

Fire and Other Disturbances of the Forests in Mount Rainier National Park

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The recent history of catastrophic disturbances in forests was reconstructed at Mount Rainier National Park. Basic data were ages of trees based on ring counts of early seral conifer species and maps of age-class boundaries from field work and aerial photographs. Maps illustrate age classes of the forests and show disturbances from fires, snow avalanches, and lahars (volcanic mudflows). Fires are by far the most important major disturbers, followed by snow avalanches and lahars. Fires over 250 ha in size are called fire events. Burns over 1000ha, which may have been one fire or a series of fires within a short time, are called fire episodes. Important fire events or episodes occurred in the years 1230, 1303, 1403, 1503, 1628, 1688, 1703, 1803, 1825, 1856, 1858, 1872, 1886, 1894, 1930, and 1934 A.D. The largest fire episode was in 1230: it affected approximately 47% of the forests in the park. The majority of the forests are over 350 yr old, and several stands are over 1000 yr old. Stands 350 yr and 100 to 200 yr in age are the most extensive age classes in the park. Three fire frequency indices are compared. None describe fire frequency at Mount Rainier well. Natural fire rotation was estimated at about 434 yr. All but two episodes of major fires since 1300 A.D. correspond well with major droughts reconstructed for locations east of the Cascade Range crest. Impacts of humans on the disturbance regime may have increased the frequency of fire in the 1850-1900 period, followed by a decrease in frequency after 1900. Fuel build-up as a result of fire suppression should have no significant impact on fire frequency, since fires are relatively infrequent and fuels accumulate naturally.

INTRODUCTION

Forest disturbances are natural processes in most temperate forest ecosystems. They liberate nutrient capital long imprisoned in large woody debris and tree boles. They open habitat for pioneer species. They create forest mosaics of young and old stands which increase plant and animal diversity. Although climatic fluctuations have occurred throughout the Holocene, information about disturbances in the past 1000 yr can help clarify species distribution and forest development patterns for the last several thousand years.

Knowledge of forest disturbances—type, extent, frequency, and intensity—is fundamental to accurate interpretation of the dynamics of individual forest stands and of the stand mosaic that makes up the land-

scape. This knowledge is, in turn, necessary to predict the role of future disturbances, including the effect of management programs and other human activities.

Mount Rainier National Park contains representative examples of the dense coniferous forests that once covered much of the Pacific Northwest. Disturbances have created a mosaic of forest stands only slightly impacted by recent human activity. The effect of fires, avalanches, lahars (volcanic mudflows), and other disturbances have been preserved in the extensive forests of the park. Little is known, however, about the natural role of disturbances in Pacific Northwest forests, especially on the western slopes of the Cascade Range. This information is important to resource managers who must evaluate the impacts of human activities and plan to deal with future forest disturbances, especially fire.

Patterns of catastrophic disturbance were

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studied at Mount Rainier for 3 yr, to answer several questions. (1) What was the timing and extent of catastrophic forest disturbances during the last 1000 yr? (2) How do fires, snow avalanches, lahars, and other disturbances rank as destructive agents? (3) How are disturbance patterns related to physiographic features and to climatic fluctuations? (4) How has recent human activity altered the disturbance regime?

Small-scale disturbances that affect patches or destroy only part of a stand are probably frequent but do not usually produce a recognizable cohort of early seral trees. Mortality of individual trees or small groups of trees at Mount Rainier may result from biotic influences (disease, root rot, insect attack, girdling by bears), windthrow, small soil mass movements (slumps, slides), snow avalanches, lightning strikes, small fires, and so forth. The small holes created in dense canopies by these disturbances may be significant in allowing some less-tolerant tree species to perpetuate themselves in small numbers.

Larger or catastrophic disturbances permit the establishment of an identifiable, more or less even-aged class of early seral conifers. Three types of events that produce catastrophic disturbances at Mount Rainier were studied: fires, snow avalanches, and lahars (flows of rock, debris, and water that originate on the slopes of a volcano).

Because fire was the most important disturbing agent in the 1000-yr period covered by this study, the paper deals mainly with the fire history of the park. Results have application throughout much of the western Cascade Range, Olympic Mountains, and Coast Ranges of the Pacific Northwest.

THE STUDY AREA

Mount Rainier National Park is located on the crest and western side of Washington's Cascade Range about 100 km southeast of Seattle (Fig. 1). Mount Rainier volcano dominates the park, rising to 4367

m at Columbia Crest. Nine major rivers originate in the extensive glacier system that covers much of the mountain. Timberline varies around the mountain but is generally between 1600 and 2000 m.

Mount Rainier National Park has the long, cool, wet winters and relatively dry, warm summers typical of the Pacific Northwest. Most precipitation falls as rain or snow during the winter (Fig. 2). Orographic effects increase precipitation with elevation; e.g., the average annual precipitation increases from 205 cm at Longmire to 269 cm at Paradise. Precipitation is less in the rainshadow on the northeastern and eastern sides of the mountain, as winter storm winds are predominantly from the southwest and west. This difference, though it affects the distribution of plant communities and the role of fire, is not as dramatic as the climatic change from the west slope of the Cascade Range to the east slope. Temperatures are moderately cool throughout the year (Fig. 2).

Much of the topography reflects Pleistocene glaciation. All major river valleys supported large glaciers as recently as 10,000 yr ago (Crandell and Miller, 1974). Some of the still-extensive systems of glaciers extend as low as 1100 m. Steep-sided glacial valleys separate rolling uplands and sharp ridges which radiate away from the mountain. These produce rapidly changing elevational gradients that combine with changes in aspect to create widely varying microclimatic conditions.

Soils are mainly developed in colluvium and in tephra from Mount Rainier and other volcanoes (Hobson, 1976). Thornburgh (1967) described the soils in his study area, adjacent to the southwest corner of Mount Rainier National Park, as deep, well-drained, coarse-textured brown podzolics intergrading to undifferentiated lithosols. Tephra layers form extensive deposits over the park (Mullineaux, 1974). Some tephras are sufficiently recent and distinct to serve as reference points in evaluating the probable age of charcoal found in and on the soil, particularly:

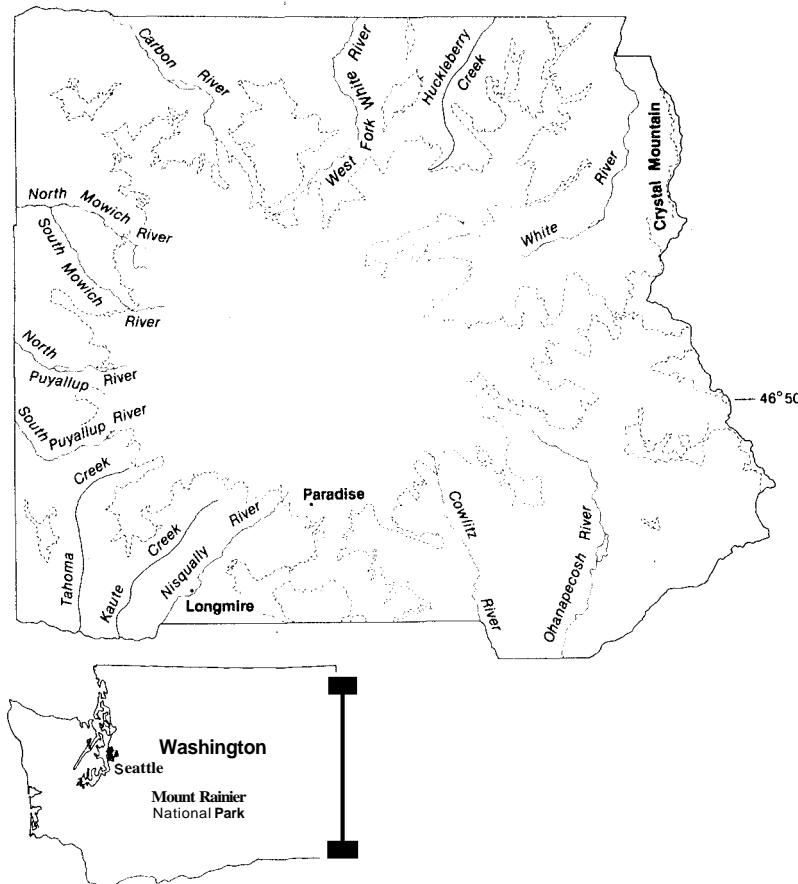


FIG. 1. Outline map of Mount Rainier National Park and location of the park in Washington. The dashed line is approximate upper timberline

Tephra unit	Source volcano	Approximate age (yr)
X	Mount Rainier	150
W	Mount St. Helens	450
C	Mount Rainier	2200
Set P	Mount St. Helens	2500–3300
Set Y	Mount St. Helens	3400–4000

The forests of Mount Rainier National Park are extensive and diverse. Over 56% (53,000 ha) of the total area (94,000 ha) is forested. The composition and successional dynamics of the forests are relatively well known as a result of work by Brockman (1931), Franklin (1966), Thornburgh (1967), and Franklin *et al.* (1979b). Below about 900 m, western hemlock (*Tsuga heterophylfa*) is the dominant climax species.

