-August precipitation averages less than 5 percent of the total. Normal summer afternoon temperatures at lower elevations vary from 15 to 20°C, usually accompanied by relative humidities near 60 percent. The prevailing wind in summer blows from the west and northwest (Phillips and Donaldson, 1972).

Dense coniferous forest predominates on the two-thirds of the Park that is below

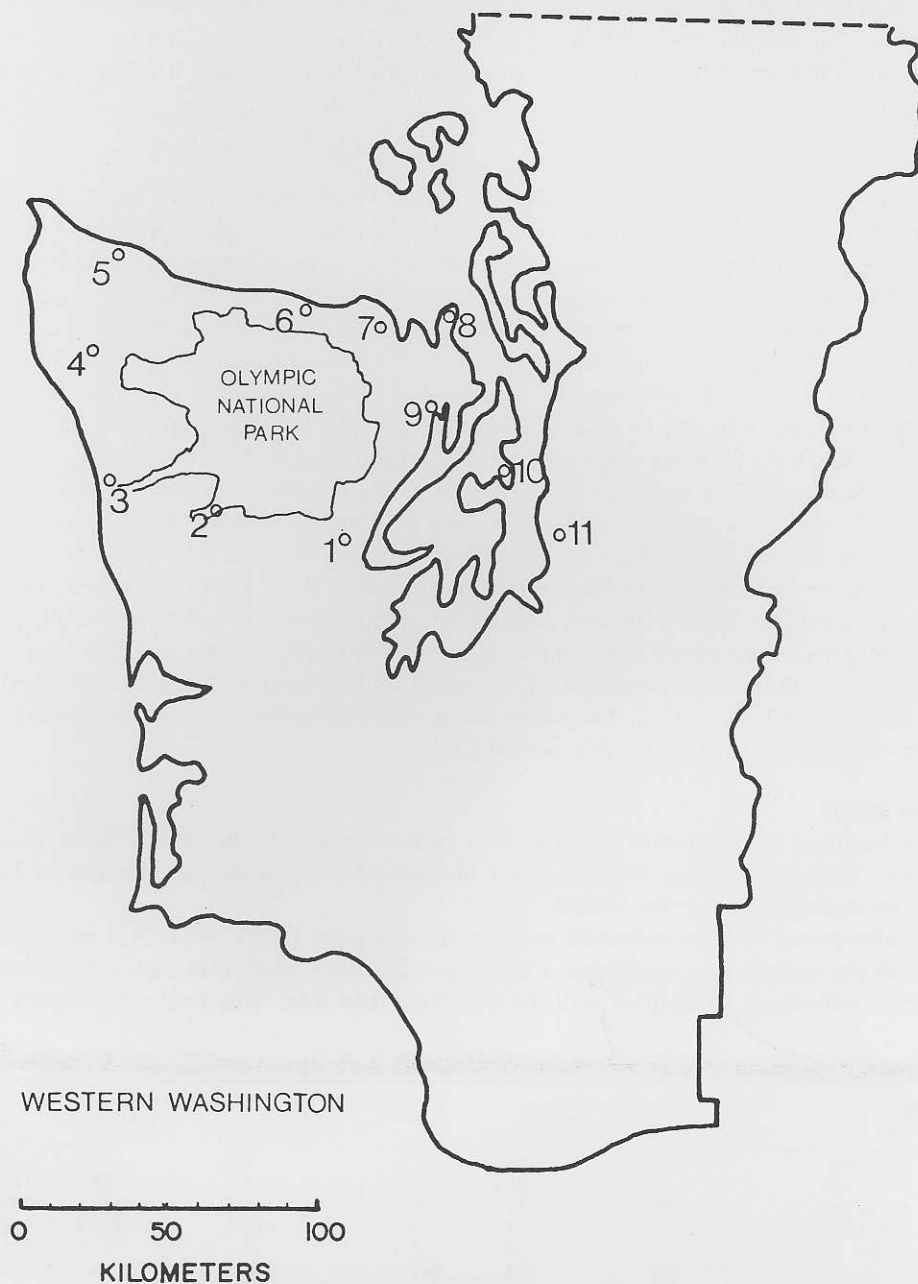


Figure 1. Location of Olympic National Park and weather stations used for references: 1. Cushman Dam; 2. Quinault R.S.; 3. Clearwater; 4. Forks; 5. Clallam Bay; 6. Port Angeles; 7. Sequim; 8. Port Townsend; 9. Quilcene; 10. Bremerton; and 11. Seattle/Sea-Tac.

