AN ABSTRACT OF THE THESIS OF

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in BOTANY (PLANT ECOLOGY) presented on May 7, 1979

Title: A RECENT DISTURBANCE HISTORY OF FOREST ECOSYSTEMS AT MOUNT RAINIER NATIONAL PARK

Abstract approved: Jerry F. Franklin

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An analysis was made of the recent catastrophic disturbance history of forests at Mount Rainier National Park. Basic data were tree ages from ring counts of increment cores taken from the early seral cohort, field mapping of age class boundaries and aerial photograph interpretation. Maps of present stand ages were constructed as a series of successive approximations after each field season. These maps illustrate the relationship among the major forest disturbers, fires, avalanches, and lahars (volcanic mudflows), and with topography. The forests are dominated by stands over 350 years old. Large stands (690 ha total) are over 1000 years old. South-facing slopes, especially high elevations, burn more frequently than protected north-facing slopes and streamside corridors. Fires are by far the most important major disturber, followed by snow avalanches and lahars.

Fire frequency indices proposed by Heinselman (1973), Tande (1977) and Van Wagner (1978) were compared and found to poorly describe fire frequency at Mount Rainier, partly due to the natural regime of infrequent, catastrophic fire. Natural fire rotation was found to be 434 years

and 306 years using Heinselman's and Van Wagner's index, respectively.

Episodes of major fire also correspond well with major droughts reconstructed for locations east of the Cascade crest by Keen (1937) and Blasing and Fritts (1976). Only two major fires since 1300 AD do not correspond to a major drought reconstructed by either of these investigators. Of the eight major droughts from Keen (1937) only two lack a corresponding large fire at Mount Rainier.

Modern man's impacts on the disturbance regime have been relatively slight, perhaps involving an increase in fire frequency during the 1850 to 1900 period followed by a decrease in fire frequency since 1900. No unnatural fire frequency or fuel build-up patterns have occurred, since fires are relatively infrequent and fuel build-ups high.

Since fire plays an important natural role in maintaining the forest mosaics at Mount Rainier, it should be included as a basic natural agent in the Park's management. Both fires, especially during prolonged droughts, and lahars are potentially very destructive. Given the long natural interval between major fires, there is some lee-way in a time schedule for fire management.

A Recent Disturbance History of Forest Ecosystems at Mount Rainier National Park

by

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A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Doctor of Philosophy

Commencement June 1979

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Date thesis is presented May 7, 1979

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ACKNOWLEDGMENTS

This thesis involved the labor and spirit of several people to whom I owe more than I can say. I consider Dr. Jerry Franklin to be one of the finest instructors and counselors I have ever had the good fortune to know. Without his help, the process of research and construction of this thesis might have been a much less valuable effort.

And to thank my wife, Nancy, who stuck with me through thick and thin, my words of gratitude are insufficient. Without her support, this all would not have been possible.

Several people helped immeasurably in the field and in criticism. I am lucky to have had the aid and companionship of Sarah Lewis, Will Moir, Karen Luchessa and Ted Thomas.

The National Park Service personnel were very helpful and supportive of this effort. Especially kind were the people of the Ohanapecosh Ranger Station, and Stan Schlegel and Larry Henderson.

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A RECENT DISTURBANCE HISTORY OF FOREST ECOSYSTEMS AT MOUNT RAINIER NATIONAL PARK

INTRODUCTION

Disturbance of forest stands and their subsequent regeneration accomplishes the crucial natural process of renewal in most temperate forest ecosystems. Nutrient capital long imprisoned in large woody debris and tree boles is made available. Habitat opens for pioneer species. A forest mosaic of young and old stands is created which supports high species diversity among plants and animals. Understanding the natural role of forest disturbance, and how modern man has changed it, is essential to interpreting the distribution of forest mosaics over the landscape, investigating their successional dynamics and evaluating the impact of future disturbances and management practices.

Mount Rainier National Park contains sterling examples of the dense coniferous forests which once covered much of the Pacific Northwest. A variety of disturbance types create a mosaic of forest stands which have been only slightly impacted by modern man. The effects of fires, avalanches, lahars (volcanic mudflows) and other disturbances have been preserved in the Park's extensive forests. Little is known, however, about the natural role of forest disturbances in the Pacific Northwest, especially on the western slopes of the Cascade Range. This information is critically important to Park managers and other resource managers who must evaluate the impacts of human activities and plan to deal with future forest disturbances, especially fire.

Patterns of catastrophic forest disturbance have been studied at Mount Rainier for the past three years. There were several objectives for this investigation.

1) What were the temporal and spatial patterns of forest disturbances before the arrival of modern man? How are patterns of disturbances related to landform (e.g., slope, aspect, elevation, river drainage), when did they occur and how large were they?

2) How do fire, avalanche, lahar and other disturbances rank as forest destroyers?

3) Has modern man altered the disturbance regime?

4) What agents (e.g., climatic shifts) contribute to the timing of natural disturbances?

THE STUDY AREA

Mount Rainier National Park is located on the crest and western flank of Washington's Cascade Range about 60 miles southeast of Seattle (Figure 1). Mount Rainier volcano dominates the Park, rising to 4367 m (14,410') at Columbia Crest (Figure 2). Nine major rivers originate in the extensive glacial system which covers much of the mountain. Tree line varies around the mountain but is generally between 1600 m and 2000 m.

Situated as it is on the crest of the Cascade Range, Mount Rainier National Park experiences the long, cool, wet winters and dry, warm summers typical of the Pacific Northwest. Most of the precipitation falls as rain or snow during the winter months (Table 1). There are strong orographic effects: Longmire (837 m elevation) averages 205 cm of precipitation annually while Paradise (at over 1600 m) averages 269 cm. Rainshadow effects diminish the amount of precipitation on the northeastern and eastern flanks of the mountain. Prevailing southwesterly winter storms drop large amounts of moisture on the windward Nisqually, Puyallup, Mowich and Carbon drainages and smaller amounts in the White and Ohanapecosh drainages. Temperatures are generally moderate. Average July temperatures at Longmire and Paradise are 16° and 12° respectively. Average January temperatures are -1° and -3° (Table 1).

Much of the Park's topography reflects long eras of Pleistocene glacial erosion. All major river valleys supported large glaciers as recently as 10,000 years ago (Crandell and Miller 1974). Mount Rainier is presently clothed in an extensive system of glaciers, some of which extend as low as 450 m. Steep-sided glacial valleys separate rolling uplands and sharp ridges which radiate away from the mountain. These

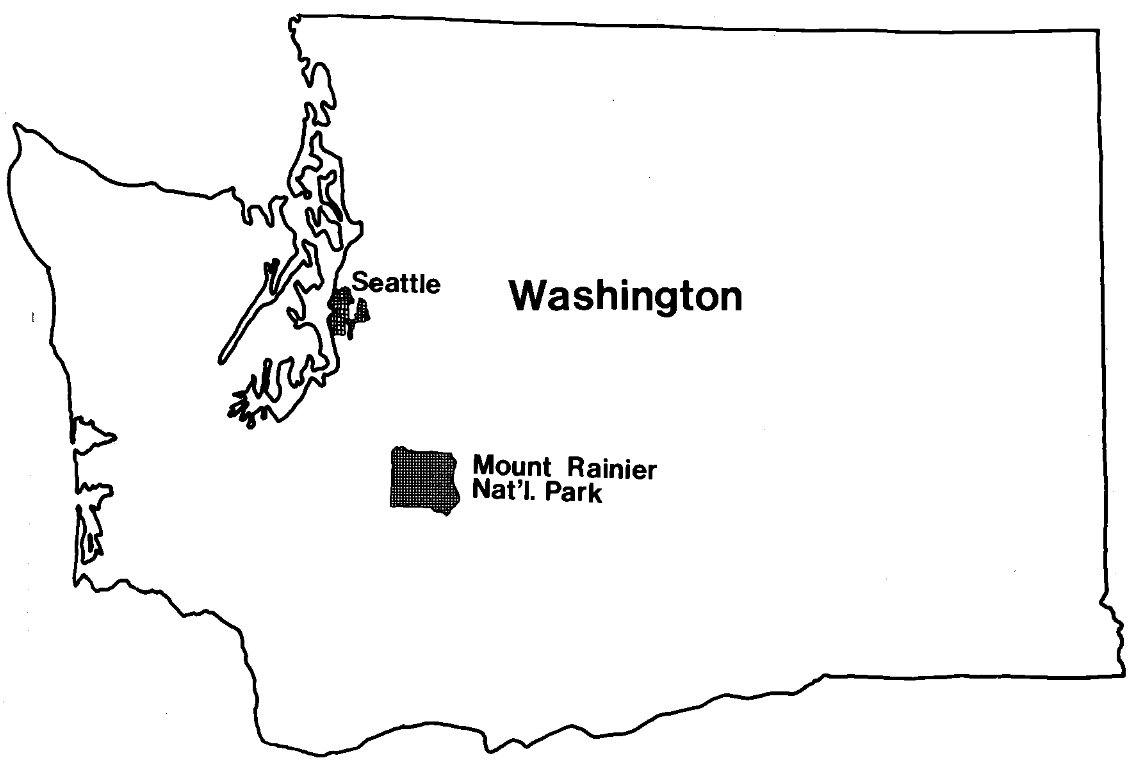

Figure 1. Location of Mount Rainier National Park in Washington.

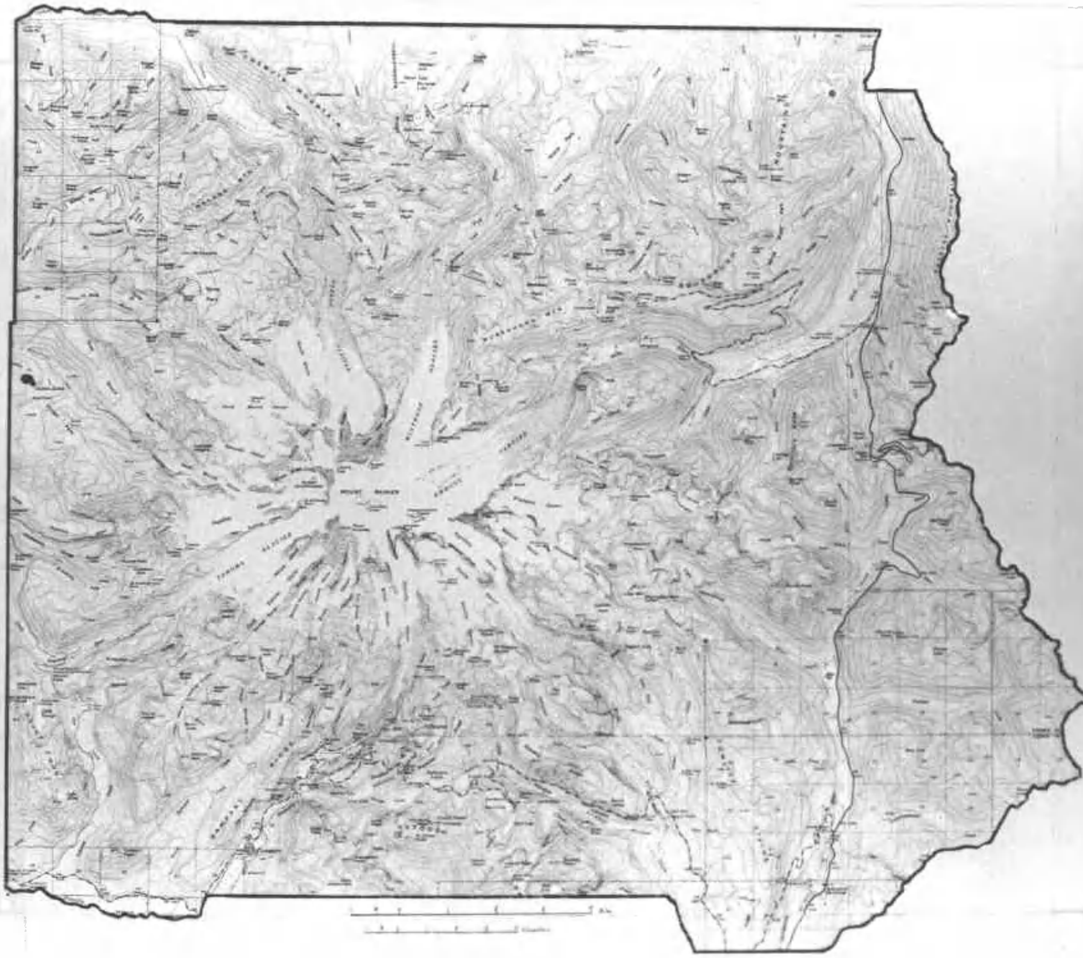

Figure 2. Topographic map of Mount Rainier National Park.

Table 1. Climatic summary of Mount Rainier National Park.[1]

Longmire: Elevation 837 m - 1930 to 1959

Month	Temperature °C Mean Daily Maximum	Temperature °C Mean Daily Minimum	Temperature °C Mean Monthly	Precipitation cm Mean Total	Precipitation cm Mean Snowfall
Jan.	2.2	-4.4	-1.1	27.5	122.9
Feb.	4.2	-3.3	0.4	22.6	95.5
Mar.	6.7	-2.4	2.1	20.6	81.8
Apr.	11.4	-0.2	5.7	12.5	22.9
May	16.4	2.9	9.7	10.1	1.8
Jun.	18.9	6.0	12.5	9.2	T
Jul.	23.8	8.5	16.2	3.4	-
Aug.	23.2	8.4	15.8	4.0	-
Sep.	20.2	6.3	13.3	9.9	T
Oct.	14.1	3.1	8.6	21.8	3.6
Nov.	7.2	-0.5	3.4	29.3	36.6
Dec.	3.7	-2.2	0.7	34.8	86.4
Year	12.7	1.8	7.3	205.7	451.4

Paradise: Elevation 1682 m - 1920 to 1959

Month	Temperature °C Mean Daily Maximum	Temperature °C Mean Daily Minimum	Temperature °C Mean Monthly	Precipitation cm Mean Total	Precipitation cm Mean Snowfall
Jan.	0.5	-6.3	-2.9	36.8	298.7
Feb.	1.6	-5.7	-2.1	27.0	225.3
Mar.	2.9	-5.7	-1.4	26.4	250.4
Apr.	6.6	-2.7	1.9	17.1	137.4
May	10.1	0.2	5.2	11.2	54.1
Jun.	13.2	2.6	7.9	11.9	10.9
Jul.	17.7	6.4	12.1	4.3	0.8
Aug.	17.1	6.3	11.7	6.7	T
Sep.	13.8	4.0	8.9	17.6	13.2
Oct.	8.9	0.6	4.8	30.5	55.9
Nov.	4.8	-2.9	0.9	36.9	164.1
Dec.	1.3	-5.6	-2.1	42.8	267.0
Year	8.2	-0.7	3.7	269.2	1478.5

1/ Compiled from Phillips (n.d.)

produce steep elevational gradients which combine with changes in aspect to create widely varying local conditions.