Above 900 m, it gradually gives way to Pacific silver fir (*Abies amabilis*), the major climax dominant to timberline at about 1600 m. In the extensive areas of subalpine forest–meadow mosaic, extending to 2000 m, whitebark pine (*Pinus albicaulis*), subalpine fir (*A. lasiocarpa*), and mountain hemlock (*T. mertensiana*) are the persistent species. Other widespread tree species include Douglas fir (*Pseudotsuga menziesii*), western white pine (*P. monticola*), western red cedar (*Thuja plicata*), noble fir (*A. procera*), and Alaska cedar (*Chamaecyparis nootkatensis*). Engelmann spruce (*Picea engelmannii*) and lodgepole pine (*P. contorta*) are significant in the northeastern quadrant of the park. Mountain hemlock and the two cedars have climax roles in some habitat types, the

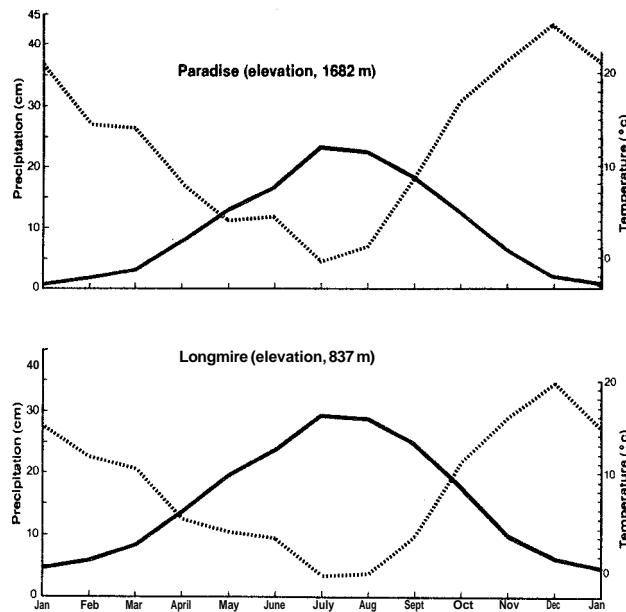


FIG. 2. Average monthly precipitation and temperature, Paradise and Longmire, Mount Rainier National Park. Dashed line, precipitation; solid line, temperature. (Compiled from Phillips, n.d.)

other species are considered seral (Thornburgh, 1967; Franklin *et al.*, 1979b), except in the subalpine forest-meadow mosaic where successional relations are unclear.

Some seral tree species at Mount Rainier are sufficiently shade intolerant and long-lived to be useful in studying the disturbance history of the park. Combinations of Douglas fir, noble fir, western white pine, Engelmann spruce, and subalpine fir dominate early seral stands, depending on site conditions (Thornburgh, 1967; Franklin and Dyrness, 1973). These species do not reproduce well under closed canopies in forests at Mount Rainier.² The ages of trees in stands of these species established after a disturbance therefore provide estimates of the minimum elapsed time since disturbance. Douglas fir is especially long lived, commonly surviving over 700 yr. The

longevity and relative shade intolerance of Douglas fir allow reconstruction of forest disturbance history to nearly 1000 yr ago. Noble fir, western white pine, and Engelmann spruce reach maximum ages of about 600 yr, but subalpine fir generally dies before reaching 400 yr.

Alaska cedar and mountain hemlock are somewhat less useful for dating disturbances because they occasionally regenerate under a closed canopy. Their ages can be used to estimate the minimum time since disturbance when the preferred species for indicating disturbances are not present. Alaska cedar and mountain hemlock may survive more than 1200 and 700 yr, respectively.

Human activity has affected patterns of natural disturbance, especially fire. Several tribes of Indians inhabited the area for at least the past 10,000 yr (Dryden, 1968). Indians used fire to concentrate game, increase berry harvests, and improve hunting visibility and grazing (Taylor, 1922; Morris, 1937; Lutz, 1956); they could have ignited fires which burned into Mount

² This is not necessarily the case in other areas, however. For example, subalpine fir is considered a climax species on the eastern slopes of the Cascade Range and in the Rocky Mountains but is generally replaced by Pacific silver fir in the western Cascade Range (Franklin and Mitchell, 1967).

Rainier National Park. Because of the difficulty of separating them from lightning fires, fires set by Indians are included in the natural fire regime. There is some doubt, in fact, that fires set by Indians were important in the western Cascades (Burke, 1980).

Anglo-Europeans first appeared as a few explorers and trappers moving through the area in the late 18th and early 19th centuries. Settlement in western Washington and modern influences on fire patterns probably began between 1825 and 1835 (Dryden, 1968). The first settlements along the lower Cowlitz River date from about 1845. Significant logging, begun about 1850, was extensive by 1880 but never reached the park boundaries. The first activity of Anglo-Europeans in the park was a homestead settled by Longmire in the 1880s. Early settlers, including Longmire, doubtless used fire freely to clear forests. Such fires often escaped, traveling great distances through forest, and may have burned into Mount Rainier National Park. The park was formally established in 1899, and a forest-fire suppression program was soon begun.

METHODS

All studies of the history of forest disturbance face common problems. The primary problem is the increasing loss of information with time (Lutz, 1956; Schmidt, 1970; Frissell, 1973; Heinselman, 1973; Henry and Swan, 1974). Mortality of individual trees and subsequent stand disturbances erase the record of earlier disturbances. This loss is proportionate to the frequency, intensity, and size of disturbances. In addition, because steep, rugged topography and a large study area present problems of access and thorough coverage, mapping efforts depend on interpreting age-class boundaries from canopy texture on aerial photographs.

The best technique for accurately dating disturbances is counting rings on sections or wedges from scarred trees or stumps (Heinselman, 1973; Rowe and Scotter,

1973; Henry and Swan, 1974; Arno, 1976; Tande, 1977). Aesthetic considerations ruled out taking wedges from scarred trees. Fire-scarred trees are also uncommon at Mount Rainier. Intense, infrequent catastrophic fires usually obliterate previous stands, leaving few scarred survivors. Trees that survive these conflagrations usually suffer only charred bark or have sufficient time to cover wounds with living tissue.

Because analysis of fire scars was not practical, we relied on age structure in stands of early seral tree species to obtain dates for disturbances. We distinguished two categories of large fires: fire events and fire episodes. A single fire over 250 ha in size is a fire event. The probable date is estimated from the beginning of the pulse of seral tree species establishment after the fire. The pulse of regeneration which begins soon after a fire, usually within a year or two, produces a skewed age structure in stands of early seral trees. The number of trees regenerating in a single year generally rises to a peak within 20 yr and may drop to a low level within 50 yr or may continue at slowly declining levels for 100 to 150 yr (Franklin *et al.*, 1979a). A fire episode may be several separate fire events so closely spaced in time that the age structure of early seral stands merge into an age distribution that often spans 50 or more years without evident breaks into age classes from individual fires. Burns from widely separated locations were not considered part of the same episode unless their probable fire dates were less than 20 yr younger than the oldest fire date.