timberline—generally 1670-1830 m. The main species are Douglas-fir (*Pseudotsuga menziesii* Mirb. Fromes), western and mountain hemlocks (*Tsuga heterophylla* Rap. Sarg. and *T. mertensiana* (Bong.) Carr), western redcedar (*Thuja plicata* Donn., sub-alpine and Pacific silver firs *Abies lasiocarpa* (Hook.) Nutt., and *A. grandis* (Dougl. Forbes), western white and lodgepole pines (*Pinus monticola* Dougl., and *P. contorta* Dougl.), Alaska yellowcedar (*Chamaecyparis nootkatensis*) (D. Don), and red alder (*Alnus rubra*) Bong. Fonda and Bliss (1969) identified the major community types as Douglas-fir, Douglas-fir—western hemlock, western hemlock—Douglas-fir, and silver fir—western hemlock in the montane zone; and silver fir—mountain hemlock and sub-alpine fir in the subalpine zone.

Methods

The 1916-1975 fire history of the Park was compiled from records of the Pacific Northwest Region, U.S. Forest Service, Portland, Oregon, and from those records of Park Headquarters, Port Angeles, Washington. Information on thunderstorm occurrence came from fire lookout and weather station observations obtained by the Washington State Department of Natural Resources for the years 1945-1963. Published weather records and summaries for the same period from 11 peripheral stations (Figure 1) provided data on precipitation and wind (Phillips and Donaldson, 1972). Probability that occurrence of lightning would start one or more fires was calculated as a function of the number of rainless days since a day on which all 11 stations reported at least 2.5 mm of rain.

Surface fuels were measured by the line-intercept technique (Brown, 1974) along 10 or 15 randomly oriented transects in each of 8 stands representing 7 community types (Fonda and Bliss, 1969). At the end of each transect, duff depth was measured and converted to weight according to relations found by Balci (1964); expected initial rate of spread of surface fire and probability of crownfire occurrence (crowning potential) were determined with objective keys (Fahnestock, 1970); and fire rate of spread and resistance to control were estimated with reference to regional standards (U.S. Forest Service, 1968). Extensive reconnaissance indicated that the samples were sufficiently representative for this general study.

Fire History

The statistical record showed that 747 fires burned about 2502 ha from 1916 through 1975 (Table 1); of these, 63 percent were man-caused, but lightning fires accounted for 81 percent of the total area burned.

Man-caused fires are an annual feature; only two years (1954, 1972) had none. The maximum number in a single year (1965) was 23. Since 1946, man-caused fires have burned only about 10 ha in all, with no fire larger than 4 ha. This good record appears

TABLE 1. Summary of forest fire experience 1916-1975.

Size Class	Number of Fires			Hectares Burned		
	Man-caused	Lightning	All	Man-caused	Lightning	All
A (<.1 ha)	408	159	567	2.8	2.0	4.8
B (.1-3 ha)	47	78	125	34.0	77.3	111.3
C (3-30 ha)	16	27	43	283.0	415.8	698.8
D (30-300 ha)	2	7	9	145.7	586.2	731.9
E (>300 ha)	—	3	3	—	955.5	955.5
TOTAL	473	274	747	465.5	2,036.8	2,502.3

due to effective prevention and prompt suppression, especially in view of greatly increased visitor use.