Soils are largely developed in colluvium and tephra. Hobson (1976), after an extensive field study of Mount Rainier's soils, decided not to describe them by traditional methods but by parent material. Thornburgh (1967) described the soils in his study area, adjacent to Mount Rainier National Park's southwest corner, as deep, well drained, coarse-textured brown podzolics intergrading to undifferentiated lithosols. Tephra layers, volcanic ash from Mount Rainier and other volcanoes, form extensive deposits over the Park, some having originated as far away as Mount Mazama in the southern Oregon Cascades (Mullineaux 1974). Some of these are sufficiently recent and distinct to serve as age markers for approximately dating charcoal from fires in the last 1000 years (Table 2).

Mount Rainier National Park's forests are extensive and diverse. Over 56 percent (53,000 ha) of the Park's total area (94,000 ha) is forested. Below about 900 m western hemlock (<u>Tsuga heterophylla</u> [Raf.] Sarg.) is the dominant climax species. From 900 m up to about 1390 m hemlock dominance slowly gives way to Pacific silver fir (<u>Abies amabilis</u> [Dougl.] Forbes) which is the major climax dominant to tree line at about 2000 m (Thornbourgh 1967). Other coniferous species are important as seral or minor climax elements (Table 3). Thornburgh (1967) examined the dynamics of the true fir-hemlock forests of the area and studies have been made of the Park's forest vegetation (Brockman 1931, Franklin and Moir 1977).

Some of the seral tree species at Mount Rainier are relatively shade-intolerant and sufficiently long lived to be useful for catastrophic disturbance history study. Combinations of Douglas-fir (<u>Pseudotsuga</u>

Table 2. Tephra Layers, Their Source Volcanoes, and Approximate Ages.

Tephra Unit	Source Volcano	Approximate Age
X	Mount Rainier	150
W	Mount St. Helens	450
C	Mount Rainier	2200
Set P (4 layers)	Mount St. Helens	2500-3000
2 layers	Mount St. Helens	3000-3300
Set Y Yn	Mount St. Helens	3400
2 layers	Mount St. Helens	3500-4000
B	Mount Rainier	4500
H	Mount Rainier	4700
F	Mount Rainier	5000
S	Mount Rainier	5200
N	Mount Rainier	5500
D	Mount Rainier	6000
L	Mount Rainier	6400
A	Mount Rainier	6500
O	Mount Mazama	6600
R	Mount Rainier	greater than 8750

Taken from Mullineaux (1974)

Table 3. Summary of the Successional Status of Important Coniferous Species in Selected Habitats.

Selected Habitat Types[1] Mount Rainier Area	Abies amabilis	Abies grandis	Abies lasiocarpa	Abies procera	Chamaecyparis nootkatensis	Picea engelmannii	Pinus monticola	Pseudotsuga menziesii	Thuja plicata	Tsuga heterophylla	Tsuga mertensiana
Tsuga heterophylla/Oplopanax horridum	c	sc						S	Sc	SC	
Tsuga heterophylla/Achlys triphylla	c							S	Sc	SC	
Tsuga heterophylla/Polystichum munitum	c							S	Sc	SC	
Abies amabilis/Gaultheria shallon	C			s			s	S	sc	SC	
Abies amabilis/Vaccinium alaskaense	SC			S	c		s	S	sc	Sc	
Abies amabilis/Berberis nervosa	SC			S	c		s	S	sc	Sc	
Abies amabilis/Oplopanax horridum	SC	SC		s	Sc	s		S	c	SC	sc
Abies amabilis/Menziesia ferruginea	SC			s	SC		s	s		Sc	Sc
Abies amabilis/Xerophyllum tenax	SC		S	S	sc		s	S			sc
Abies amabilis/Rubus lasiococus	SC		S	S	Sc	s		s			Sc

1/Habitats selected to span environmental range, compiled from Thornburgh (1967) and Franklin and Moir (1977). Major climax species, C; minor climax species, c; major seral species, S; minor seral species, s.

menziesii [Mirbel] Franco.), noble fir (Abies procera Rehder), western white pine (Pinus monticola Dougl.), Engelmann spruce (Picea engelmannii Parry) and subalpine fir (Abies lasiocarpa [Hook.] Nutt.) dominate early seral stands depending on site conditions (Thornbourgh 1967, Franklin and Dyrness 1973). These species are relatively shade-intolerant and do not reproduce well under closed canopies. For this reason, ages from stands of these trees which become established after a disturbance provide estimates of the minimum elapsed time since the disturbance. In addition, all of these tree species may live more than 350 years. Douglas-fir is especially long lived, commonly surviving over 700 years. The longevity of Douglas-fir is a major reason why the disturbance history of Mount Rainier National Park's forests has remained evident through nearly 1000 years. Noble fir and western white pine reach maximum ages of around 600 years, but Engelmann spruce and subalpine fir generally die before reaching 400 years of age.

Ages of other tree species are somewhat less useful for dating disturbances because they occasionally regenerate under a closed canopy. These ages can be used to estimate the minimum time since disturbance when the preferred species are not present. Alaska-cedar (Chamaecyparis nootkatensis [D. Don] Spach.) and mountain hemlock (Tsuga mertensiana [Bong.] Carr.) were used in such instances. Individual Alaska-cedar and mountain hemlock may survive more than 1200 and 700 years, respectively.

Small scale disturbances, although they may be frequent, are not of stand-wide proportions and do not usually produce a recognizable cohort of early seral trees. Mortality of individual trees or small groups of trees may result from biotic influences (disease, root rot, insect attack, girdling by bears, etc.), windthrow, small soil mass movements (slumps, slides, etc.), snow avalanches, lightning strikes and so forth. Even though not large, these disturbances may produce essential holes in dense canopies.

Larger disturbances, also called catastrophic in this paper, affect an area of forest great enough to result in eventual establishment of a more or less even aged cohort of early seral tree species. Three types of events at Mount Rainier produce catastrophic disturbances: fires, avalanches and lahars. Avalanches are mostly of snow. Lahars are flows of rock, debris and water which originate on the slopes of a volcano. A series of disturbance events over a relatively short time period and probably related to the same set of triggering factors is an episode.

Human activity has affected patterns of natural disturbance, especially fire. Several tribes of indians inhabited the area for at least the last 10,000 years (Dryden 1968). They may have used fire to concentrate game, increase berry harvests and improve visibility and grazing (Taylor 1922, Morris 1937, Lutz 1956). Some of these fires probably destroyed forests in Mount Rainier National Park. These indian-set fires can be considered part of the natural fire regime. Modern man first appeared as a few explorers and trappers moving through the area in the late eighteenth and early nineteenth centuries. Settlement in the vicinity 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. Seattle was established in 1853. Significant logging began around 1850 and was extensive in 1880. The first settlement within the Park's boundaries was a cabin built by Longmire in the 1880's. Without a doubt, early settlers used fire freely to open forests. Longmire started a fire in 1894 which burned about 270 hectares. By the end of the nineteenth century, over one-third of the timber in Lewis County, which contains part of Mount Rainier National Park, was burned, at least partly by man-caused fires (Gannett 1902). The Park was formally established in 1899. A rigid forest fire suppression program began soon thereafter.

METHODS

The forest disturbance history study encountered problems common to similar studies elsewhere. Increasing loss of information with time often plagues forest history analysis (e.g., 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 increases in proportion to the frequency and size of disturbances in an area. In addition, since steep, rugged topography and large study area present access and ground coverage problems, mapping efforts depend on aerial photograph interpretation. Interpretation of age class boundaries from canopy texture on photographs can be difficult on rough terrain.

The best technique to get accurate disturbance dates is counting rings on sections or wedges from scarred trees (Heinselman 1973, Rowe and Scotter 1973, Henry and Swan 1974, Arno 1976, Tande 1977). High visitor use at Mount Rainier and aesthetic considerations ruled out taking wedges from scarred trees. In addition, fire scarred trees are uncommon at Mount Rainier. Intense, infrequent catastrophic fires usually obliterated previous stands, leaving few scarred survivors. Trees which survive these conflagrations have usually only suffered charred bark or have had sufficient time to recover wounds with living tissue.

Tree ages estimated from increment cores and trail-cut stumps or logs provided the best approximations of major disturbance dates at Mount Rainier. Cores were usually taken from the relatively shade-intolerant species: Douglas-fir, noble fir, western pine, subalpine fir and Engelmann spruce. Where these species were unavailable, Alaska-cedar and mountain hemlock sufficed with the understanding that they may regenerate under closed canopies. Ages from the latter provide conservative stand origin dates.

Information was recorded about physical site conditions as well as core data for each core taken. Percent slope, aspect (degrees azimuth), elevation in meters and general location described the site. Each tree age was carefully plotted on USGS $7\frac{1}{2}$-minute topographic maps. Features important in distinguishing the type of disturbance were noted. The position of charcoal layers in relation to the stratigraphy of tephra deposits of known age provided some guidelines about time since fire. Fire lines and stand boundaries were noted and sketched on maps.

Tree age records included information about the tree, rings counted using a hand lens and dissecting needle, total age and age corrections. The species, DBH (diameter breast height), and diameter core height were recorded for each core. Age corrections were made to adjust ring counts for years of growth 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 core. The inner growth rate observed on the core was used to estimate the number of rings missing for a tree with the given radius, bark thickness and core length. For example, an increment core 35 cm long lacks about 20 cm of reaching the pith of a tree 120 cm in diameter which has bark 5 cm thick. If the innermost portion of the core with 200 counted rings shows an average ring width of 0.5 cm, the tree is about 240 years old at core height. If the average growth rate of saplings of the same species in a similar site is 0.5 m per year and the core was taken at 1.6 m from the ground, the tree would be about 246 years old assuming a three year period of seedling establishment and three more years to 1.6 m height. Whenever possible, the extrapolation from the distal core growth rate to the pith was checked by measuring the inner ring widths of nearby trail-cut stumps or logs of the same species and age. Due to generally favorable conditions for growth, ring widths for the majority of trees examined decreased uniformly with age.

Successive approximations of stand age maps evolved in the laboratory after each of the three field seasons. Each year's field data provided ground truth and better age samples to improve the accuracy of stand ages and age class boundaries. Mapping units for stand ages generally exceeded five hectares. Areas less than five hectares are not easily mapped from 1:24000 scale aerial photographs and may not result in the establishment of a cohort of early seral species (Thornburgh 1967). Even after three field seasons and over 1000 tree ages recorded and mapped, some gaps exist in the age sample coverage of the Park's forests. Many of the undersampled areas present access problems, especially in unpredictable weather. Because of limitations imposed by difficult access and time allotted for field work, the age samples were not randomly chosen and do not form a statistically usable sample set.

Nine overlays of the USGS topographic map of the whole Park were developed to reconstruct past episodes of catastrophic disturbances. Each overlay is an attempt to reconstruct the original extent of a particular disturbance episode. These reconstructions are based on some important assumptions.

1) Uniformity. The present behavior of the disturbance-vegetation complex holds the key to interpreting the behavior of similar systems in the past. This is an adaptation of a fundamental geologic principle. Even if not explicitly stated, most fire

history studies have relied on this principle (e.g., Lutz 1956, Haines and Sando 1969, Schmidt 1970, Heinselman 1973, Tande 1977).

2) Age continuity. Trees in stands of similar age, separated by younger stands and not by either vegetative or topographic fire breaks, probably originated after the same disturbance episode. For example, large expanses of subalpine parkland, high, rocky ridges and distances of more than four or five kilometers were considered significant fire-breaks. This assumption has often been used although perhaps not stated in exactly the same way (see especially Heinselman 1973).

3) Fire behavior. Fires tend to burn upslope to some topographic or vegetative barrier. If a valley bottom burns and there are no barriers to ridgeline, the slopes above the bottomlands probably burn as well. The converse may not be true; fires on an upper slope cannot be reconstructed to bottomlands lacking stands of the same age.

4) Topographic consistency. This assumption is based on the tendency for particular types of disturbances to leave identifying tracks in terms of topographic location and charcoal deposits. The presence of a surface layer of charcoal indicates fire. Fires can burn over a wide range of topography. Other disturbances occur in more characteristic locations and do not leave a charcoal layer at the mineral soil surface. Lahars typically destroy valley bottom and lower slope stands (Crandell 1971). Avalanches characteristically operate on steep, gulleyed slopes which head at elevations and in topographic sites where snow

accumulates (Luckman 1978).

5) Regeneration span. The age distribution of the early seral cohort on the western slopes of the Cascade Range frequently spans more than 75 years.

6) Conservative limits. Mapping reconstructed disturbance episodes emphasizes conservative boundaries as limited by one through five above. Most similar studies have been conservative in mapping reconstructed disturbance episodes. In the Boundary Waters Canoe Area, Heinselman (1973) emphasized the decrease in information available for fire reconstruction with time. Other investigators experienced the same limitation (e.g., Lutz 1956, Frissell 1973, Tande 1977). To avoid the dangers of extrapolation beyond the data base, all recreated disturbance boundaries at Mount Rainier were conservative within the limits of the other assumptions. Even if there were no physical barriers, disturbances were not extended into areas where indicative survivor trees were lacking except as allowed by assumptions two and three.

In order to test the validity of assumption five, a series of three transects were sampled in a burn of historically documented age. Each transect was 200 m long and followed a compass line parallel to the contour of the sampling area. At 50 m intervals along the transect, a sample point was established. The total ages, correct to within two years, of the 25 individuals of the five early seral species nearest the sample point were recorded. Each transect was a systematic random sample of 100 early seral trees. The three transects were located in different physical sites: the first on a southeast-facing lower slope with fairly deep soils, the second on a southeast-facing upper slope with thin, rocky soils, and the third on a northeast-facing lower slope bench with deep soils. The distributions of ages of the early seral cohorts from the three transects were examined to see if a wide range of ages was present in supposedly even aged stands as had been found in the Oregon Cascades (Franklin et al. 1979).