Tree ages were estimated from increment cores and stumps or logs along trails. Over 1000 increment cores and ring counts of stumps were collected during this study. Ring counts were usually made on cores or stumps from relatively shade-intolerant species: Douglas fir, noble fir, western white pine, subalpine fir, and Engelmann spruce. Where these species were unavailable, Alaska cedar and mountain hemlock

were used with the knowledge that they may regenerate under closed canopies. Ages from the latter provide more conservative dates of the origin of stands.

Information was recorded about physical conditions at each site where ring counts were made: percent slope, aspect (degrees azimuth), elevation in meters, and general location. Each tree age was carefully plotted on U.S. Geological Survey 7½-min topographic maps. Features important in distinguishing the type of disturbance were noted. Shallow soil pits were dug and the presence of charcoal layers noted. The position of charcoal layers, in relation to the stratigraphy of tephra deposits of known age, sometimes provided relevant information about time since fire. Fire lines and stand boundaries were noted and sketched on maps.

Records of tree ages included species, rings counted on the cores or stumps using a hand lens and dissecting needle, correction of age, and total age. Diameter breast height (dbh) and diameter at coring height were recorded for each core. Age corrections adjusted ring counts for years to reach core height and for the number of rings remaining between the end of the core and the pith. The radius of large trees frequently exceeded the length of the 65-cm-long corer. The inner growth rate observed on the core was used to estimate the number of rings missing for a tree with a given radius, bark thickness, and core length. Rings were recounted until successive counts were within 10 yr. Whenever possible, the extrapolation from the growth rate of the centermost portion of the core was checked by measuring the widths of inner rings of nearby stumps or cut logs of the same species and age. It is, of course, difficult to hit the center of large old-growth trees even when an increment corer of sufficient length is available. The dates for old fires are the best approximations we could make. Accuracy is best for the most recent fires dated from younger and smaller trees.

Maps of stand age were refined after each

of the three field seasons. Mapping units for stand ages generally exceeded 5 ha. Areas less than 5 ha are not easily mapped from 1:24,000-scale aerial photographs and may not result in the establishment of a cohort of early seral species (Thornburgh, 1967). Coverage of the park was good, although access was difficult and resulted in some undersampled areas. Because of topography and time limits, the age samples were not randomly chosen and do not form a statistically based sample of the park.

Nine overlays of the topographic map of the park were prepared to show the original extent of individual episodes of catastrophic disturbance. Areas covered by reconstructed disturbances were estimated, with the following assumptions:

(1) *Uniformity*. The nature of vegetation responses to fire have not changed during the period covered by this study.

(2) *Age continuity*. Trees in stands of similar age, separated by younger stands but not by significant vegetative or topographic firebreaks, probably originated after the same fire episode. Although fires may burn across them, large expanses of subalpine parkland, rocky ridges, and distances of more than 4 or 5 km were considered significant firebreaks.

(3) *Fire behavior*. Fires tend to burn up-slope to some topographic or fuel barrier.

(4) *Topographic consistency*. This assumption recognizes correlations between particular types of disturbance, topographic location, and charcoal deposits. A surface layer of charcoal indicates past fire regardless of topographic location. Other disturbances occur in characteristic topographic locations and do not leave a charcoal layer at the mineral soil surface. Lahars typically affect stands on the valley bottom and lower slopes (Crandell, 1971). Snow avalanches characteristically operate on steep, gulleyed slopes at relatively high elevations (Luckman, 1978).

(5) *Regeneration span*. The age distribution of the early seral cohort on the western slopes of the Cascade Range fre-

quently spans more than 75 yr (Franklin *et al.*, 1979a; Hemstrom, 1979).

(6) *Conservative limits.* Mapping reconstructed episodes of disturbance emphasizes conservative boundaries as limited by assumptions 1–5 above. Even if there were no physical barriers, disturbances were not extended into areas where indicative survivor trees were lacking, except as allowed by assumptions (2) and (3). Reconstructed burn areas may, therefore, be considered the minimum areas probably burned.

Each assumption can lead to interpretive errors. Subalpine parklands or shrubfields, assumed to be natural firebreaks (2), may not have existed throughout the time interval under study and some meadows may have resulted from fire. Wildfires often burn downhill and may stop at any topographic position when the weather changes. Nevertheless, the assumptions appear reasonable in most circumstances.

To test the validity of assumption (5), we sampled a series of three transects in the historically documented 1886 Cowlitz burn (Hemstrom, 1979). The distribution of ages of the early seral cohorts from the three transects was examined to determine the range of establishment time for early seral trees. In the Cowlitz burn, Douglas fir were still becoming established more than 50 yr after the burn, especially on the dry, open

slopes of Transect 2 (Fig. 3). In older forests, interpretation of slow regeneration after fire may be caused by errors in counting rings or variation from including small disturbances of different ages. But these could hardly account for the consistent regeneration lag in these youthful forests. Some portions of the 1886 burn, once forested and now littered with snags, have not restocked.

A map was prepared to show presently active avalanches and lahars less than 1000 yr old. Avalanches were mapped from aerial photographs. Definition of presently active avalanches was based on the absence of abundant tree regeneration in sapling and larger sizes [see Smith (1974) and Cushman (1976) for discussion of snow avalanche in the North Cascades]. Lahars less than 1000 yr old were mapped from Crandell (1971).

RESULTS

Reconstructed Fire Episodes

The major river drainages at Mount Rainier differ substantially in the distribution of early seral tree age classes (Figs. 4 and 5) (Hemstrom, 1979), illustrating peaks of regeneration pulses following past disturbances and reflecting different climatic conditions. The most extensive currently existing stand age classes and the fire episodes from which they date are explained below.

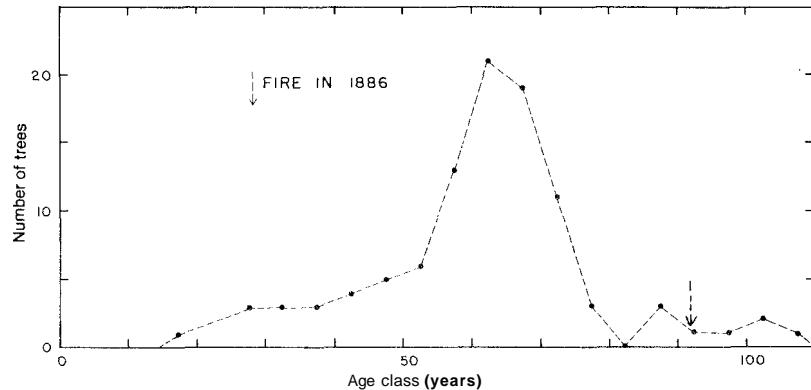


FIG. 3. Distribution of ages from trees sampled along Transect 2 (dashed line) in the 1886 burn in the Cowlitz River drainage. $N = 100$.