By contrast, lightning fires occurred in less than one-third of the past 60 years (Figure 2). Six years accounted for 82 percent of all lightning fires; three years had more than 50 fires each. Ninety-four percent of the total area burned by lightning fires occurred in only four years, three of which were also high-occurrence years. Fifty-seven percent of all lightning fires burned less than 0.1 ha each; another 29 percent were smaller than 4 ha, and only 4 percent (11 fires) exceeded 40 ha. The largest fire in 1924 burned 348 ha.² A downward trend in maximum fire size may reflect improving fire-control capabilities and changing fire control policy. In the early days, inaccessible

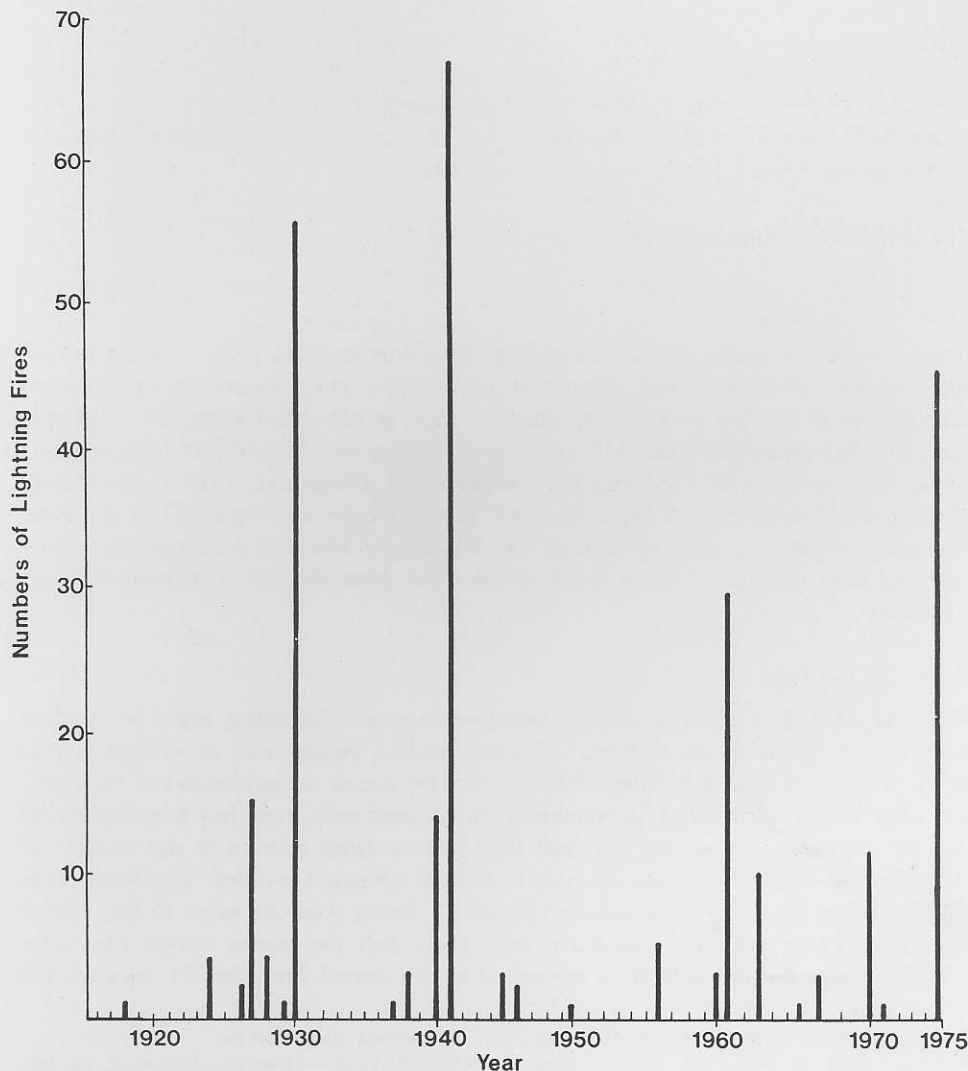


Figure 2. Annual occurrence of lightning fires, 1916-1975.

lightning fires had low suppression priority and could burn unmanned for considerable periods (William Goodpaster, Hoodspout, Washington, pers. comm.).