A map was prepared to show presently active rock and snow avalanches and lahars less than 1000 years 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 years old were mapped from Crandell (1971).

RESULTS

Present Stand Ages

Old-growth forest (greater than 350 years old) clearly dominates the landscape at Mount Rainier National Park (Figure 3, Table 4). Park-wide, such forests comprise about 53 percent of the forested area. Forests greater than 750 years old cover over 12 percent of the Park. Distribution of old-growth forests by drainage reflects to some extent the rainshadow effect of the mountain. Except for the Ohanapecosh Valley, which has a high proportion of old-growth forest, river drainages on the windward slopes have relatively more old-growth forest than lee-side drainages.

Forests at several locations around the Park show no evidence of disturbance for over 1000 years (Figure 3). The oldest trees in the Park grow in protected valley bottoms and on slopes in the Ipsut and Cataract Creek drainages in the Park's northwest sector. Except for avalances on steeper, higher slopes and a small burn over 600 years old in the upper reaches of the valley, the forests of Ipsut Creek valley have not seen a major disturbance in over 1200 years as indicated by conservative age estimates on large Alaska-cedars. Forests along Cataract Creek, an adjacent 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 years. Both drainages are short hanging valleys running north into the Carbon River bounded on three sides in high rocky ridges.

Other very old stands in the Park occupy protected topographic loca-

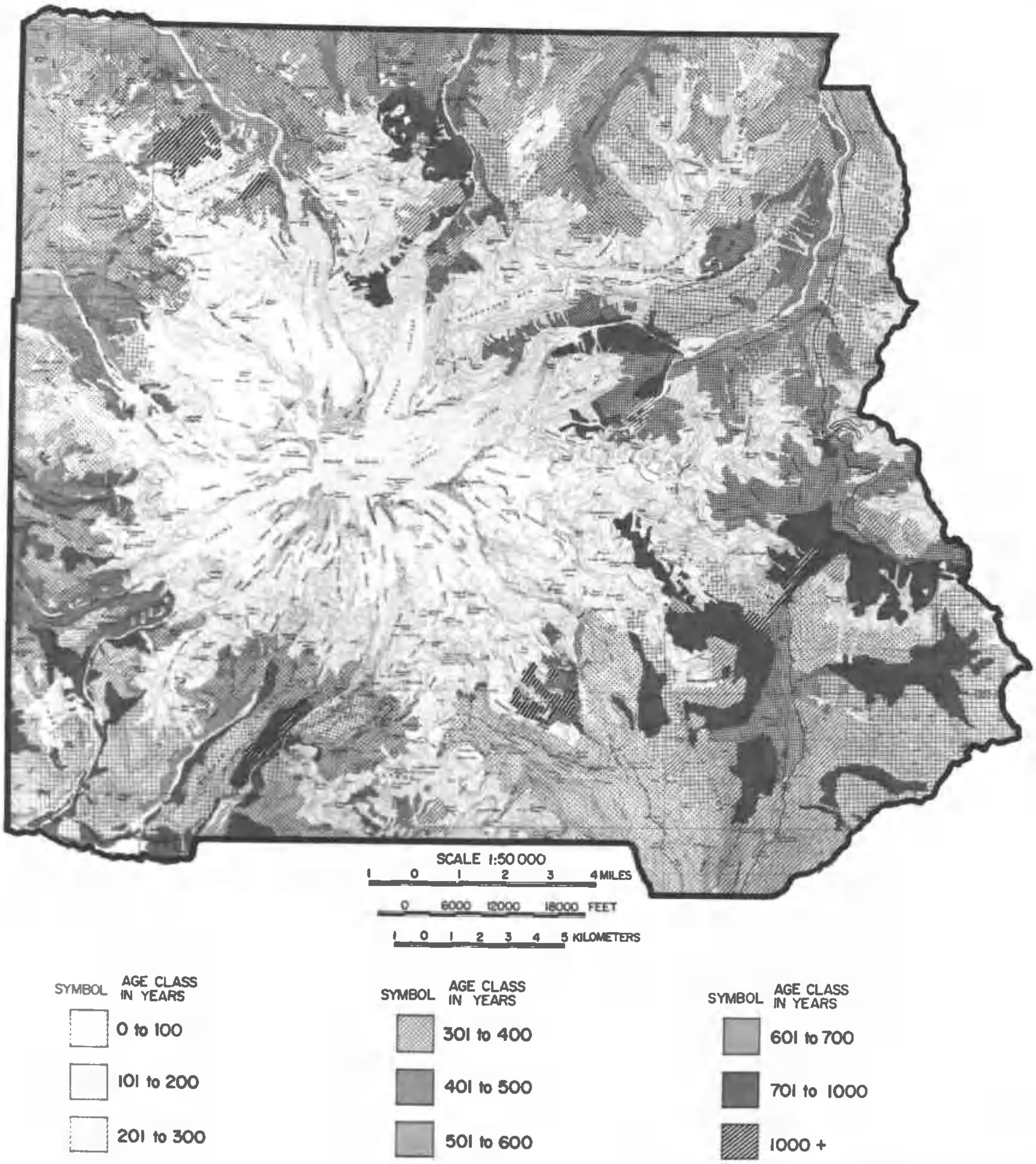

Figure 3. Present stand ages.

Table 4. Summary of Percent Areal Coverage of Present and Reconstructed Stands, Correspondence With Drought and Estimated Maximum Error for Important Fire Episodes.

Episode	Interval[1]	Present Area ha	Present Area Percent	Reconstructed Area ha	Reconstructed Area Percent	Drought[2]	Drought[3]	Number of Trees
1230	±25	6265	12	25000	47	[4]		48
1303	±25	1450	3	6000	11	X		7
1403	±25	6910	13	13700	26	X		66
1503	±25	4700	9	13680	26	X		70
1628	±25	11060	21	12900	24	X		80
1688	±25	1200	2	4410	8	X		4
1703	±25	2700	5	5140	10		X	54
1803	±10	2230	4	2230	4	X	X	51
1825	± 5	2400	5	2480	5		X	31
1856	± 2	490	1	2800	5	X	X	5
1858	± 2	3040	6	3700	7		X	51
1872	± 2	600	1	600	1	X	X	7
1886	± 1	3800	7	4280	8		X	59
1894		270	1	270	1			23
1930		680	1	680	1	X	X	5
1934		770	1	770	1	X	X	9

1/Size of interval which includes midpoint in years.

2/First of second magnitude drought from Keen (1937).

3/Drier than normal winter types for the Pacific Northwest from Blasing and Fritts (1976).

4/The 1230 episode predates applicable climatic reconstructions.

tions. Much of the Ohanapecosh River drainage supports stands over 700 years old. In fact, stands occupying northerly-facing slopes and alluvial flats along the Ohanapecosh above its confluence with Chinook Creek have not experienced catastrophic disturbance for over 1000 years. Many individuals of the 1000-year-old cohort of Douglas-fir died during the past century or two leaving the forest floor littered with logs nearly three meters in diameter.

Unique in some respects are stands over 1000 years old in the Nisqually River Drainage near Cougar Rocks campground. Crandell (1971) mapped the surficial geology as a lahar of the Paradise lahar assemblage. Part of this assemblage is radiocarbon dated at just over 1000 years old, very close to the maximum age of the Douglas-fir growing on it. These trees have very slow growth rates; many specimens 50 to 100 centimeters DBH are about 1000 years old. Some were cut when the campground was established and ring counts of the stumps are quite accurate. The forest seems to be a first generation stand on nutrient-poor lahar material. Like other very old stands, the Cougar Rocks old-growth occupies a protected valley bottom.

The most extensive stand age in the Park is the 350-year-old age class found in the Park's western half. Stands of this age comprise 19 percent of the total forested area and occupy over 50 percent of the forest area in the Mowich Drainage (Figure 3, Table 4). Ages from early seral trees fall close to 350 years in stands as widely separate as Chenuis Creek and the Nisqually River. As will be discussed later, these stands seem to have originated after one fire event or a series of very closely timed events.

Stands from 100 to 200 years old make up the second largest age class in the Park. These regenerated after many separate fires between 1700 and 1800. Especially notable are the high elevation burn in upper Laughingwater Creek of ca. 1803, the 153-year-old forests of the Nisqually area dating from ca. 1825, the original extent of "The Burn" in the Cowlitz in ca. 1856, and the "Sheepherder Burn" on Crystal Mountain in the White River drainage dating from ca. 1858. A 0-to 155-year-old age class created by including more recent fires (those less than 100 years old) and excluding the 1803 Laughingwater burn incorporates all areas burned since the arrival of modern man. This 0-to 155-year-old age class occupies over 15,000 hectares or 29 percent of the Park's forested land, an area larger than that occupied by 350-year-old stands.

The major river drainages at Mount Rainier differ substantially in the distribution of age samples of early seral trees (Figure 4 through 11). Samples were not randomly chosen and the distributions do not precisely indicate the relative aerial extents of stands of different ages nor the age distributions of the forests. They do show peaks of past regeneration pulses following disturbance.

Both the distribution of ages in the early seral cohort of "even-aged" stands and in the sample transects in the 92-year-old Cowlitz burn illustrate an interesting facet of the forest age structure. More than 100 years may pass before the regeneration of early seral species after a disturbance ceases. In the Cowlitz burn, Douglas-fir were still becoming established after more than 50 years, especially on the dry, open slopes of transect number two (Figure 12). In older forests, some of the lag may be due to errors in counting rings or to noise from including small disturbances of different ages. But these could hardly account for the consistant regeneration lag from forests of different ages.

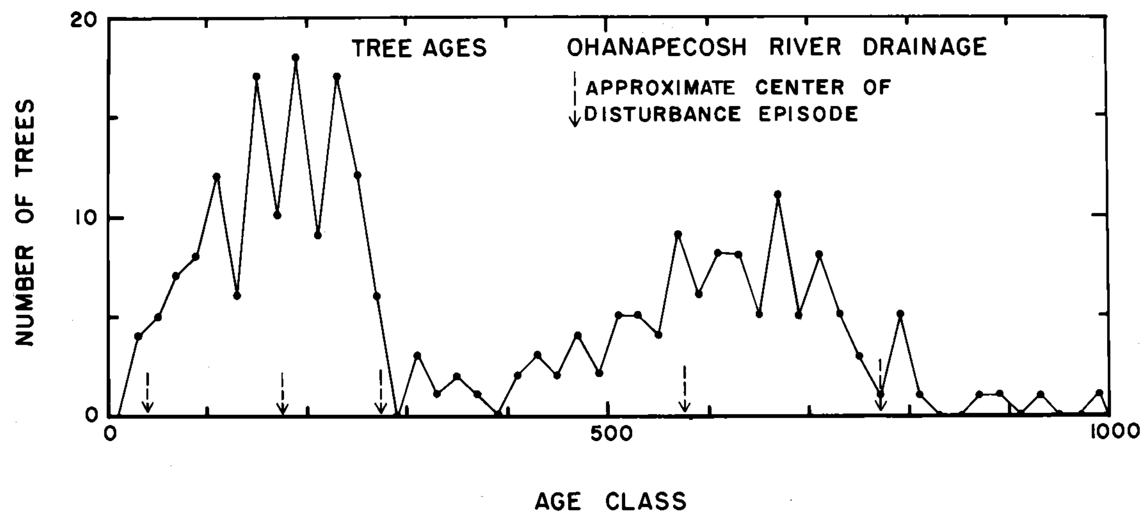

Figure 4. Distribution of ages from trees sampled in the Ohanapecosh River Drainage.

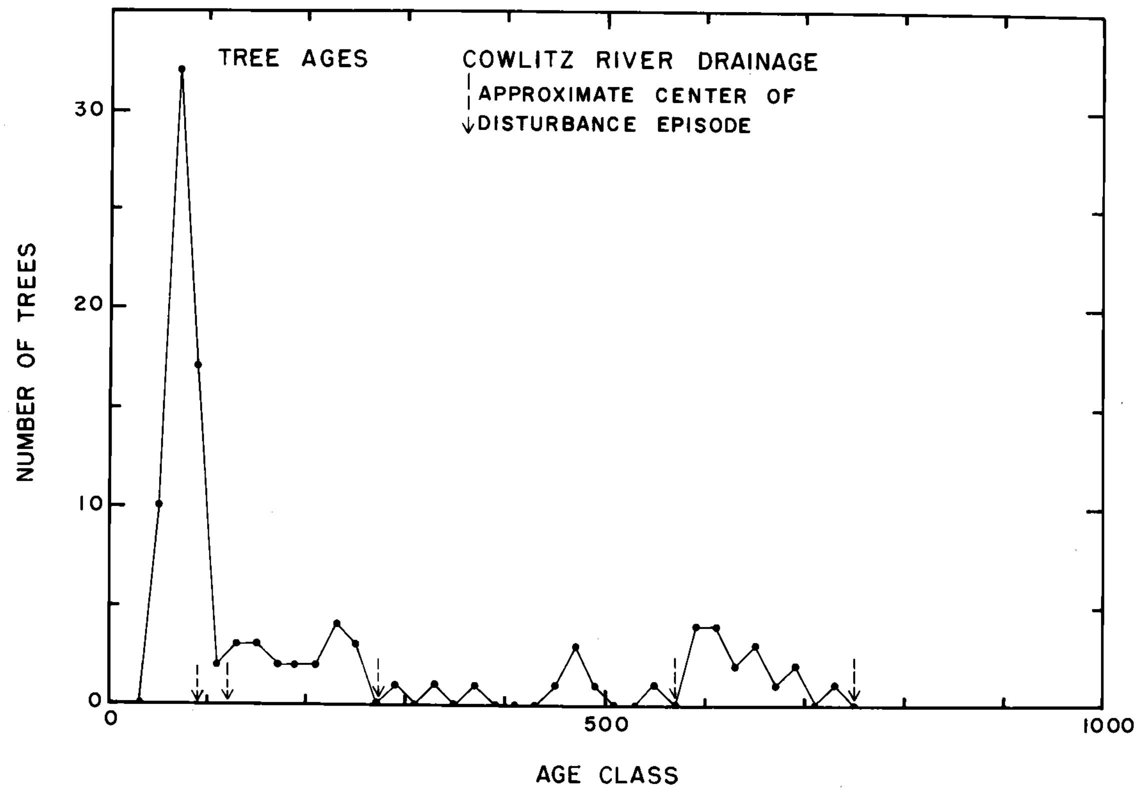

Figure 5. Distribution of ages from trees sampled in the Cowlitz River Drainage.