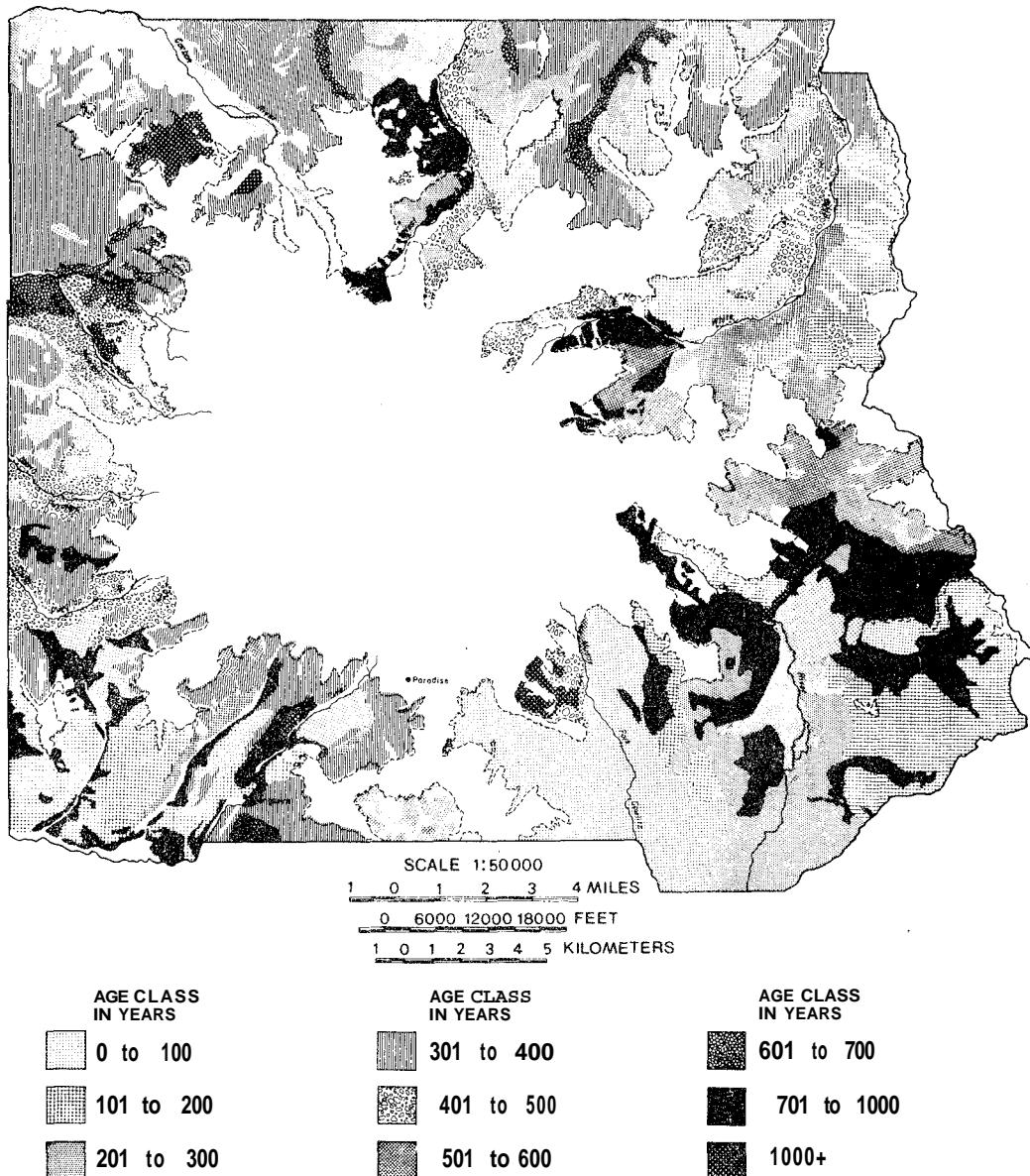


FIG.4. Present stand ages, Mount Rainier National Park.

Forests at several locations around the park show no evidence of disturbance for over 1000 yr (Fig. 4). The oldest trees grow in protected valley bottoms throughout the park and on slopes in the Ipsut and Cataract Creek drainages, tributaries of the Carbon River. Except for avalanches on steeper, higher slopes and a small burn over 600 yr old in the upper reaches of the valley, the forests of Ipsut Creek valley apparently

have been free of major disturbance for over 1280 yr as indicated by conservative age estimates of large Alaska cedar.³

³ Many Cupressaceae make extra rings in arid climates, but we believe Alaska cedar does not in this favorable climate. Alaska cedar can survive fires, but these trees have no identified fire scars. This fact, plus the absence of any long-lived, highly intolerant species, such as Douglas fir, supports our interpretation of a very long, fire-free period for this drainage.

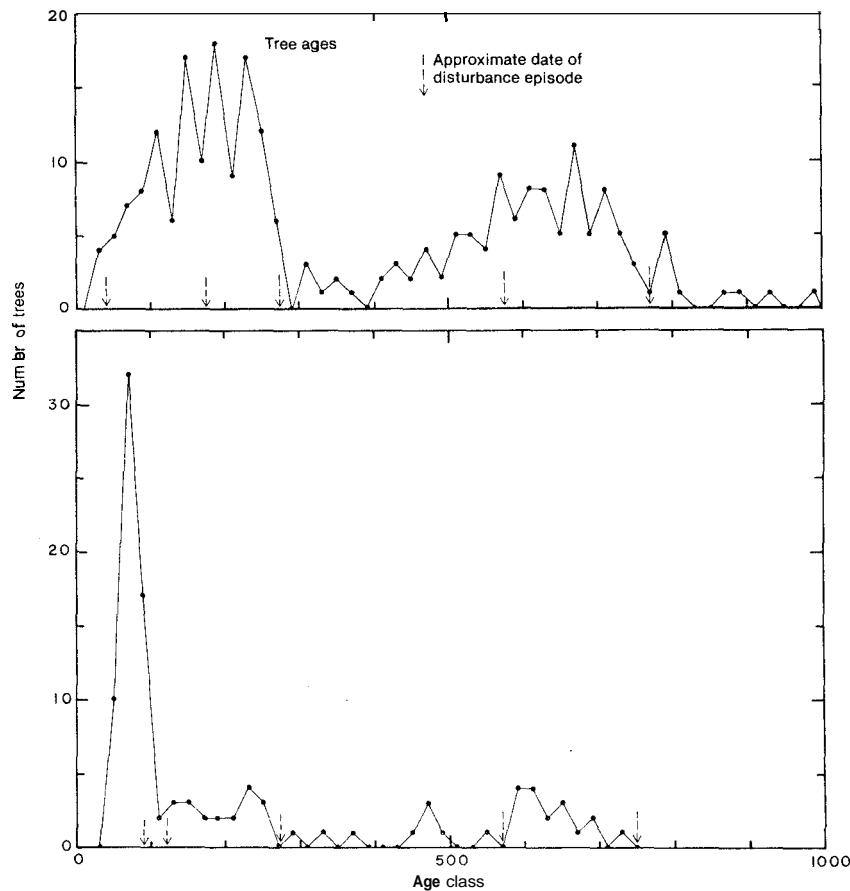


FIG. 5. Distribution of ages from trees sampled in the Ohanapecosh River (top) and Cowlitz River (bottom) drainages.

Forests along Cataract Creek, a tributary to the Carbon River, lack large Alaska cedar but are otherwise similar to those along Ipsut Creek. No early seral trees exist, and there is no evidence of catastrophic disturbance in the lower valley for well over 1000 yr. Both drainages are short, north-facing hanging valleys, bounded on three sides by high, rocky ridges. Other very old stands in the park occupy protected topographic locations. Stands occupying north-facing slopes and alluvial flats along the Ohanapecosh River above its confluence with Chinook Creek have not experienced catastrophic disturbance for over 1000 yr. Many individuals of the 1000-yr-old cohort of Douglas fir have died in the past several centuries, leaving the forest floor littered with logs nearly 3 m in diameter.

The 1000-yr-old stand in the Nisqually River drainage near Cougar Rock Campground has a unique origin compared to other very old stands. Crandell (1971) mapped the landform as part of the Paradise lahar assemblage. The surface of this assemblage is radiocarbon dated at just over 1000 yr old, very close to the maximum age of the Douglas fir growing on it. These trees grew very slowly; many specimens 50- to 100-cm dbh are about 1000 yr old, based on ring counts of stumps. The forest seems to be a first generation stand on nutrient-poor, laharic material. Like other very old stands, the old-growth stand at Cougar Rock is in a protected valley bottom.