Extensive stands of relatively young forest containing occasional fire-scarred older trees bear witness to fires antedating the statistical records. The largest such areas are in the north and northeast part of the Park. Limited fire-scar dating placed the last fire in the Elwha at 1891 and that in Maiden Creek at 1901. Another fire had occurred about 45 years earlier in Maiden Creek, and still older scars undatable with the period of exploration and early development suggest the fires were man-caused, as others in the general area are known to have been.³

Some areas burned more than once, as evidenced by occasional deeply scarred trees, usually western redcedar, with the wood exposed by the first fire charred by a subsequent fire. We found one of these that had last burned more than 220 years ago, judging from the charred face. Ages of old, evenaged Douglas-fir stands were 300-plus years in several instances, suggesting that the Olympic Peninsula experienced the same fire episode that burned millions of hectares on Vancouver Island and the adjacent mainland of British Columbia (Schmidt, 1970). Although lightning probably caused most prehistoric fires in the Park, Indians may have started some, since certain tribes (e.g., Quilleute, Quinault) hunted in the interior during summer (Singh, 1966).

Fire in Relation to Environmental Factors

Weather Effects

Occurrence of Lightning

Thunderstorms generally develop in western Washington when cool, unstable, marine air is advected aloft over warm continental air. This process commonly takes place when an upper-level low lies over the region or is moving northward along the California coast. Frontal, orographic, and radiational thunderstorms also occur either independently or in conjunction with this situation (Phillips and Donaldson, 1972). From 1945 through 1963, June through September, 447 thunderstorms were reported in the Park, averaging 24 per year and ranging from 3 to 50 per year. Heaviest thunderstorm activity occurred from mid-July through mid-September, but June also had significant numbers of storms.

Occurrence of Fires

Some reported thunderstorms produce no cloud-to-ground lightning, some occur when fuels are too green or wet to burn, and some produce enough rain to extinguish part or all of the fires they start. From 1945 to 1963, for one or a combination of these reasons, lightning fires in Olympic National Park occurred only from July 6 to September 12. The percentage of storms that start fires bears a direct relation to the number of days between the storm and the last rain of at least 2.5 mm (so-called "significant rainfall") at all of the 11 weather stations (Figure 3). Fewer than one storm in five started fires within five days of a significant rain; about half the storms started fires after 15-20 dry days, but upwards of 70 percent of storms started fires after 25 dry days. On

²Since completion of this study, the 1978 Hoh Lake fire burned about 400 ha.

³Olympic National Forest file memorandum 1—INFORMATION—Olympic—Historical, of Jan. 21, 1943, by Vondis E. Miller.

Washington coast; the second, most common in fall and winter, involves development of high pressure east of the Cascades due to inflow of cold continental air (Cramer, 1957). The July 17, 1941 fire "bust" came at the end of the first type of situation; on September 11-12, 1961, winds produced by the second situation caused severe fire control problems on several fires which had started earlier.

Topographic Effects

Physiography

The Park can be divided logically into a western slope that includes only westward-flowing drainages and an eastern section whose streams flow north, east, and south except for the Quinault River above the mouth of O'Neill Creek. As noted earlier, the west slope receives very heavy annual rainfall, the eastern section much less. The eastern section comprises 57 percent of total area, but has had 87 percent of all lightning fires, including all but one of those larger than 40 ha (Fig. 4). The physiographic effect appears to be purely a matter of precipitation.

Elevation

Lightning fire occurrence in Olympic National Park, as in the northern Rocky Mountains (Barrows, 1951), varies with elevation. Eighty-two percent of the fires have started above 914 m and 51 percent above 1220 m. Above 1220 m, occurrence rate has been about the same (1.1/50,000 ha/yr) on both sides of the Park; at lower elevations, the eastside rate (.72/50,000 ha/yr) is about triple that of the westside (.23/50,000 ha/yr). Fires larger than 4 ha accounted for 96 percent of all burned area; 75 percent of this area resulted from ignitions above 1220 m and 91 percent from ignitions above 915 m. Only two fires that reached 40 ha started below 915 m.