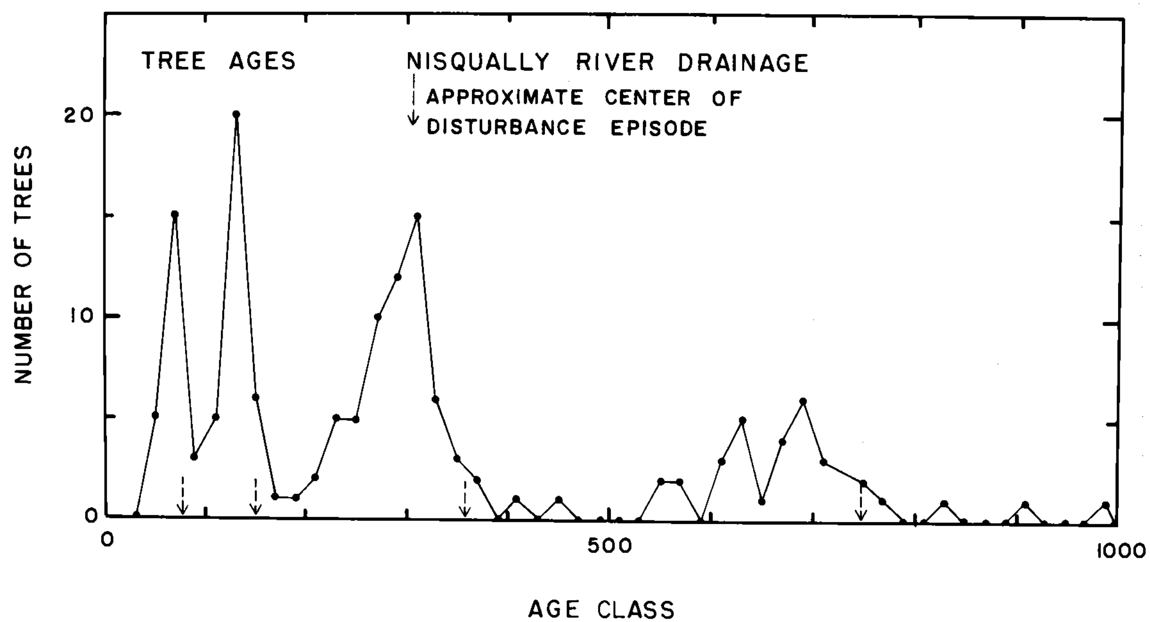

Figure 6. Distribution of ages from trees sampled in the Nisqually River Drainage.

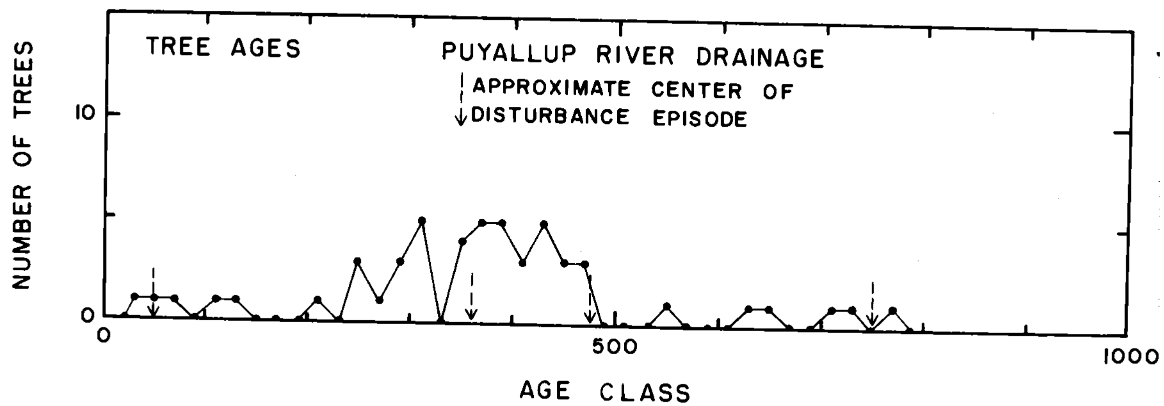

Figure 7. Distribution of ages from trees sampled in the Puyallup River Drainage.

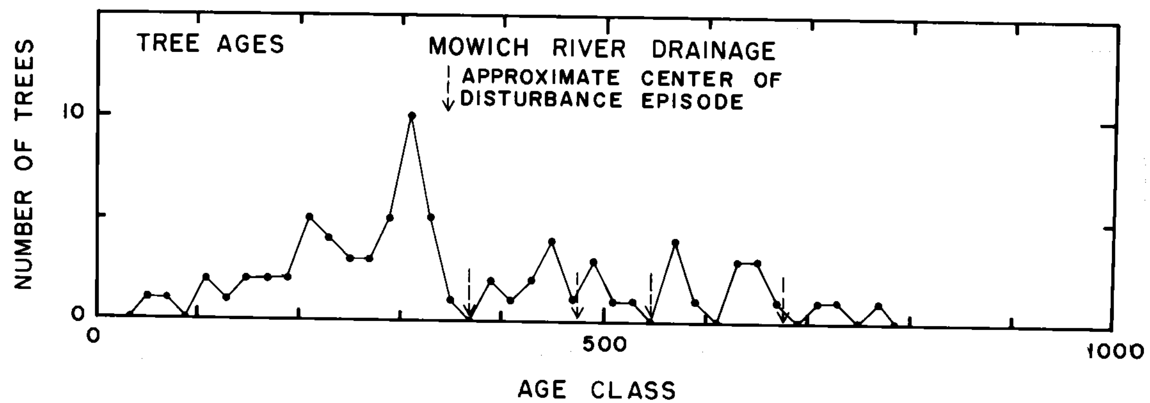

Figure 8. Distribution of ages from trees sampled in the Mowich River Drainage.

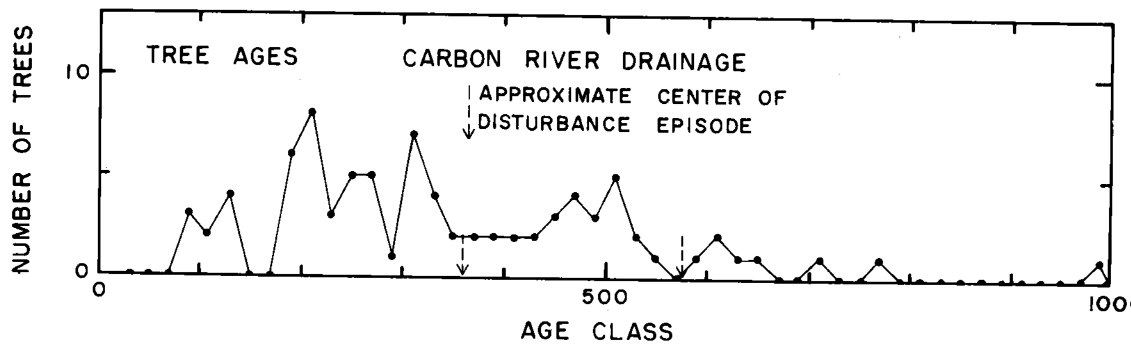

Figure 9. Distribution of ages from trees sampled in the Carbon River Drainage.

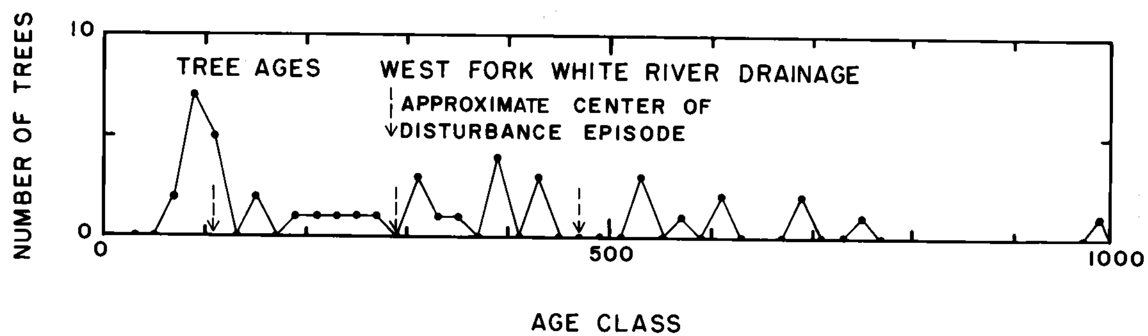

Figure 10. Distribution of ages from trees sampled in the West Fork White River Drainage.

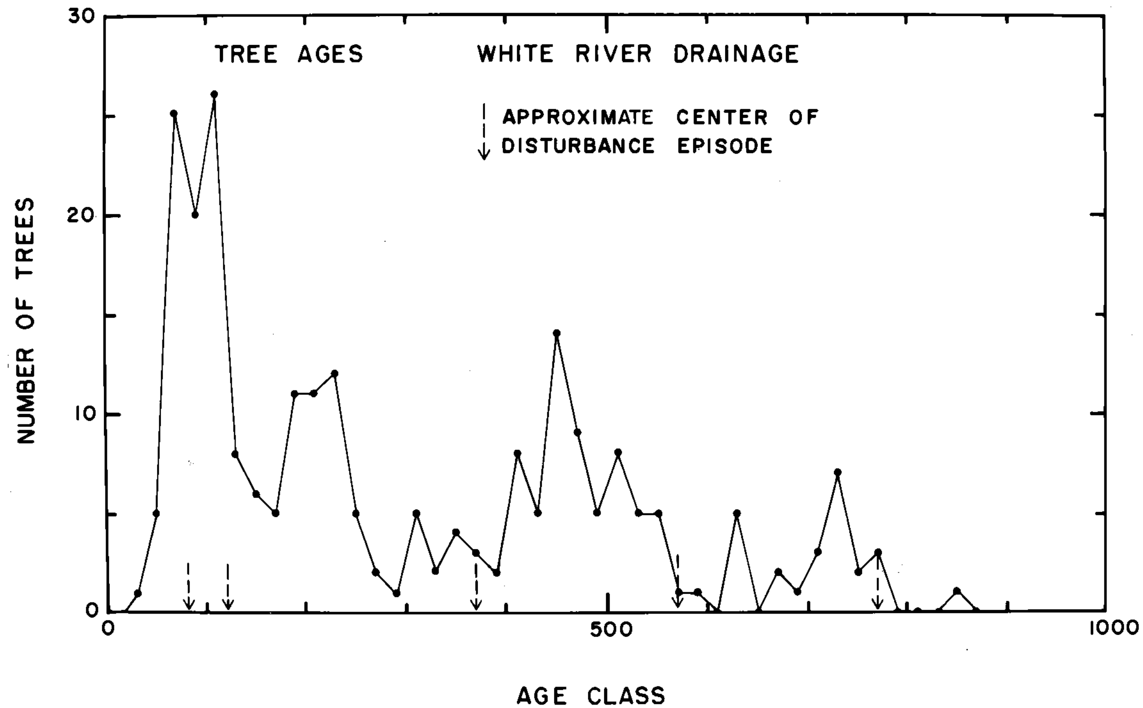

Figure 11. Distribution of ages from trees sampled in the White River Drainage.

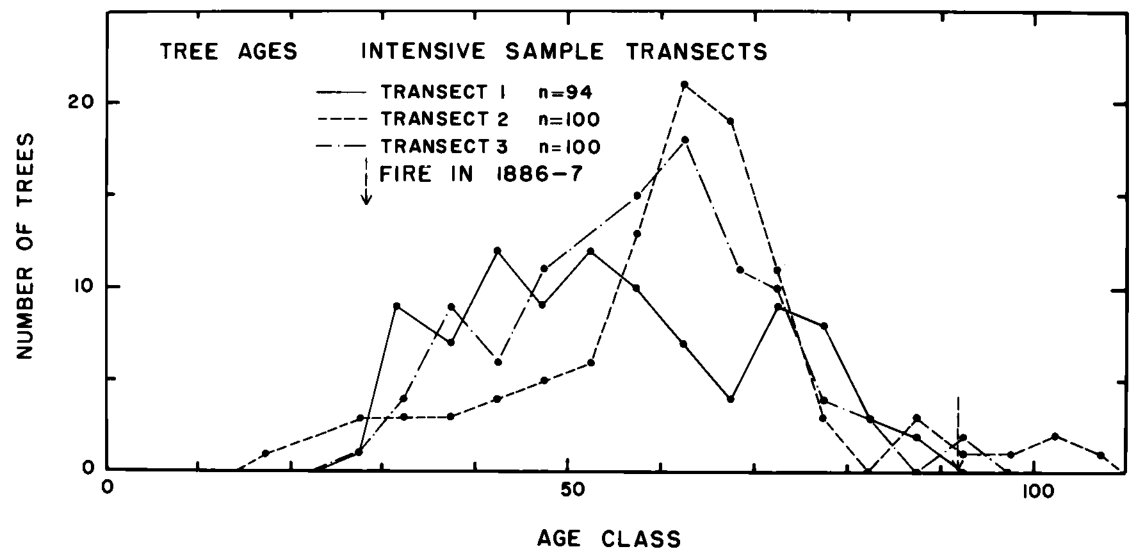

Figure 12. Distribution of ages from trees sampled along three transects in the Cowlitz River Drainage.

Even today, 92 years after the latest burn in the Cowlitz, large areas, once forested and now littered with snags, have not restocked.

Reconstructed Fire Episodes

The oldest and largest disturbance documented by this study was a wide-spread fire episode dating from ca. 1230 (Figure 13, Table 4). The distribution of stands and individual trees from this episode indicates that it was the largest disturbance during the past 1000 years. Ages from widely separate trees from this episode usually range within 25 years of 1230 AD. This episode might have been one large blaze or several smaller fires within a short time span. Much of the original extent of this episode has been obscured by subsequent fires but the reconstructed boundaries, based on the ages of 48 Douglas-fir, roughly approximate the original extent. The fact that stands in well protected spots, since unburned, were destroyed during the 1230 episode indicates that the fire or fires were unusually encompassing. Stands of 750-year-old trees, usually Douglas-fir, still dominate much of the Ohanapecosh and portions of the White, Nisqually, Cowlitz, West Fork White, and Puyallup River drainages.