The oldest and largest disturbance documented by this study was a widespread fire episode in about 1230 A.D. (Fig. 6A,

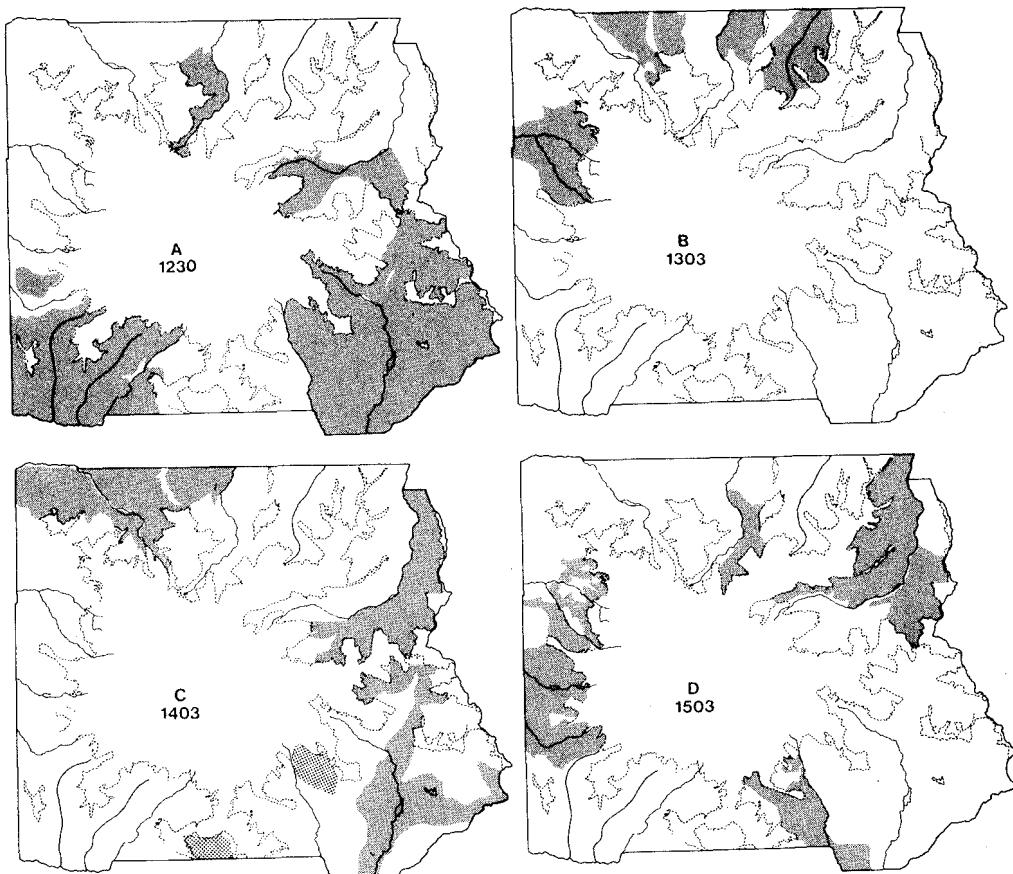


FIG. 6. Reconstructed fire episodes, with shaded areas representing the approximate original extent of the burns. Dates of episodes: (A) is approximately 1230 A.D.; (B) is approximately 1303 A.D.; (C) is approximately 1403 A.D.; (D) is approximately 1503 A.D.; (E) is approximately 1628 A.D. with a small area in the White River burned around 1658 A.D. included; (F) is approximately 1703 A.D.; (G) is approximately 1803 A.D.; and (H) shows areas burned since 1820 A.D.

Table 1). Much of the original extent of this episode has been obscured by subsequent fires. Stands in well-protected spots, since unburned, were destroyed in the 1230 episode, suggesting conditions unusually favorable for large fires. Stands of 750-yr-old trees, usually Douglas fir, still dominate much of the Ohanapecosh River drainage and portions of the White, Nisqually, Cowlitz, West Fork White, and Puyallup River drainages.

The next major disturbance dates from about 1303 A.D. when parts of the Mowich River and nearby Chenuis Creek drainages burned (Fig. 6B, Table 1). The Carbon River valley, which lies between the Mowich

River and Chenuis Creek, contains no evidence of a fire in 1303. Scattered individual trees about 675 yr old are mixed with younger and older trees in the alluvial flats of the West Fork of the White River. The lack of charcoal at the mineral soil surface and the bouldery, gravelly surface suggest that these pockets of trees may have been established after floods or small lahars. Stands of 675-yr-old Douglas fir in the Huckleberry Creek drainage, east of the West Fork White River, appear to have regenerated after this fire episode.

A fire episode almost as extensive as the one in 1230 A.D. burned large areas of forest in the White, Ohanapecosh, Cowlitz, and

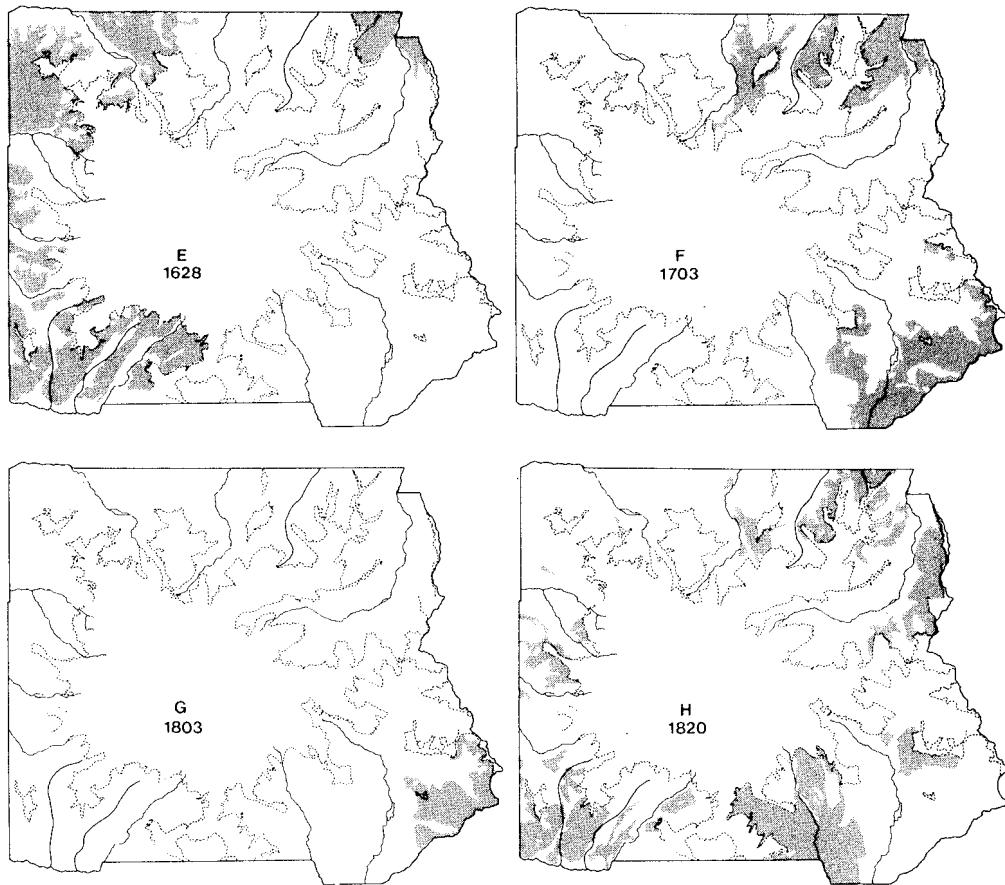


FIG. 6--Continued.

Nisqually River drainages in about 1403 A.D. (Fig. 6C, Table 1). Most of the area burned during this era has subsequently reburned. Only the White and Ohanapecosh River valleys currently possess extensive stands 575 yr old. The age class in these two valleys appears to be connected via Chinook Pass, which is currently subalpine parkland. This fire may have burned up the Cowlitz and Ohanapecosh River valleys, then over Chinook Pass into the White River drainage.

Stands about 550 yr old (originating about 1428 A.D.) dominate lower slopes in the Carbon River valley. The fire in the Carbon River area does not appear to be a continuation of the 1403 fire. Much of the higher elevation forest in the Carbon River valley burned again about 1628, destroying evi-

dence about the original extent of the 1428 fire.