Fuel Effects

A fuel-type map of the Park (in Olympic National Park Fire Atlas) as of about 1940 shows roughly 90 percent of the area as non-forest or low to moderate in both expected rate of fire spread and expected resistance to control (U.S. Forest Service, 1968). Relative numerical ratings corresponding to descriptive words are:

	Low	Moderate	High	Extreme
Rate of spread	1	5	25	125
Resistance to control	1	2	4	8

The fuel-type map, adapted from the U.S. Forest Service's 1936 "Forest Type Map for the State of Washington," shows fuel hazard in subalpine and some bottomland forest as Low-Low, in other oldgrowth as Low-Moderate, and in young forest (less than 100 years old) as mostly Moderate-Moderate, with some areas of Moderate-Low and Moderate-High. A few thousand hectares of recent burn, in scattered patches, have higher ratings due to the presence of standing and fallen fire-killed trees. The old map still gives a generally valid picture of fuel hazard in the Park.

Surface fuel loading tends to be light (<112 tonne/ha) in subalpine community types and moderate (112-224 tonne/ha) in montane types that have been undisturbed for a long time (Table 2, Figs. 5, 6). Expected rate of spread is low to moderate according to U.S. Forest Service (1968) standards and never more than 12 (usually much lower) on the 100-point scale of an objective key (Fahnestock, 1970). Resistance to control is generally low to moderate. Probability of crownfire is moderate to high

TABLE 2. Dead fuels and fuel ratings in relation to habitat type.¹

Community Type ²	Woody Surface			Forest Floor ³	Total Surface Fuel	Snags	Fuel Rating ⁴			
	<7.6 cm	>7.6 cm	All				By Key ⁵		R-6 R/S	Standard R/C
							R/S	C/P		
	tonne/ha			no./ha						
Subalpine types :										
LP	6.1	53.6	59.7	26.9	86.6	27	2	7	Mod.	Low
AF	6.3	53.4	59.7	28.7	88.4	16	7	6	Low	Mod.
MH-SF	4.7	16.4	21.1	23.5	44.6	3	1	3	Low	Mod.
Montane types :										
DF (Sa)	6.9	61.0	67.9	43.7	111.6	2	4	2	Low	Mod.
DF (He)	9.6	26.2	35.8	57.2	93.0	2	4	3	Low	Low
DF (Bu)	6.3	64.8	71.1	37.0	108.1	40	2	4	Low	Mod.
DF-WH	9.0	82.3	91.3	57.2	148.5	8	1	2	Low	Mod.
WH-DF	15.9	119.9	135.8	60.5	196.3	5	4	3	Low	Mod.
WH-DF (Bu)	9.6	216.8	226.4	168.1	394.5	9	7	4	Mod.	High