The next major disturbance dates from ca. 1303 when parts of the Mowich River and Chenuis Creek drainages burned (Figure 14, Table 4). The Carbon River valley, which lies between the Mowich River and Chenuis Creek, contains no evidence of a fire in 1303. Since forests in the Carbon valley were extensively burned in ca. 1428 and 1628, stands from the 1303 episode could have been destroyed. Scattered individuals about 675 years 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

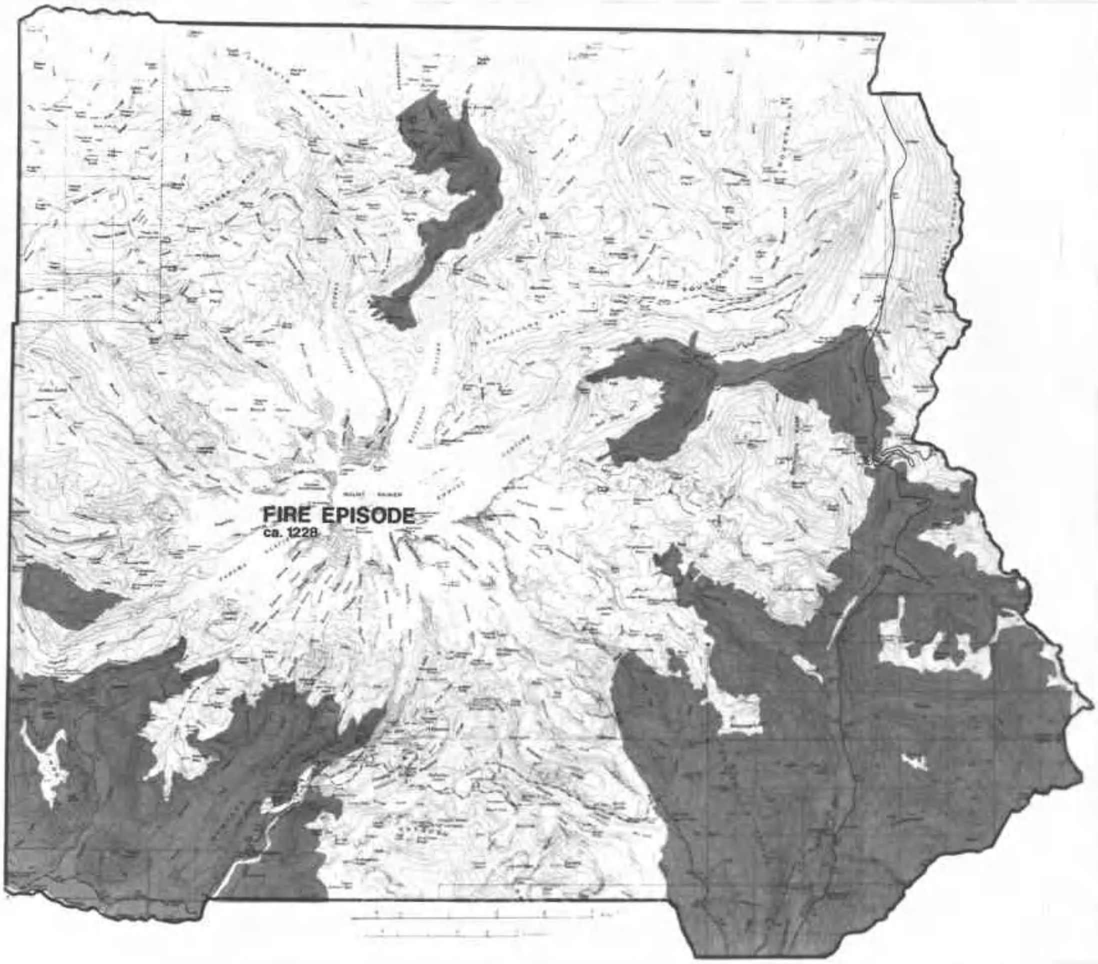

Figure 13. Reconstructed fire episode of ca. 1230. The shaded area represents the approximate original extent.

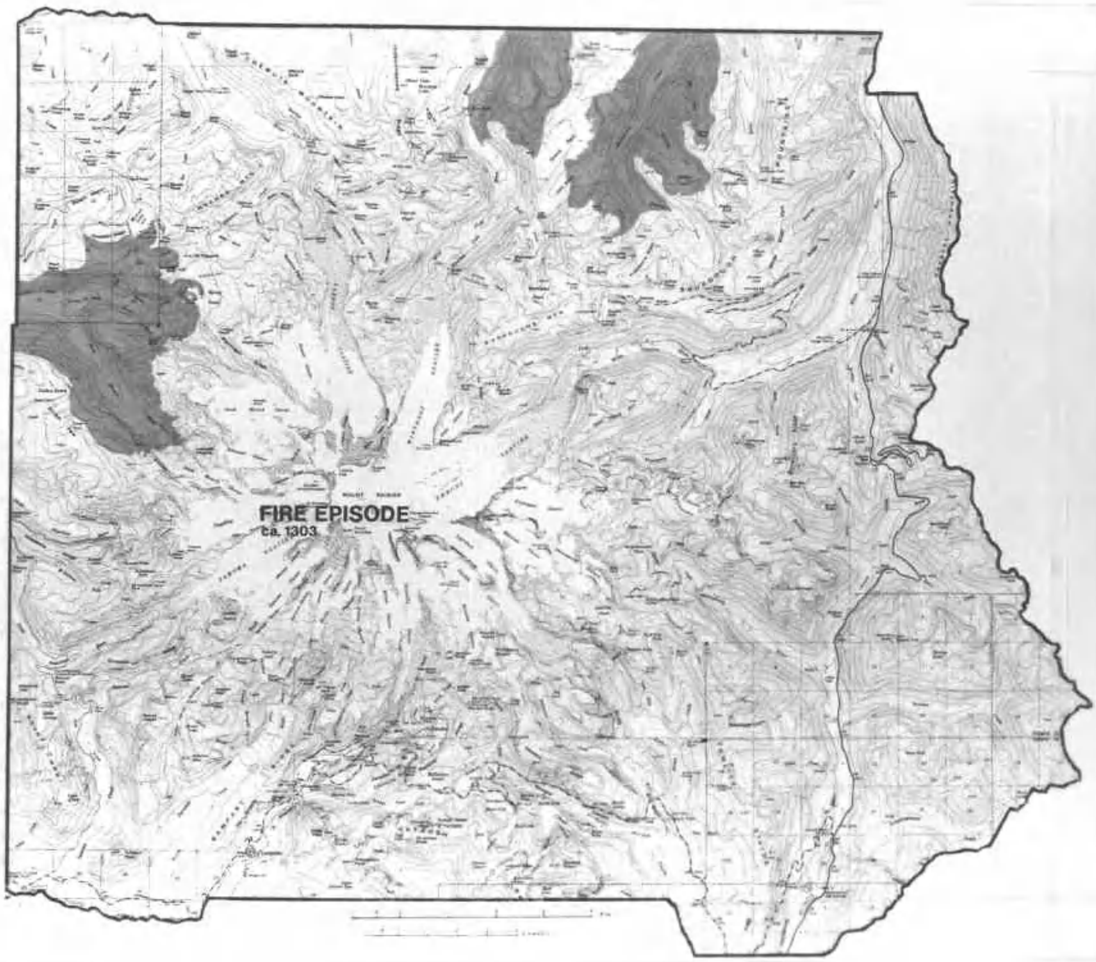

Figure 14. Reconstructed fire episode of ca. 1303. The shaded area represents the approximate original extent.

mineral soil surface and the bouldery, gravelly surface suggest that pockets of trees may have been established after floods or small lahars.

An extensive fire episode at Mount Rainier National Park destroyed large areas of forest in the White, Ohanapecosh, Cowlitz, Nisqually and Carbon River drainages in ca. 1403 (Figure 15, Table 4). Widespread but similarly aged remnant stands indicate that this episode must have been nearly as large as the 1230 episode. Most of the area burned during this era has subsequently reburned. In many places, only a few veterans of this age class persist. Burned areas were less protected, for the most part, than those of the 1230 episode. Only the White and Ohanapecosh River valleys currently possess extensive stands 575 years old. The age class in these two valleys appears to be directly connected via Chinook Pass. The presence of stands 575 years old in Butter Creek, a small drainage rimmed off from the rest of the Park by the Tatoosh Range, suggests that this fire burned up the Cowlitz River from outside the Park and branched off into the Butter Creek, Cowlitz and Ohanapecosh River valleys then over Chinook Pass into the White River drainage. Stands of similar age along Kautz Creek may not be from the same fire since large topographical barriers exist.

Stands around 550 years old (originating ca. 1428) dominate lower slopes in the Carbon River valley. The fire in the Carbon River area does not appear to be a continuation of the Cowlitz fires of similar age. But, along with the Kautz Creek stands, they could have originated after separate fires during a short time span. Much of the higher elevation forest in the Carbon River valley burned again in ca. 1628, destroying evidence about the original extent of the 1428 fire.

A fire episode 475 years ago (ca. 1503) occurred as isolated burns

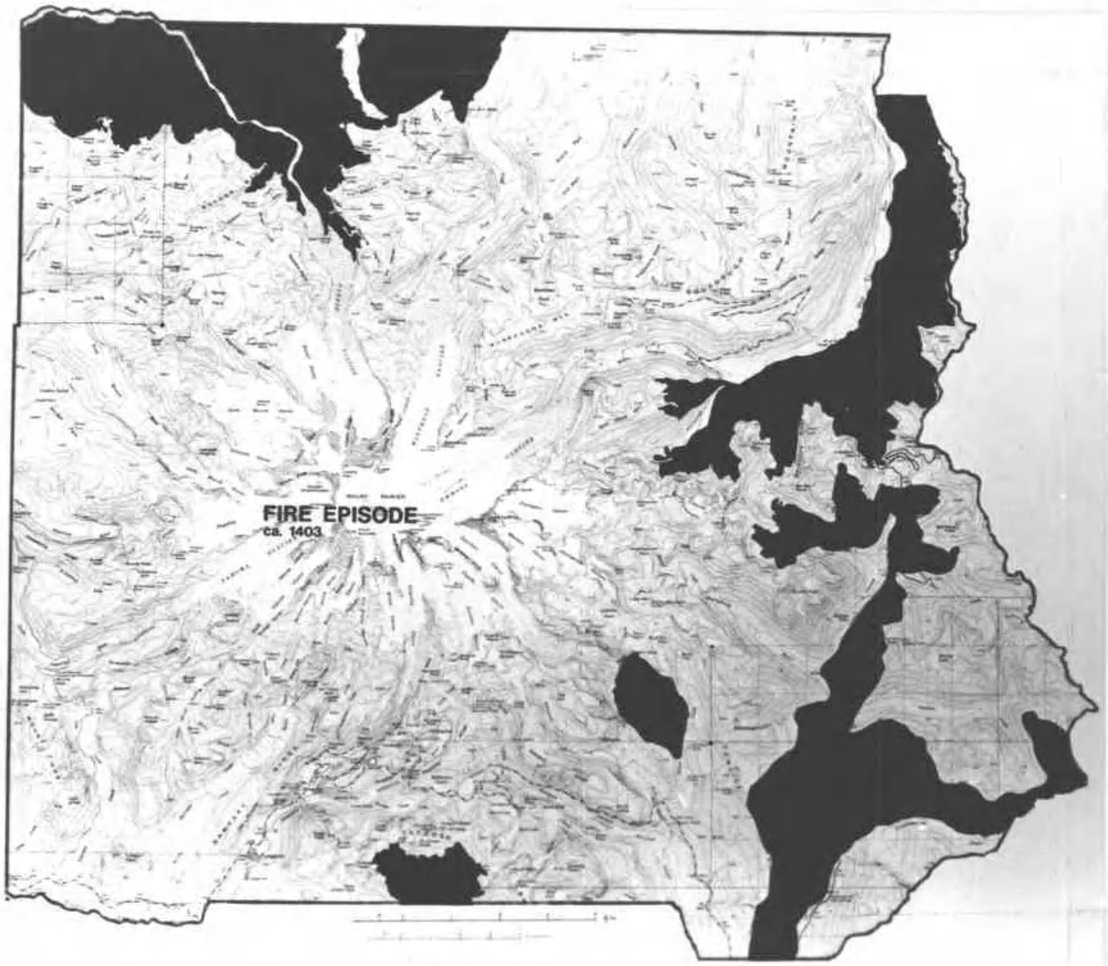

Figure 15. Reconstructed fire episode of ca. 1403. The shaded area represents the approximate original extent.

in the White, Cowlitz, Puyallup and South Mowich River drainages (Figure 16, Table 4). This age class forms extensive stands on both sides of the White River near its confluence with Klikitat Creek and in the Klikitat Creek valley. Apparently, it once covered much of the area burned 120 years ago (ca. 1858) on Crystal Mountain where fire scarred individual Douglas-fir still survive. Yet another fire burned a large area in the Cowlitz River valley in ca. 1503. Much of this area subsequently burned in ca. 1856 and ca. 1886. Only a few individuals 475 years old remain. A separate fire burned large areas in the North and South Puyallup and South Mowich River drainages. Part of the burned area had been destroyed by the large Electron mudflow about 125 years earlier (Crandell 1971). Although these three fires probably did not result from the same ignition, tree ages scattered around the Park from this episode bear remarkable resemblance. All three fires could have occurred during the same drought period.