A fire episode 475 yr ago (about 1503 A.D.) consisted of burns in the White, Cowlitz, Puyallup, and South Mowich River drainages (Fig. 6D, Table 1). Apparently it once covered much of the area burned again 120 yr ago (about 1858 A.D.) on Crystal Mountain in the White River drainage. Much of the area burned in the Cowlitz River valley burned again in about 1856 and 1886. Part of the burned area in the South Puyallup drainage had been affected by the Electron mudflow about 125 yr earlier (Crandell, 1971).

One of the largest fire episodes at Mount Rainier National Park in the past 1000 yr took place about 350 yr ago (about 1628 A.D.). Stands of this age are the most ex-

TABLE 1. MAJOR FIRES, THEIR CORRESPONDENCE TO PERIODS OF DROUGHT, AND THE PRESENT AND RECONSTRUCTED ORIGINAL EXTENT OF RESULTING SERAL FORESTS AT MOUNT RAINIER NATIONAL PARK

Episode date (A.D.)	Present forested area		Reconstructed forested area		Drought period
	Hectares	Percent of total	Hectares	Percent of total	
1230	6265	12	25,000	47	
1303	1450	3	6000	11	1290-95'
1403	6910	13	13,700	26	1406-13"
1503	4700	9	13,680	26	1477-90"
1628	11,060	21	12,900	24	1627-33'
1688	1200	2	4410	8	1686"
1703	2700	5	5140	10	1700"
1803	2230	4	2230	4	1801"
1825	2400	5	2480	5	1823-26"
1856	490	1	2800	5	1856"
1858	3040	6	3700	7	1856"
1872	600	1	600	1	1869-73"
1886	3800	7	4280	8	1888'
1934	770	1	770	1	1917-36"

^a No climatic reconstructions available for dates before 1250 A.D.

^b Keen (1937) first- or second-magnitude drought.

^c Blasing and Fritts (1976) abnormally dry winter.

tensive single current age class (Fig. 6E, Table 1), comprising 19% of the present forest area. They dominate upper slopes in the Carbon, Mowich, Puyallup and, to a lesser extent, Nisqually River drainages. Charcoal near the mineral soil surface overlies the W tephra (Mullineaux, 1974) where W is recognizable. Evidently a single fire or a series of very closely timed fires swept up the side of Mount Rainier from the west and burned most of the upper-slope forests in the western half of the park. The wide area affected in the park suggests that this fire probably formed extensive burns outside the park to the south, west, and north. Thornburgh (1967) reports an extensive 370-yr-old age class in his study area adjacent to the southwest corner of the park.

Slightly younger stands are scattered throughout the White River drainage. Because the oldest trees from these areas are consistently 15-35 yr younger than those in stands in the western half of the park, the

White River fires of about 320 yr ago were not part of the 1628 episode.

The next major fire episode occurred approximately 275 yr ago (about 1703 A.D.). Two (probably separate) fire events comprise this episode (Fig. 6F, Table I). One fire approximately 290 yr ago (about 1688 A.D.) occurred in portions of the West Fork White River and Huckleberry Creek drainages. At about the same time, large fires burned on the Ohanapecosh and Cowlitz River drainages. Subsequent, massive fires in the Cowlitz area obliterated most evidence of the 1703 fire. In any case, it was not as extensive as the 1503, 1403, and 1230 fires in the Cowlitz; along the upper slopes of the ridge dividing the Cowlitz and Ohanapecosh valleys, only a few 275-yr-old trees have survived extensive burning since 1703.

Large areas in the Ohanapecosh drainage support 275-yr-old stands. This fire episode is apparent in small stands in the Butter Creek area and must have resembled the

fire 575 yr ago in burning up the Cowlitz River valley from outside the park and into the tributary Ohanapecosh River and Butter Creek drainages. Ages of trees south of the park adjacent to the Ohanapecosh valley match the 275-yr-old ages in the park (Fig. 6F, Table 1).

Many areas in the Ohanapecosh valley burned again nearly 100 years later, about 1803 A.D. Extensive contemporary stands occur outside the park south of the Ohanapecosh valley and in adjacent high elevation areas inside the park southeast of the Ohanapecosh River (Fig. 6G, Table I). Much of the area burned was steep, relatively open subalpine parkland and Pacific silver fir forest.

The next major fire occurred about the time settlers of European extraction arrived in the area, although no evidence links the fire to early settlers or explorers. Extensive stands in the Nisqually River drainage indicate a fire about 1825 A.D. (Fig. 6H, Table 1). The 1825 fire generally did not burn onto alluvial flats forested by stands from the 1230 episode. Maines (1953) mentions an 1835 fire in the park covering about 4000 ha; since no other large fires occurred in the park around that date, his information may have been several years in error.

Large fires were recorded in Oregon and Washington in 1856 (Plummer, 1900; Morris, 1937). Plummer (1900) wrote that the hills north of the Cowlitz River burned in 1841 and 1856. Although we found no stands dating from 1841, remnants of a once-extensive age class dating from 1856 occur in parts of the Cowlitz River drainage (Fig. 6H, Table 1).

Shortly after the Cowlitz fire in 1856, large areas on the slopes above the White River burned (Fig. 6H, Table 1). Relict trees 475 yr old are common in parts of the 1858 burn. Large areas of this burn at high elevation remain poorly stocked to the present. Avalanche tracks frequently dissect the 120-yr-old stands and extend nearly to the river in places. Loss of anchoring tree cover on steep slopes has probably

contributed to more extensive and frequent snow avalanches on the steep slopes east of the White River. Plummer (1900) reported that sheepherders often burned forests to improve grazing. Although no firm evidence links sheepherders to the 1858 White River fires, the name "Sheepherder Burn" persists.

The steep, high-elevation slopes between Huckleberry Creek and the West Fork White River burned in 1872 (Fig. 6H, Table 1). Restocking is not yet complete, presumably because of the severe, high-elevation environment. Frequent avalanches dissect these stands.

Young forests which had regenerated after the 1856 burn in the Cowlitz River valley again burned extensively in 1885 (Fig. 6H, Table 1). This fire burned nearly all of the upper Cowlitz River drainage. Large areas at moderate to high elevation are still poorly stocked. Widespread avalanches, dense stands of vine maple (*Acer circinatum*) and Sitka alder (*Alnus sinuata*), and rigorous site conditions have virtually halted regeneration of conifers in many places. Plummer (1900) lists large fires in the Cowlitz drainage in 1885 which, he said, were repeated burns of areas burned in 1841 and 1856.

Two fires since the 1890s are linked to human activities. A fire believed to have been set by Longmire in 1894 to destroy hornets (Haines, 1953) eventually spread upslope, burning sizable areas of the upper Nisqually River valley. An escaped slash fire burned extensive areas of high-elevation forest and subalpine parkland near the north Puyallup River in November of 1930. Some portions of the area have yet to restock. Fire suppression efforts by the National Park Service may have reduced the size of the fire (Mount Rainier National Park Fire Reports, Form 10-400, 1930).