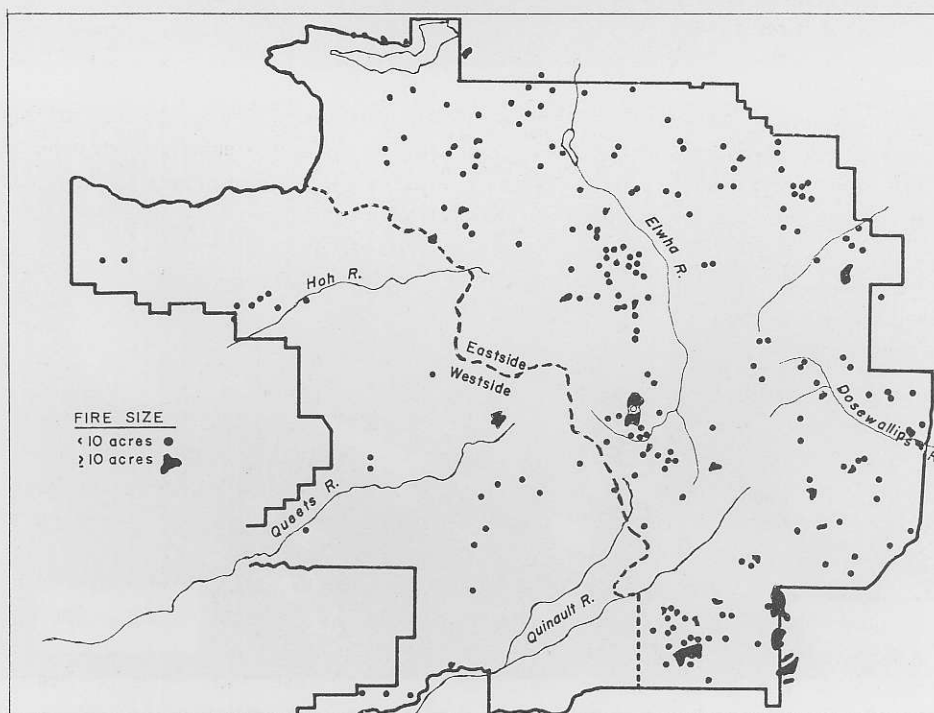
¹According to Fonda and Bliss (1969).²AF=Subalpine fir; DF=Douglas-fir; LP=Lodgepole pine; MH=mt. hemlock; SF=Pacific silver fir; WH=western hemlock; (Bu)=1917 burn; (He)=herbaceous understory; (Sa)=salal understory.³On the basis of 13 tonne/ha per cm of depth (Balci, 1964).⁴R/S=rate of spread; R/C=resistance to control; C/P=crowning potential.⁵On a relative scale of 0-100 for R/S and 0-10 for C/P (Fahnestock, 1970).⁶On descriptive levels of Low, Moderate, High, and Extreme (USDA Forest Service, 1968).

Figure 4. Lightning fire locations and area burned in Olympic National Park, 1916-1975.

(3-7) in the subalpine zone, low to moderate (2-4) elsewhere. Crown fuel is abundant but relatively unlikely to ignite initially because of wide separation from surface fuel. A 59-year-old burn (man-caused) in montane forest (Table 2) had by far the heaviest dead-fuel loading and the highest fuel-type rating (Moderate-High). The worst fuels seen (but not measured) rated Extreme-Extreme, and were in a previous winter's blow-down just east of the Elwha River above Elkhorn Guard Stations (Fig. 6d). Occurrence



Figure 5. Forest and fuels of the subalpine zone; a. General view, showing discontinuity that tends to limit fire spread; b. View in the very common oldgrowth subalpine fir type with typically patchy fuel.

of older blowdowns nearby emphasized the known effect of occasional high winds as a cause of high fuel hazards.

Fuel types for the east side of the park can be redefined somewhat to incorporate a few refinements based on the present study. The entire subalpine zone is rated as Low-Low. (Some of the old burns technically still may have higher hazard, but they are too small and scattered to be of consequence.) Both oldgrowth and younger montane forest is Low-Moderate. However, separate mapping of the two age-classes appears desirable because they present somewhat different suppression problems: bigger wood to cut in the oldgrowth, higher probability of crowning in the young forest. Oldgrowth is also divisible into Douglas-fir and other species because of variation in resistance to control from very low in the herbaceous-understory (Fig. 6b) to high in the salal phase (Fig. 6c) (Fonda and Bliss, 1969). The "non-commercial rocky" classification on the 1936 forest type should be rated Low-High: fires spread slowly in the sparse fuel, but are hard to control because of rough terrain and rocky soil.

Fire Impact

Lightning fires of the past 60 years in Olympic National Park have had negligible impact, in terms of area burned. At the present rate, nearly ten thousand years would be required for the whole Park to burn over once. As noted earlier, however, there is ample evidence of much more extensive burning before the period of record. In any case, impact is a matter of what fire does to an ecosystem, not just how much area it covers.