One of the largest fire episodes at Mount Rainier National Park in the past 1000 years took place about 350 years ago (ca. 1628). Stands of this age are the most extensive current forest age class (Figure 17, Table 4). They dominate upper slopes in the Carbon, Mowich, Puyallup and, to a smaller extent, Nisqually River drainages. Tree ages from this episode consistently cluster near 350 years for older members of the cohort. Charcoal near the mineral soil surface overlies the W tephra (Table 2) in areas where the W is recognizable. Evidently a single fire or a series of very closely timed fires swept up the flank of Mount Rainier from the west and burned most of the upper-slope forests in the Park's western half. Much of the burn stands out clearly on aerial photographs. It is superimposed on stands mostly over 500 years old and

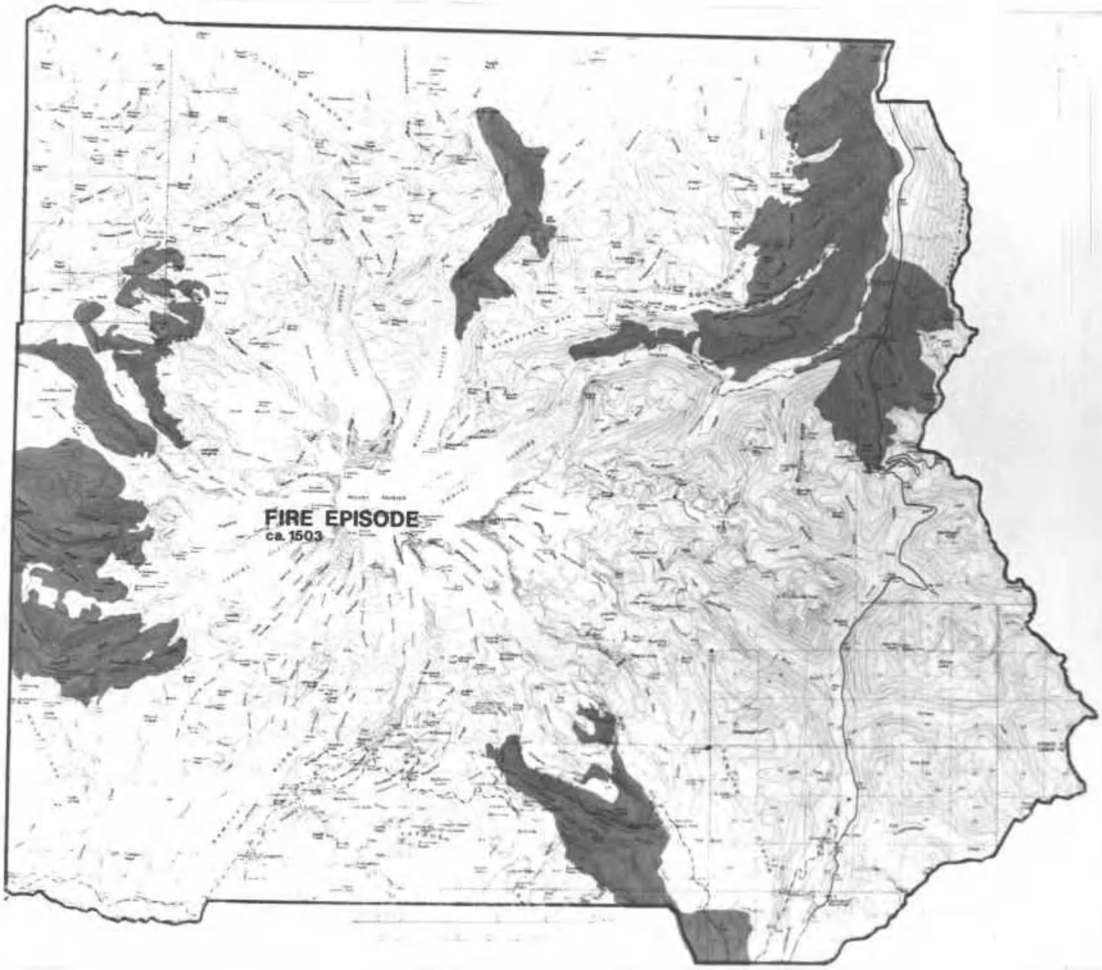

Figure 16. Reconstructed fire episode of ca. 1503. The shaded area represents the approximate original extent.

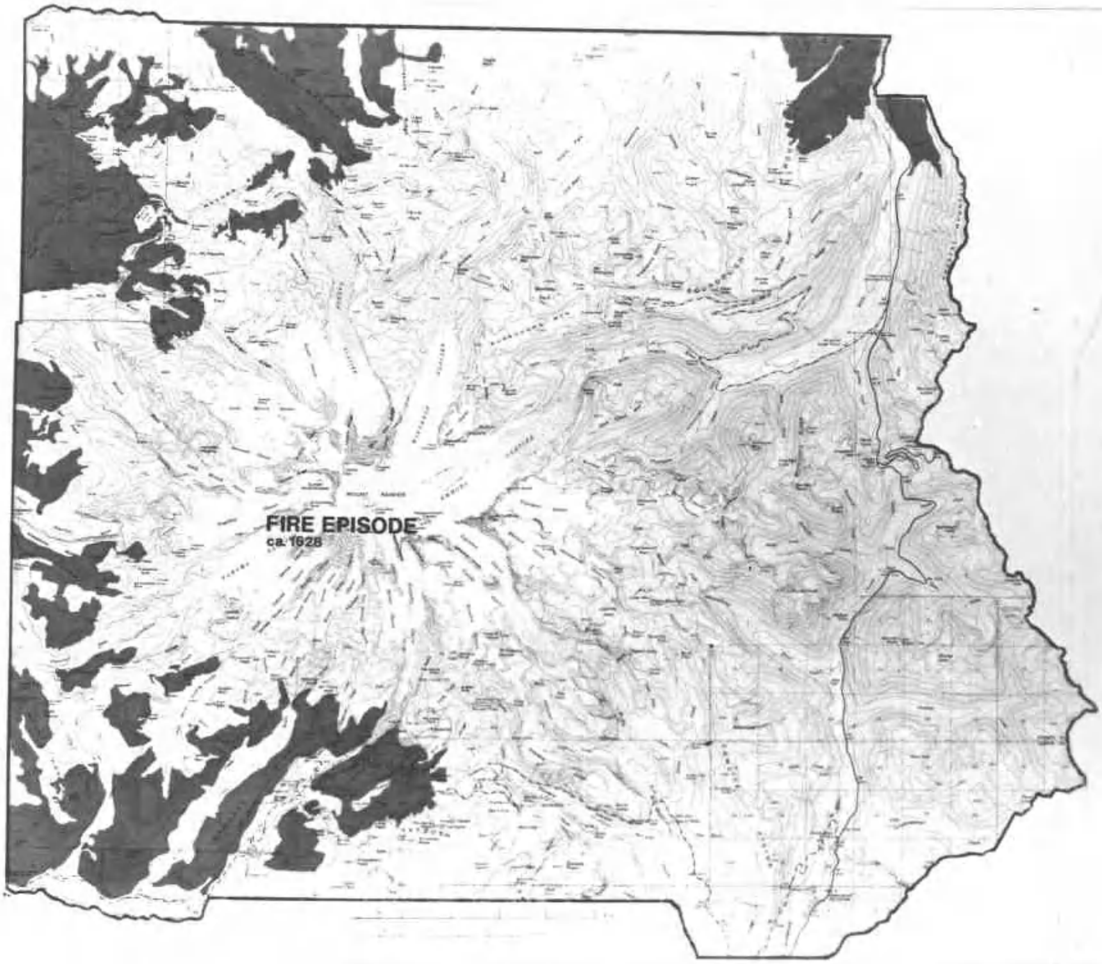

Figure 17. Reconstructed fire episode of ca. 1628. The shaded area represents the approximate original extent.

not reburned since; only in the Nisqually River drainage do more recent events obscure the boundaries. Judging from the wide area affected in the Park, this fire probably formed extensive burns outside the Park in rugged topography to the south, west and north. Thornburgh (1967) reports an extensive 370-year-old age class from his study area adjacent to the Park's southwest corner.

Although there are scattered stands of comparable age in the White River drainage, the episode appears less important there. Since ages of trees from these areas are consistently 15 to 35 years younger than those in stands of the Park's western half, the White River fires of about 320 years ago might not have been part of the same episode.

The next era of major fire disturbance was approximately 275 years ago (ca. 1703). Two, probably separate, fires comprise this episode (Figure 18, Table 4). One fire about 290 years ago (ca. 1688) occurred in portions of the West Fork White River and Huckleberry Creek drainages on generally west-facing slopes. Some reservations are necessary since only four trees were sampled from stands of this age, but the stands seem distinct on aerial photographs. About the same time, large fires burned in the Ohanapecosh and Cowlitz River drainages. Subsequent, massive fires in the Cowlitz area obliterated most evidence of the 1703 fire there. In any case, it was not as extensive as the 1503, 1403 and 1230 fires in the Cowlitz; only a few 275-year-old trees remain along the upperslopes of Backbone Ridge and Cowlitz Divide.

Large areas in the Ohanapecosh drainage support 275-year-old stands (Figure 18, Table 4). Fire lines stand out clearly against the overall matrix of stands older than 500 years. Protected north and east facing slopes and valley bottoms escaped burning. This fire episode is appar-

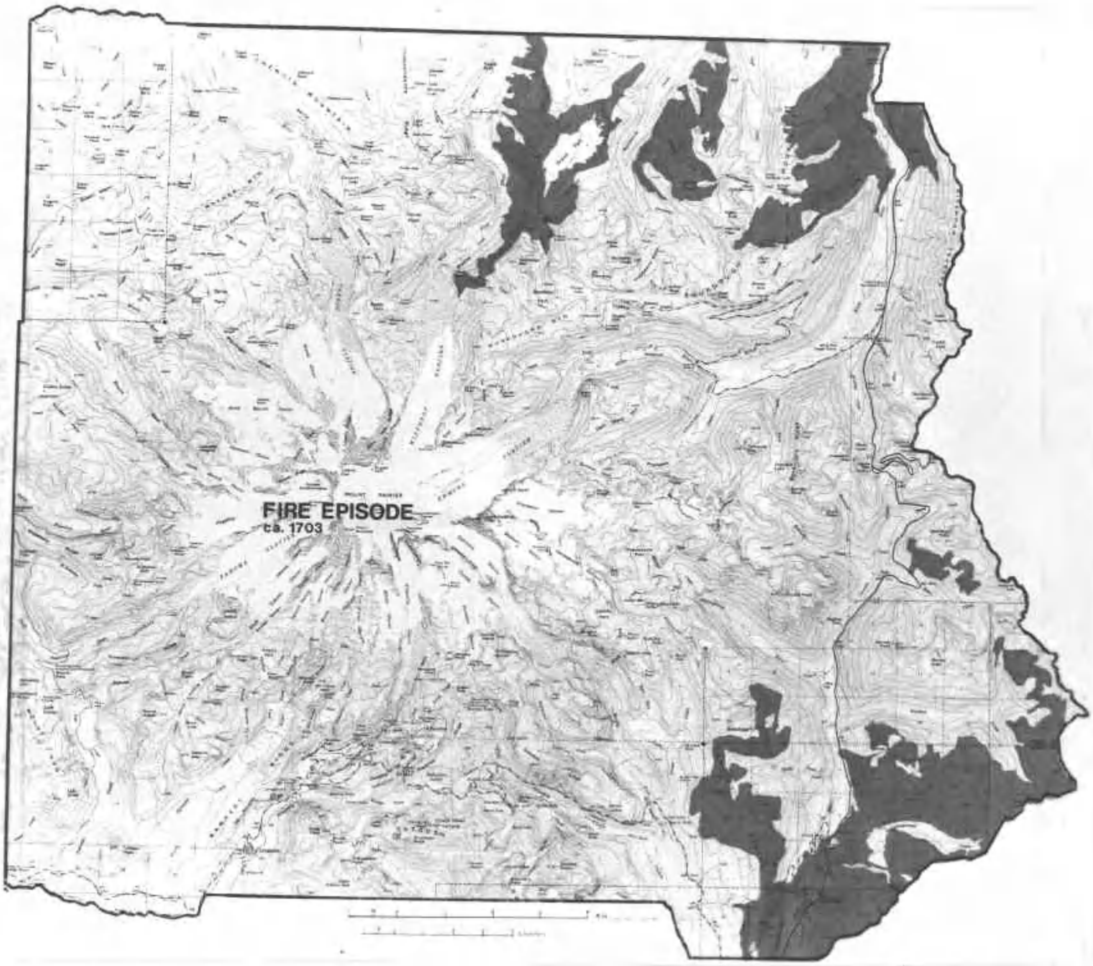

Figure 18. Reconstructed fire episode of ca. 1703. The shaded area represents the approximate original extent.

ent in the Butter Creek area and must have resembled the fire 575 years ago in burning up the Cowlitz River valley from outside the Park and into the tributary Ohanapecosh River and Butter Creek drainages. Tree ages from south of the Park in the Summit and Carlton Creek drainages match the 275-year-old ages in the Park.

Many stands in the Ohanapecosh valley reburned nearly 100 years later, ca. 1803. Extensive contemporaneous stands occur outside the Park near Carlton Creek and in adjacent high elevation areas along upper Laughingwater Creek inside the Park (Figure 19, Table 4). This fire may have burned north up Carlton Creek, over low divides and into the Park. Much of the area burned was steep, relatively open subalpine parkland and Pacific silver fir forest.

The next major fire occurred about the time modern man arrived in the area, although no evidence links the fire to early settlers or explorers. Stand ages from 31 trees sampled in extensive stands in the Nisqually drainage indicate a fire in about 1825 (Figure 20, Table 4). Ages from relict trees indicate that many of the stands burned in 1825 had regenerated after the 1230 episode. The 1825 fire generally did not burn out onto alluvial flats forested by stands from the 1230 episode, however. Haines (1953) lists a fire in the Park covering about 10,000 acres in 1835; no other large fires were observed in the Park suggesting Haines' date, implying that his information about the fire date may have been several years in error.