Three other significant fires occurred after 1900. An area east of the Ohanapecosh River was burned by fires that began outside the park on August 1, 1929 (Fig. 6H, Table 1). Fire report forms (Mount Rainier

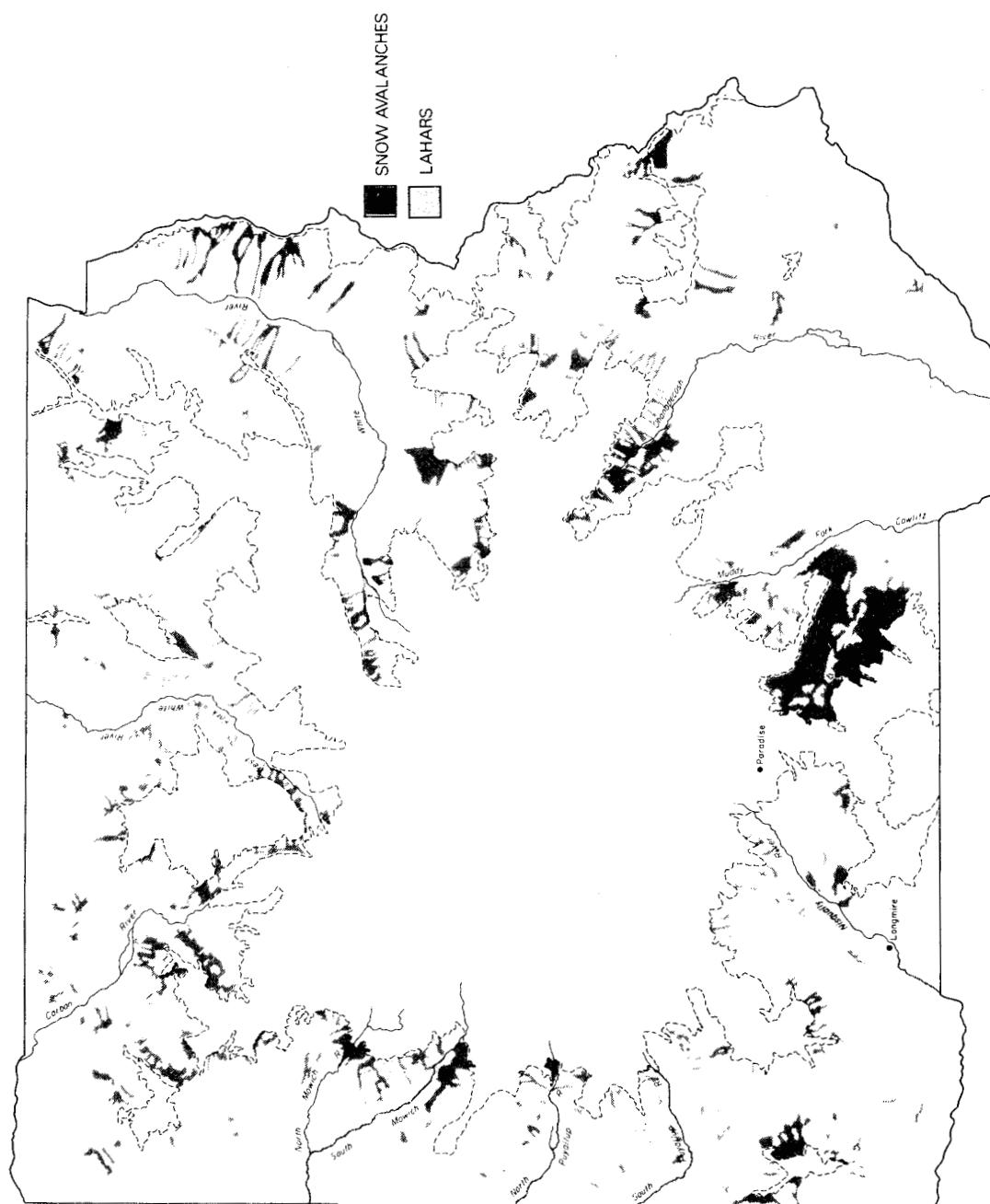


FIG. 7. Area impacted by avalanches in the recent past and by lahars during the last 1000 yr.

National Park, 1929) list the area as part of an old burn of unknown age, possibly dating from the 1803 episode. Part of the area burned in 1929 burned again in July 1934 and September 1935. Two small fires occurred in 1966, one in high-elevation forest and parkland in Grand Park and one on Pigeon Peak near the West Fork of the White River. Lightning was the probable cause of all these fires. The effect of suppression activities on the final size of these burns is unknown.

Other Forest Disturbances

The total area of large snow avalanche tracks in Mount Rainier National Park is about 4270 ha, approximately half of which is in the White and Cowlitz River drainages (Fig. 7). The largest areas of avalanche activity correspond to recent burns. Large, complex avalanche tracks dissect the 1886 Cowlitz burn and the 1858 Crystal Mountain burn. At Mount Rainier, snow avalanches tend to be chronic disturbers of a relatively small area of forest but may become more extensive when fires destroy vegetative cover (Winterbottom, 1974).

Lahar-associated stands form only a small portion of the existing forests of Mount Rainier National Park. During the past 1000 yr, lahars disturbed stands in the White, West Fork White, Ohanapecosh, Nisqually, Kaukz, Tahoma, Puyallup, and Mowich River drainages (Fig. 7) (Crandell, 1971). The 1000-yr-old stands at Cougar Rock Campground near Longmire, even though vegetatively similar to other stands, may be first-generation forest on a lahar of the Paradise lahar assemblage. Smaller stands may have regenerated following lahars 440 yr ago along Tahoma Creek, 30 to 450 yr ago along Kautz Creek, and 120 to 1000 yr ago along the Nisqually River. The Electron mudflow in the Puyallup River drainage reached about 30 mi down-valley from Mount Rainier about 600 yr ago. Fires in the same area about 475 yr ago destroyed most or all of the first-generation lahar forests. Fires in the White River and West

Fork White River valleys also destroyed first-generation lahar stands on lahar surfaces deposited approximately 1000 yr ago. Small stands presently exist on less-extensive, more-recent alluvium along the White River.

DISCUSSION

Climatic Influences

Periods of prolonged drought appear to play a crucial role in the occurrence of major fires at Mount Rainier National Park. To analyze the effects of drought on major fires in the park, we compared the timing of large fires with reconstructions of the area's past climate. Recent dendroclimatological studies have shown good correlation between climatic conditions and tree-ring widths in the Pacific Northwest (Brubaker, 1980), and climatic reconstructions are in progress. The most detailed available reconstructions come from studies of tree rings of ponderosa pine (*P. ponderosa*) in semiarid regions east of the Cascades (Keen, 1937) and other species throughout western North America (Blasing and Fritts, 1976; Fritts *et al.*, 1979). Brubaker (1980) has shown that major climatic fluctuations are comparable on both sides of the Cascade Range. Keen's (1937) reconstructions for eastern Oregon extend back to about 1270 A.D. Blasing and Fritts (1976) reconstructed fluctuations in the winter climate of the Pacific Northwest back to about 1700 A.D. They identified two weather patterns which produce lower precipitation than normal in the Pacific Northwest. One or the other of these patterns occurred in 103 of the 276 yr spanned by their study. Historic records and studies of fire frequency in the Pacific Northwest were also useful (Plummer, 1902, 1912; Fenby, 1914; Morris, 1937; Haines, 1953; Cowan, 1961; Weaver, 1961; Soeriaatmadja, 1966; Schmidt, 1970; see also Fire Report Form 10-400 for Mount Rainier National Park, 1928-1967, and the report on fire protection requirements for Mount Rainier National Park, 1930).

The correspondence between drought and major fire at Mount Rainier National Park is striking (Table 1). Fire episodes occurring in 1303, 1403, 1503, 1628, 1856, 1929, and 1934 A.D. correlate well with first- or second-magnitude droughts from Keen (1937). Of the eight droughts reconstructed for eastern Oregon by Keen (1937), only two—1739–1743 and 1756–1759—lack a corresponding large fire in the park. Fire episodes occurring in 1703, 1803, 1825, 1856, 1858, 1872, 1886, 1920, and 1934 A.D. correspond well with drought winters from Blasing and Fritts (1976). The only major fire in the park not correlated with a reconstructed drought is the large episode of about 1230 A.D., well before Keen's (1937) earliest reconstruction.

This correspondence of drought and fire frequency is widespread in northern temperate to boreal forests (Cwynar, 1977; Heinselman, 1973; Loope and Gruell, 1973; Rowe and Scotter, 1973; Pickford *et al.*, 1977). Haines and Sando (1969) found that large fires in the north-central United States are closely associated with 3 to 8 months of below-normal precipitation, 1 to 3 months of continuous drought or wilt experienced by vegetation, long-term, below-normal humidity, and above-average sunshine. At Mount Rainier, one to several years of weather that is drier than normal may be necessary to bring into juxtaposition dry fuels, low-elevation ignition, and the proper weather to create a favorable situation for holocaustic fires. Brubaker (1980) suggests that droughts lasting 5 yr or more are common in western Washington.