A variant of the catastrophic fire regime prevails in the Park, as in other moist conifer forests made up of short-needled species (Fahnestock, 1976). That is to say, fires of appreciable size tend to occur at long intervals, kill a large proportion of the trees, and leave more fuel, consisting of fire-killed trees, than existed before. The subalpine situation fits the picture especially well: the fires of the twentieth century there are highly visible from the air because large living trees have been virtually eliminated, but dead trees are conspicuous, both standing and down. Similarly, the sharp edges and even-aged expanse of some relatively young stands appear to show the outlines of older fires rather precisely. However, low elevation burns in old growth can be hard to identify from the air. Mortality may be limited to thin-barked, sub-canopy species—hemlocks, true fir, some redcedar—leaving a nearly continuous high cover of Douglas-fir and big cedar crowns; e.g., the 1938 burn traversed by the Lake Constance Trail.

The really significant fact of fire impact in the Park is that burned areas are reforested quickly and completely. The extensive young-growth areas became established within a decade of the fires that gave rise to them, and the stands are denser than a timber-management forester would want, often of the "dog-hair" type. Young trees are less prominent and stands sparser at high elevations, but this situation is to be expected because slow development and spotty distribution are characteristic of subalpine forest. Thus, the qualitative impact of fire is to revise general age-class structure and species composition, not to cause prolonged denudation.

Summary and Conclusions

Lightning-caused forest fire is a significant natural process in Olympic National Park. From 1916 to 1975, one year in three has had at least one fire, one in six has had 10 or more; appreciable area burned one year in 15. Nevertheless, the net fire impact was

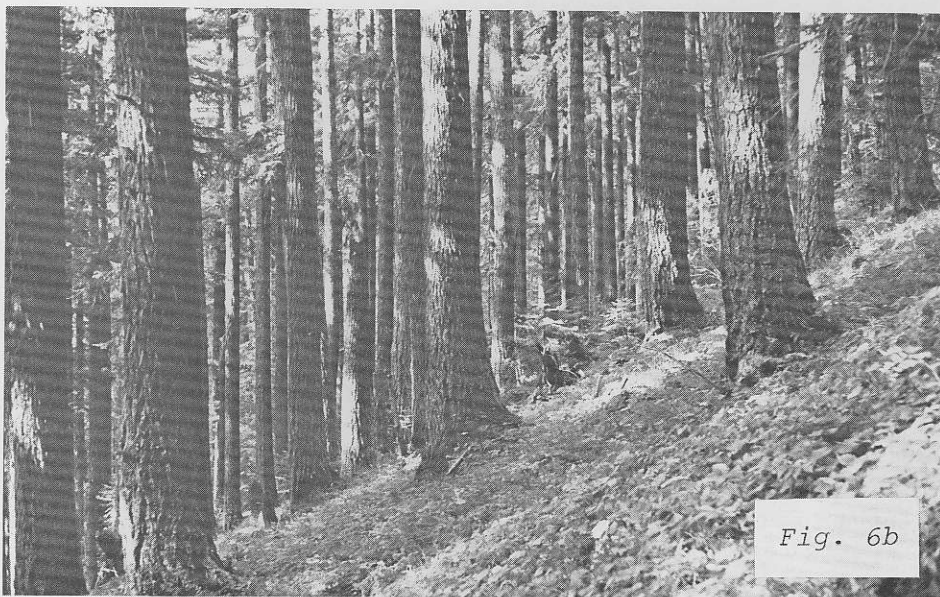




Fig. 6c



Fig. 6d

Figure 6. Forest and fuels of the montane zone: a. Typical Douglas-fir—western hemlock type; b. Herbaceous phase of Douglas-fir type; c. Salal (*Gaultheria shallon*) phase of Douglas fir type; d. Recent blowdown in the Douglas-fir—western hemlock type.

negligible during the period: 2502 ha burned, but no fire was larger than 348 ha. Fire-scarred trees and extensive evenaged stands are evidence of big fires at long intervals. The most recent of these (late 1800s) may have been man-caused; earlier big fires probably resulted from lightning. During the period of record, man's activities have been responsible for nearly twice as many fires but only one fifth as much burned area as lightning.