Remnants of apparently large stands dating within two years of 1856 occur in parts of the Cowlitz drainage (Figure 20, Table 4). Almost all the area burned in 1856 subsequently reburned some years later. Only relatively small stands at high elevations and occasional survivors in

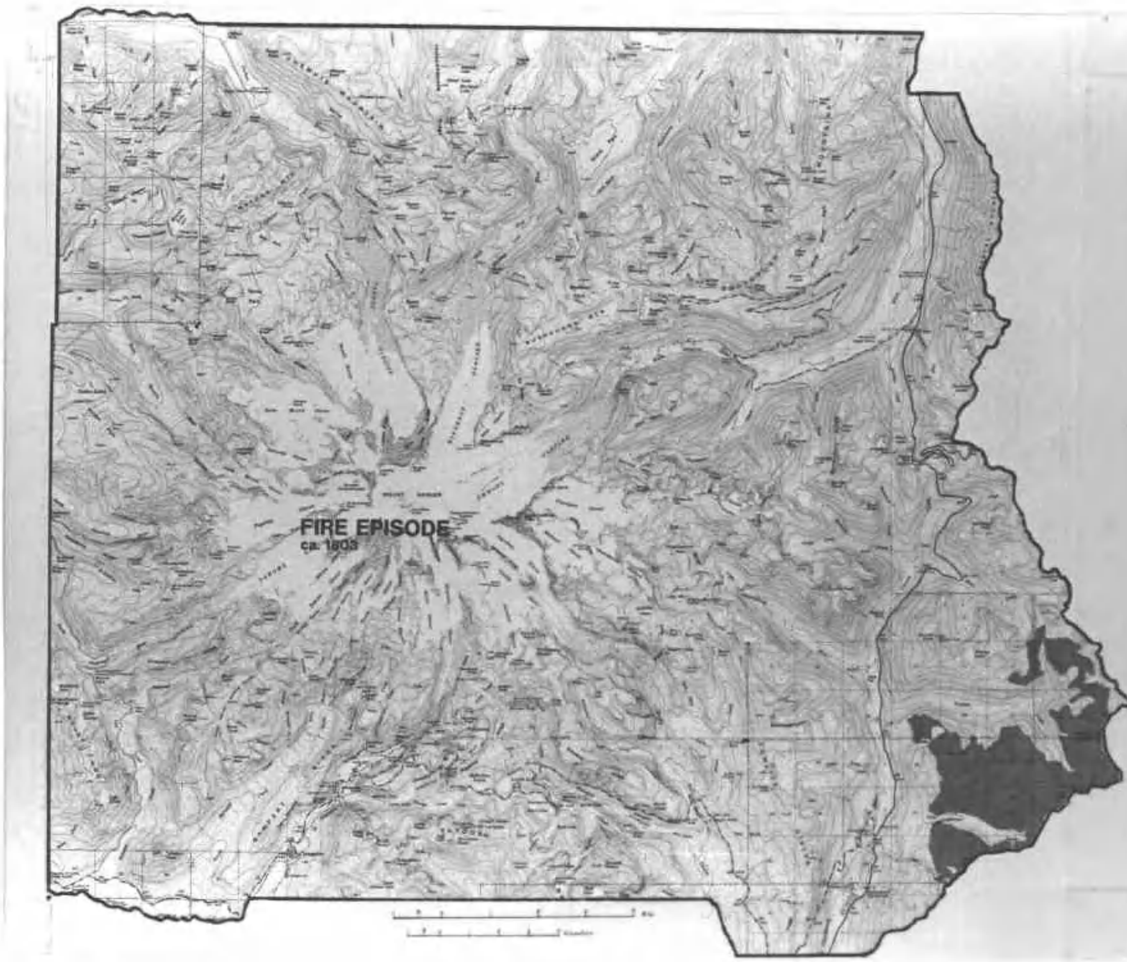

Figure 19. Reconstructed fire episode of ca. 1803. The shaded area represents the approximate original extent.

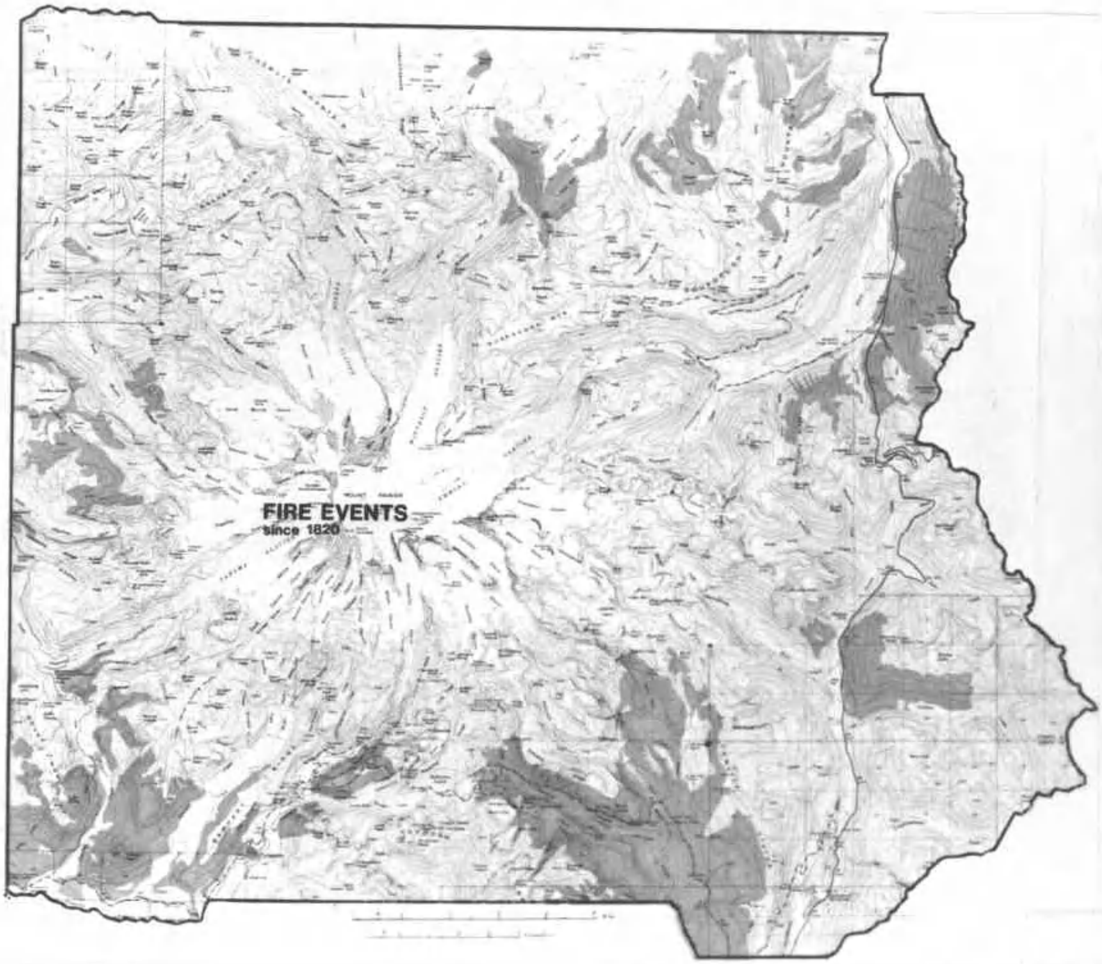

Figure 20. Reconstructed fire events since 1820. The shaded areas represent their approximate original extents.

younger stands indicate the probable former extent of stands regenerated after the 1856 fire. Large fires were recorded in Oregon and Washington in 1856 (Plummer 1900, Morris 1937). Plummer (1900) reporting on the Mount Rainier Forest Reserve wrote that the hills north of the Cowlitz River burned in 1841 and 1856. No stands aged in the Park date from 1841. Historical records do not indicate the ignition source but settlement of the area had begun.

Shortly after or coincident with the Cowlitz fire in 1856, large areas on the slopes above the White River burned, possibly intentionally set by sheepherders (Figure 20, Table 4). The stands burned probably formed part of the elsewhere extensive stands dating from the 1403 and 1503 episodes. Relict trees 475 years-old are common in parts of the 1858 burn. Large burned areas at high elevations remain poorly stocked to the present. Avalanche tracks frequently dissect the 120-year-old stands and extend down almost to the river in places. Loss of anchoring tree cover on steep slopes has probably contributed to enlarged and more frequent snow avalanches on Crystal and Sourdough Mountains. Plummer (1900) reported that sheepherders often burned forests to improve grazing. Although no hard evidence links sheepherders to the 1858 fires above the White River, the name "Sheepherder Burn" persists.

The steep, high-elevation slopes north of Grand Park burned about 106 years ago (Figure 20, Table 4). Although this burn shows well on aerial photographs, only seven trees supply the basis of age estimates. Because of the high elevation of parts of the burned areas, restocking is not yet complete. Frequent avalanches descend through these stands.

Young forests which had regenerated following the 1856 burn in the Cowlitz experienced a devastating reburn in 1886 or 1887 (Figure 20,

Table 4). This fire burned the whole of Stevens Canyon, except for small patches near Reflection Lake, the Nickel Creek area and the Muddy Fork of the Cowlitz. Large areas at moderate to high elevation remain poorly restocked at present. Widespread avalanche activity, dense stands of vine maple (Acer circinatum Pursh) and Sitka alder (Alnus sinuata [Regel] Rydb.) and rigorous site conditions have virtually halted conifer regeneration in many places. Plummer (1900) lists large burned areas in the Cowlitz drainage in 1886 which, he said, were reburns of areas burned in 1841 and 1856. Like the 1856 fire, no hard evidence links modern man's activities with the 1886 burn.

Two fires since the 1890's are linked to man's activities. A fire burned parts of the upper reaches of the Nisqually drainage in 1894 (Figure 20, Table 4). This fire spread up slope and covered sizeable areas near Frog Heaven. A larger burn in November of 1930 burned extensive areas of high-elevation forest and subalpine parkland in Sunset Park. Some portions of the area burned have yet to restock. The 1894 fire was, according to legend and historical record, set by Longmire to destroy hornets (Haines 1953). The 1930 Sunset-blaze reportedly escaped from road construction slash fires. Fire suppression efforts by the Park Service may have influenced the fire's spread (Mount Rainier National Park Fire Report Forms 10-400, 1930).

Three more fires of significant size occurred since 1900. The Shriner Peak-Panther Creek area was burned by fires which were started outside the Park on August 1, 1929 (Figure 20, Table 4). Fire report forms (Mount Rainier 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 of 1934 and September of 1935. Two small fires occurred since 1935, 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 given as the probable ignition source for all of these fires. Although the Park Service fought these fires, their effect on the final size of the burns is unknown.

Other Forest Disturbances

The total area of large snow avalanche tracks in Mount Rainier National Park is about 4270 hectares, approximately half of which is concentrated in the White and Cowlitz River drainages (Figure 21). The largest areas of avalanche activity correspond with recent burns. Large, complex avalanche tracks dissect the 1886 Cowlitz burn and the 1858 Crystal Mountain burn. Perhaps, following large fires at high elevations in the past, avalanches were once important in areas where they are not today. At Mount Rainier, avalanches tend to be chronic disturbers of a relatively small area of forest except when loss of vegetative cover following fire allows them to enlarge.

Lahar-associated stands form only a small portion of Mount Rainier National Park's existing forests. During the past 1000 years, lahars destroyed stands in the White, West Fork White, Ohanapecosh, Nisqually, Kautz, Tahoma, Puyallup and Mowich drainages (Figure 21, Crandell 1971). The 1000-year-old stands at Cougar Rocks campground, even though vegetatively similar to other stands, may be first generation forest on a lahar of the Paradise lahar assemblage. Smaller stands along Tahoma Creek, Kautz Creek and the Nisqually River may have regenerated following lahars 440, 450, and 120 to 1000 years ago, respectively. The Electron mudflow in the Puyallup drainage reached about 30 miles down-valley from Mount Rainier approximately 600 years ago. Fires in the same area

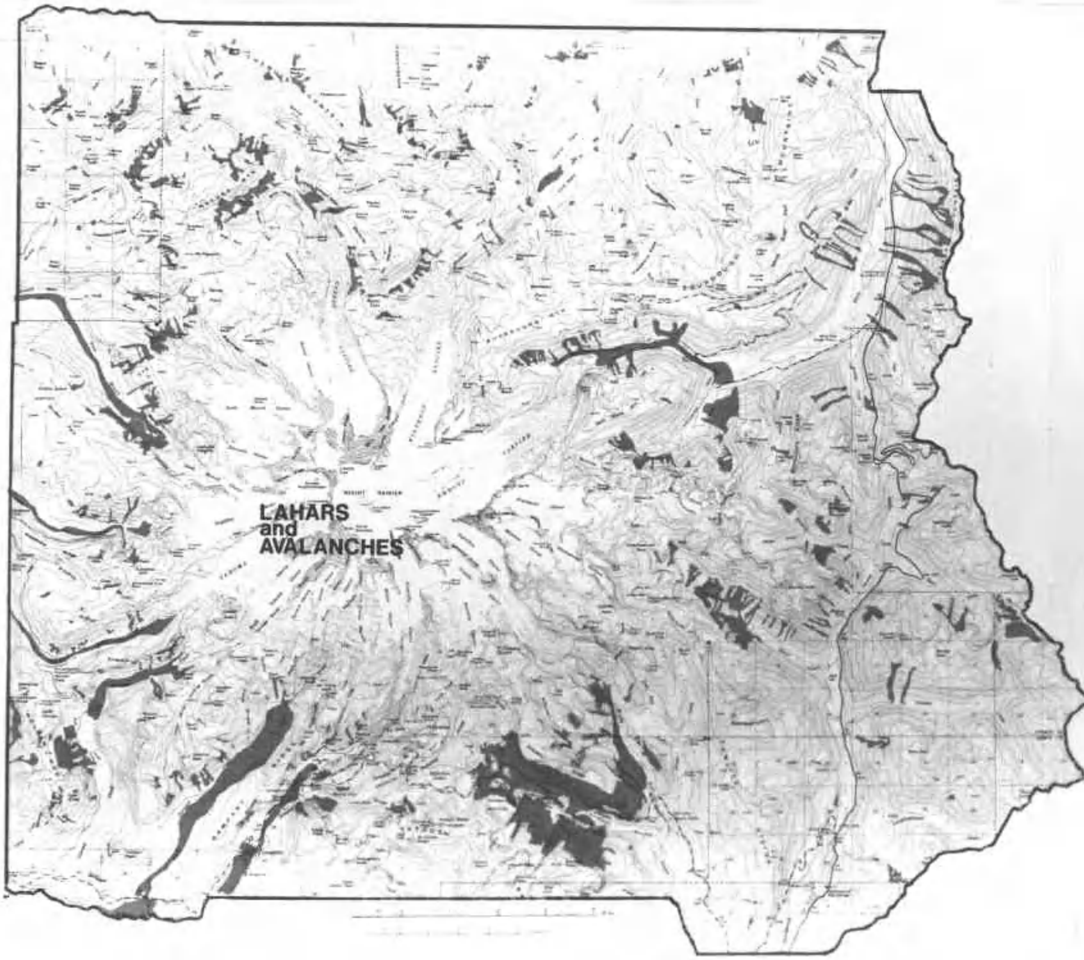

Figure 21. Area impacted by avalanches and lahars in the recent past and during the last 1000 years, respectively.

about 475 years ago destroyed most or all of the first generation lahar forests. Fires in the White and West Fork White valleys also destroyed first generation lahar stands on lahar surfaces deposited approximately 1000 years ago. Small stands presently exist on less extensive, more recent alluvial deposits along the White River.