Patterns of Wildfire Over the Landscape

Two important points emerge regarding the distribution of large fires over the landscape at Mount Rainier National Park. First, fire frequency varies with topographic position. Alluvial terraces, valley bottoms, and protected north-facing slopes are often forested with old stands (Fig. 4). Nearly every major river valley contains a streamside old-growth corridor. In the

Ohanapecosh River valley, north- and east-facing slopes are often forested with stands over 700 yr old, whereas adjacent areas south- and west-facing slopes generally support stands less than 350 yr old. A similar contrast between ages on north- and south-facing slopes appears in almost every major drainage.

Second, within the park the White, Cowlitz, and Nisqually River drainages have burned most frequently. In the Nisqually and Cowlitz River valleys, this may be due to a generally southerly aspect and lack of topographic and vegetative barriers that might prevent fires from burning into the park. It is not surprising that fires are more frequent in the relatively drier White River drainage. The extensive stands of old growth in the Ohanapecosh River drainage (Fig. 4) initially appear anomalous because the drainage faces south and opens into the frequently burned Cowlitz River valley; however, high, rocky ridges may shelter these old stands from fires moving up the Cowlitz valley.

Various investigators have devised fire frequency indices. Heinselman (1973) defines natural fire rotation (NFR) as the time necessary for fires with a given frequency to burn over and reproduce an area the size of the study area. Tande (1977) defines the mean fire return interval (MFRI) as the average time between fires of a given size. Van Wagner (1978) defines a fire frequency on the areal distribution of presently existing age classes.

Natural fire rotation, MFRI for fires burning over 10% of the park forest, and Van Wagner's (1978) negative exponential relationship were used with the maps of present stand ages and reconstructed fires to calculate fire frequency at Mount Rainier National Park. Natural fire rotation during the pre-Anglo-European era for the whole park was about 465 yr. During the early settlement era, the fire rotation dropped to 226 yr, perhaps because of increased fire from human action or a climatic change. Since initiation of fire suppression, the fire

TABLE 2. NATURAL FIRE ROTATION RATE (NFR) AT MOUNT RAINIER SINCE 1200 A.D.

Time span	Hectares burned	Percentage of total forest burned	NFR (yr)
1200–1850	85,515	161	465
1850–1900	11,722	22	226
1900–1978	1601	3	2583

rotation has risen to 2583 yr, suggesting that suppression activities may have decreased the extent of fire in the park (Table 2). This apparent decrease in fire frequency may be due to nothing more than the short time interval covered by suppression activities. Similar periods without major fires have occurred in the past and have included droughts nearly as severe as the one from 1917 to 1936.

There are problems in interpreting the natural fire rotation at Mount Rainier. As a consequence of infrequent large fires, fire rotation calculations for short time spans (1850–1900 and 1900–1978) are probably not as meaningful as those for longer times. In addition, natural fire rotations based on the reconstructed fire episodes at Mount Rainier National Park may overestimate the length of actual fire rotations, especially in areas where fires are frequent. Records of older fires are often completely erased in areas that burn frequently. Natural fire rotations calculated for long time spans for areas supporting extensive, young stands would therefore overestimate the fire rotation. Since natural fire rotation for the whole park lumps stands burned by extensive recent fires and old-growth stands together, the fire rotation for the pre-1850 era is probably less than 465 yr.

Van Wagner's (1978) negative exponential age class to area distribution fits poorly at Mount Rainier National Park. Coefficients of determination (r^2) are generally less than 0.60. The problem arises at Mount Rainier because the present area occupied by stands from a given fire episode generally increases with increasing time since the event, just the opposite of the predicted trend of the model.

Mean fire return interval also seems to describe the frequency of fires at Mount Rainier poorly. Tande (1977) used fires that had burned over 50% of his study area in calculating an MFRI of 66 yr. Reconstructed fire episodes at Mount Rainier all burned less than 50% of the area. By adjusting the cut-off level of percent of area burned, widely variable mean return intervals can be calculated. For this reason, the MFRI index is of limited use in comparing fire frequency of different areas.

None of the fire-frequency indices tested adequately represent the large fire regime at Mount Rainier. All depend on area to some extent. Natural fire rotation can be used for general comparisons between areas, but given the variability in the timing and location of large fires at Mount Rainier, an index cannot represent more than a simplistic view of the role of large fires. In fact, since many areas in the park have not burned for over 500 yr and substantial climatic changes may occur within this time frame, there may be difficulties in using past fire history to predict present or future fire regimes. The only relatively certain prediction is that because the macroclimate is typically wet and cool and fuel build-ups high, large fires, when they occur, will be intense.

Relative Importance of Disturbance Types

Fires are by far the most important catastrophic disturbers of forests in Mount Rainier National Park. Parkwide, 90% of the existing stands developed after fire, 7% following snow avalanches, and 2% after lahars. Avalanches are the most frequent disturbance, occurring yearly to once every

decade; large fires occur once every century or so, and major lahars even less often.

Other forest disturbances are important, especially wind and pathogens (insects, root-rot). Wind has been a major forest disturber in the Coast Range, Olympic Mountains, and Cascade Range (Lynott and Cramer, 1966). Although the Columbus Day storm of 1962 blew down more than 11 billion board feet of timber in Oregon and Washington, only small disturbances at Mount Rainier definitely date from this storm. After 50 to 100 yr, documentation of wind as a stand disturbance can be difficult without a detailed stem-by-stem scar analysis (as was done by Henry and Swan, 1974). No large stands were identified that were believed to have developed after disturbances caused by either wind or pathogens.

Implications for Managers

The fire regime at Mount Rainier National Park bears little resemblance to that encountered elsewhere. Fires east of the crest of the Cascade Range tend to be less intense and more frequent (Soeriaatmadja, 1966). In the mixed conifer forests of the Sierra Nevada, fires are more frequent, about every 8 yr (Kilgore, 1973), and less intense. The fire regime in the central and northern Rocky Mountains varies with fire frequency, ranging from less than 10 yr to over 400 yr (Arno, 1980). In the northern Great Lake States, Heinselman (1973) calculated an NFR of up to 100 yr.

Where there are naturally long intervals between fires, fire suppression would alter the composition and structure of the forest only after several centuries. Without large burns, the forested landscape at Mount Rainier would change from a mosaic of age classes to old growth. Eventually, even the long-lived seral species would lose their present prominence. The problem of fuel build-up with fire suppression followed by holocaustic fires does not apply at Mount Rainier. Forests in the park have naturally developed large fuel loads, and these have

probably not increased under present management programs. It is, however, entirely possible that the holocaustic fires of the past would not be amenable to present suppression technology.

CONCLUSIONS

This study of recent forest disturbance at Mount Rainier National Park revealed the following.

(1) Catastrophic disturbances played an important role in shaping the existing forest mosaic of the park. The most important disturbing agent is fire, followed by avalanches and lahars.

(2) Fire occurrence is related to topography. Extensive old stands are found in stream-side corridors and protected north-facing slopes. Stands at higher elevations and with southerly exposures burn more often.

(3) Episodes of major fire appear to correspond to periods of prolonged drought.

(4) Complete regeneration of forests after a catastrophic disturbance often requires more than 75 yr.

(5) Modern human influences on the natural fire regime at Mount Rainier have probably been negligible, although suppression may have limited the size of fires during the 1917 to 1934 drought.

(6) As a result of the infrequency of large fires and the topographic diversity of Mount Rainier National Park, calculations of natural fire rotation (Heinselman, 1973), Van Wagner's (1978) index, and mean fire return interval (Tande, 1977) are not particularly useful.

(7) Wildfire has been very important in the recent history of the park forests and, as a result, must be reviewed as an important agent in the ecosystems if they are to be maintained in a natural state.

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