Over and above the production of lightning, weather is the main determinant of when fires occur and how much area burns. The probability of a lightning fire occurring depends on elapsed time since a rain of at least 2.5 mm, ranging from less than 30 percent after eight dry days to >70 percent after 28 days. Long dry periods are associated with easterly flow produced by well-understood and rather predictable synoptic weather situations.

Topography largely determines where fires start and are most likely to become large. About 87 percent of lightning fires have started in the drier east side of the Park. More than half of the fires and 75 percent of the burned area occurred above 1220 m.

Fuel hazard is low to moderate over most of the Park; high-hazard areas are scattered and relatively small. The subalpine zone has the lowest hazard but the greatest number of fires and area burned.

The current exploratory study is hardly sufficient basis for sweeping conclusions or firm management decisions, but it has some strong implications and indicates direction for future research:

- (1). Over rather long time periods, the impact of uncontrolled lightning fires would be tolerable throughout most of the Park because of small extent and rapid recovery of burned areas;
- (2). To the extent that fire protection is considered necessary, weather forecasts and simple precipitation records can be used to direct the effort and minimize cost;
- (3). Fuels are not a critical variable governing ignition and spread of lightning fires. Sufficient fuel exists practically everywhere to support fire spread; but hazard ratings are mostly low to moderate, with too little contrast to affect management decisions significantly. However, high-hazard fuels in heavy visitor-use areas are a factor to reckon with in protection from man-caused fires; and
- (4). Fire history investigations in selected areas of the Park should be undertaken to provide better understanding of the periodicity of major fires. Climatic history should be studied concurrently, as feasible, to find out how long-term weather fluctuations affect fire periodicity.

Acknowledgments

The National Park Service, Northwest Region, financed this study through a grant to the University of Washington, College of Forest Resources. The authors are grateful for the interest and assistance of Olympic National Park personnel, notably Gordon Boyd, Paul Crawford, and Bruce Moorhead.

Literature Cited

- Balci, A. N. 1964. Physical, Chemical, and Hydrological Properties of Certain Western Washington Forest Floor Types. Univ. Wash., Seattle. Ph.D. thesis. 192 pp.
- Barrows, J. S. 1951. Forest Fires in the Northern Rocky Mountains. USDA For. Serv. North. Rocky Mountain For. & Range. Exp. Sta. Pap. 28. 251 pp.

- Brown, J. K. 1974. Handbook for Inventorying Downed Woody Material. USDA For. Serv. Gen. Tech. Rep. INT-16. Intermountain For. & Range Exp. Sta., Ogden, Utah. 24 pp.
- Cramer, O. P. 1957. Frequency of Dry East Winds over Northwest Oregon and Southwest Washington. USDA For. Serv. Pacific N.W. For. & Range Exp. Sta. Res. Pap. 24. 41 pp.
- Fahnestock, G. R. 1970. Two Keys for Appraising Forest Fire Fuels. USDA For. Serv. Res. Pap. PNW-99, Pacific N.W. For & Range Exp. Sta. 26 pp.
- . 1976. Fuels, fires and flora as factors in wilderness management: the Pasayten case. Tall Timbers Fire Ecol. Conf. Proc. 15:33-69.
- Fonda, R. W., and R. C. Bliss. 1969. Forest vegetation of the montane and subalpine zones. Olympic Mountains, Washington. Ecol. Monogr. 39:271-301.
- Phillips, E. L., and D. R. Donaldson. 1972. Washington Climate for These Counties: Clallam, Grays Harbor, Jefferson, Pacific, and Wahkiakum. Wash. State Univ. Coll. Agr. E. M. 3708. Unpaged.
- Singh, R. R. P. 1966. Aboriginal Economic System of the Olympic Peninsula Indians, Western Washington. Sacramento Anthro. Soc. Pap. 4. 135 pp.
- USDA Forest Service. 1968. Guide for Fuel Type Identification. Region 6, Portland, Oregon. 48 pp.

Received March 14, 1978

Accepted for publication January 17, 1979