Natural Regeneration Lag

The distribution of ages in the early seral cohort from both the three intensive sample transects in the 92-year-old Cowlitz River stands and from other naturally regenerated stands commonly span more than 75 years. Ages from dominant trees of the early seral cohort in stands which lack evidence of subsequent disturbance occasionally differ by more than 100 years. The 750-year-old forests in the Ohanapecosh drainage contain Douglas-fir 650 years old and 750 years old mixed in the same, apparently even-aged stands. Some lag might be the result of errors in ring counts, but in the 92-year-old Cowlitz River stands, areas which were apparently burned clear in 1886 support Douglas-fir which differ by as much as 75 years (Figure 12). Some areas of this burn are still re-stocking after over 90 years. Natural regeneration appears to be some-what slower on drier, more exposed, thin soiled sites, transects one and two, than on more mesic sites, transect three.

DISCUSSION

Climatic Influences on Disturbance History

Periods of prolonged drought appear to play a crucial role in the occurrence of major fires at Mount Rainier National Park. In order to analyze the effects of drought on major fires in the Park, the timing of large fires was compared to reconstructions of the area's climate. The most detailed climatic reconstructions relevant to the Mount Rainier area come from tree ring studies of ponderosa pine (*Pinus ponderosa* Dougl.) in semi-arid regions east of the Cascade crest (Keen 1937, Blasing and Fritts 1976). Rings from trees growing west of the crest typically lack good climatic correlations since ring width is affected mainly by competitive stress (Schmidt 1970). Since the same weather systems provide moisture on both sides of the crest, major climatic fluctations are comparable on both sides of the Cascades. Keen's (1937) reconstructions for eastern Oregon extend back to about 1270 AD. Blasing and Fritts (1976) reconstructed winter climate fluctuations in the Pacific Northwest back to about 1700 AD. Winters designated types two and four by Blasing and Fritts had below normal precipitation and above normal temperature and moderately lowered precipitation and colder than normal temperatures, respectively. Historic records of fire and drought and fire frequency studies in the Northwest were also useful (Plummer 1902, Plummer 1912, Fenby 1914, Fire Report Forms 10-400 from 1928 to 1965 Mount Rainier National Park, Report on Fire Protection Requirements Mount Rainier National Park 1930, Morris 1937, Haines 1953, Cowan 1961, Weaver 1961, Soeriaatmadja 1966, Schmidt 1970).

The correspondence of drought and major fire at Mount Rainier

National Park is striking (Table 4). Fire episodes centered in the years 1303, 1403, 1503, 1628, 1856, 1930, and 1934 relate very well with first or second magnitude droughts from Keen (1937). In fact, of the eight major droughts reconstructed for eastern Oregon by Keen (1937) only two, 1739-43 and 1756-59 lack a corresponding large fire in the Park. Fire episodes centered in 1703, 1803, 1825, 1856, 1858, 1872, 1886, 1930 and 1934 correspond well with drought winters from Blasing and Fritts (1976). Plummer (1912) noted extensive droughts in the Midwest United States corresponding within two to five years to fire episodes centered at 1688, 1703, 1856, and 1858. The only major fire in the Park not correlated with a reconstructed drought is the large episode of ca. 1230, well before Keen's (1937) earliest reconstruction.

This correspondence of drought and fire frequency is widespread in northern temperate to boreal forests (e.g., Heinselman 1973, Loope and Gruell 1973, Rowe and Scotter 1973, Pickford et al. 1977). Haines and Sando (1969) found that the extreme behavior of large fires in the north-central United States is closely associated with three to eight months of below normal precipitation, one to three months of continuous drought or wilt experienced by vegetation, long-term below-normal humidity and above-average sunshine duration. At Mount Rainier, one to several years of drier-than-normal weather may be necessary to sufficiently dry heavy loads of fuels which might then burn holocaustically if ignited.

Since fire episode dates at Mount Rainier National Park are actually intervals around a midpoint, the correspondence between drought period and fire episode may be coincidental in as much as drought period and fire episode period overlap. But coincidence is severely stretched by the nearly one-to-one correspondence between drought and fire. Additional study, perhaps using varved bog or lake sediments would shed more light on the relation between fire and drought at Mount Rainier.

Patterns of Wildfire Over the Landscape

In terms of the distribution of fire over the landscape at Mount Rainier National Park, two important points emerge. First, fire frequency tends to vary with topographic position. Alluvial terraces, valley bottoms and protected north-facing slopes tend to be forested with old stands (Figure 3). Nearly every major river valley contains a streamside old-growth corridor. In the Ohanapecosh River valley, north and east-facing slopes above the Ohanapecosh River, Dewey Creek, Deer Creek, Panther Creek and Laughingwater Creek are forested with stands over 700 years old while areas directly across these water courses support stands generally less than 350 years 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 valleys, this may be due to a generally southerly aspect and lack of topographic and vegetative barriers to fires burning into the Park. The White River drains an area in Mount Rainier's rainshadow and it is not surprising that fires are more frequent in this relatively drier region. The extensive stands of old-growth in the Ohanapecosh drainage initially appear anomalous since it generally faces south and opens into the frequently burned Cowlitz valley. One factor in the high proportion of stands over 750 years old may be that large northerly facing slopes are sheltered from fires moving up the Cowlitz by high, rocky ridges.

Patterns of Wildfire in Time

Various investigators have devised indices of past fire frequency to compare different study areas. Heinselman (1973) defines natural fire rotation (NFR) as the time necessary to burn-over and reproduce an area the size of the study area given the fire frequency. 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 cycle variable, C, in the same fashion as Heinselman, but bases his calculations of fire frequency on the areal distribution of presently existing age classes. He assumes that fires occur randomly over a forest with a certin probability, p, of burning any one stand in any one year. The fire cycle, C, is the inverse of p and can be calculated from the negative exponential relationship between stand age classes and the percent of the forest occupied by those classes. A linear regression of log-transformed percent coverages of age classes on age class midpoints provides C as the inverse of the slope of the regression line. The square of the resulting correlation coefficient provides an estimate of goodness of fit of the actual stand age distribution to that of Van Wagner's "ideal" stands. Van Wagner suggests that appropriate stratification of complex forests into more homogenous units should improve fit to his negative exponential distribution. Van Wagner's method does not require reconstructing the extents of past disturbances, only a map of the present stand ages is required.

Fire frequency at Mount Rainier National Park was calculated using natural fire rotation, mean fire return interval for fires burning over ten percent of the Park's forest, and Van Wagner's (1978) negative exponential relationship with the map of present stand ages. Natural fire rotation during the pre-modern man era for the whole Park was about 465 years (Table 5). During the early settlement era, from 1850 to 1900, the fire rotation dropped to 226 years, perhaps due to increased fire from man's activities. Then, in the fire suppression era from 1900 to 1978, the fire rotation rose to 2583 years. It appears that fire suppression may have decreased the extent of fire in the Park. Especially indicative of the effects of fire suppression are the relatively small size of fires during the 1917 to 1934 drought period. If drought and large fires are indeed linked, large fires might have been expected during this drought, one of the most intense reconstructed by Keen (1937).

There are problems in interpreting the natural fire rotation at Mount Rainier. The century-by-century fire rotation varies tremendously. In the century from 1200 to 1300, it was even lower than in the early settlement era. But in the centuries from 1300 to 1400 and from 1700 to 1800 the fire rotation was 882 years and 1033 years, respectively. This fluctuation may be due to the infrequent occurrence and large size of fires in the Park. Fire rotation calculations for short time spans, e.g. for 1850 to 1900 and 1900 to 1978, may not be as meaningful as those for longer time spans. In addition, natural fire rotations based on the reconstructed fire episodes at Mount Rainier National Park may over-estimate actual fire rotations, especially in areas where fires are frequent. South facing slopes and high-elevations in the Park seem to burn more frequently and support younger stands than north-facing and low-elevation areas.

Natural fire rotation calculations in the Ohanapecosh drainage, stratified into north and east-facing slopes versus south and west-facing slopes and areas above 970 m elevation versus areas below 970 m, show

Table 5. Natural Fire Rotation by Century and Mean Fire Return Interval.

Time Span	Area Burned ha	Percent of Total Forest	NFR[1] years	MFRI[2] years
1200 to 1300	24950	47	213	
1300 to 1400	6012	11	882	
1400 to 1500	13730	26	386	
1500 to 1600	13680	26	388	95
1600 to 1700	17300	33	307	
1700 to 1800	5135	10	1033	
1800 to 1850	4708	9	563	
1850 to 1900	11722	22	226	
1900 to 1978	1601	3	2583	78
1200 to 1850			465	

1/ Natural fire rotation (Heinselman 1973) as calculated in Table 6.

2/ Mean fire return interval (Tande 1977) for fires burning more than five percent of the total forested area. No fires this large occurred from 1900 to 1978.

just the opposite (Figure 22, Table 6). North-facing slopes below 970 m had a pre-modern man fire rotation of about 364 years while south-facing slopes above 970 m had pre-modern man fire rotations of 476 years. These discrepancies are probably due to the fact that records of older fires are often completely erased in areas which burn frequently. Natural fire rotations calculated for long time spans for areas supporting extensive, young stands would therefore over-estimate the fire rotation. Since the whole-Park natural fire rotation lumps stands burned by extensive recent fires and old-growth stands, the whole-Park fire rotation for the pre-modern man era is probably less than 465 years. Attempting to correct natural fire rotation calculations by extending old burns into areas where their presence has been masked by more recent burns involves extrapolating beyond the data base and violates assumption number six given in the methods. Estimating fire frequency by using natural fire rotation calculations based on reconstructions of fire episodes over long time periods, especially involving large areas recently burned, may be misleading and result in underestimating fire frequency.

Van Wagner's negative exponential age class to area distribution fits poorly at Mount Rainier National Park. Squared correlation coefficients (r^2) are generally less than 0.60 (Table 7). For the whole Park, r^2 is 0.72 and C, the fire cycle, is 306 years. Stratification by drainage fails to improve the situation; in fact, goodness of fit decreases in nearly every case. The problem arises from the fact that at Mount Rainier the present area occupied by stands from a given fire episode generally increases with increasing age of the event; just the opposite of the model's predicted trend. The main value of attempting

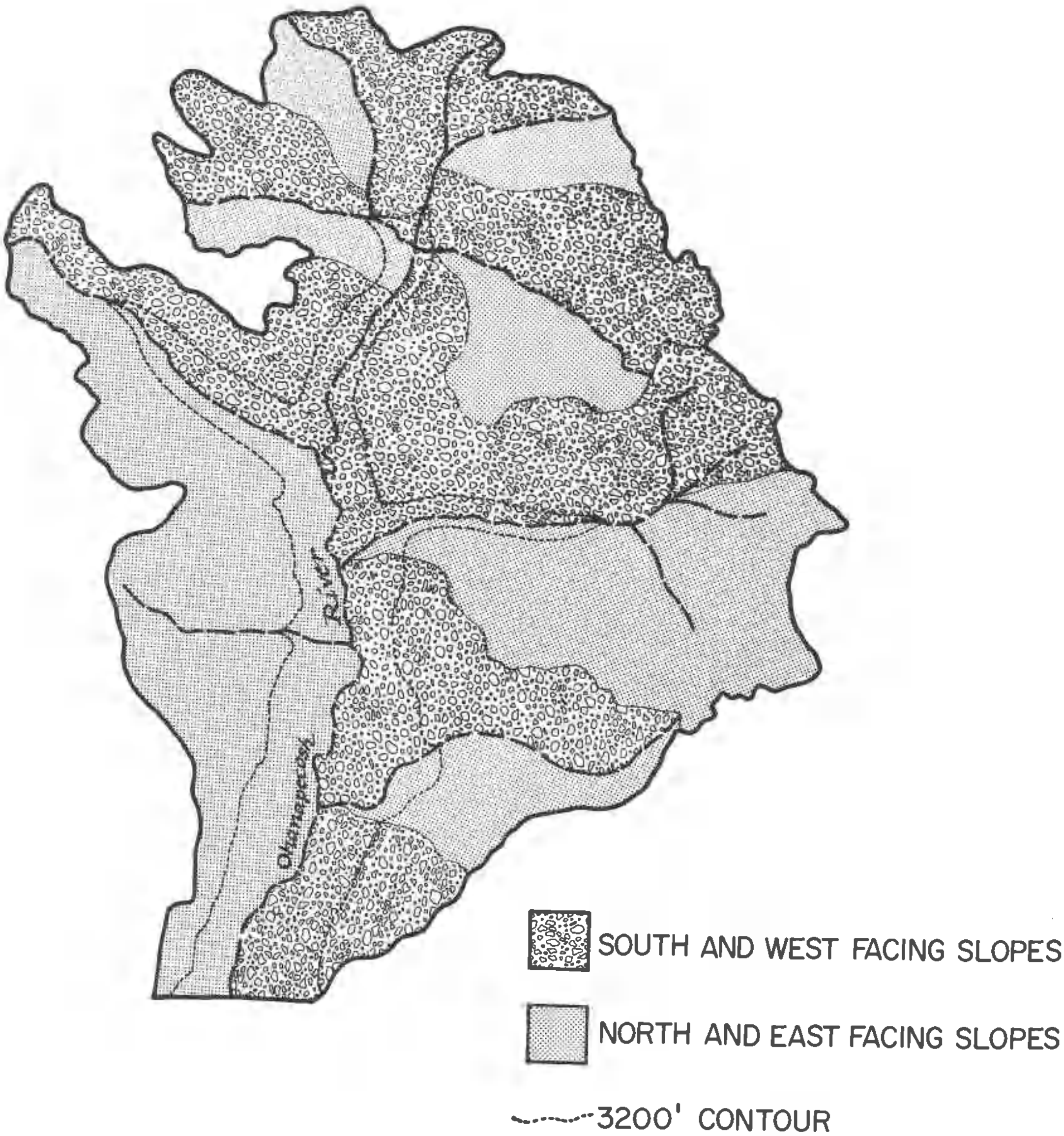

Figure 22. Stratification of the Ohanapecosh River drainage into regions above and below 970 m elevation, south and west-facing slopes, and north and east-facing slopes.

Table 6. Natural Fire Rotation in the Ohanapecosh River Drainage.[1]

	North	South	Below 970 m	Above 970 m	North Below 970 m	South Above 970 m	Total
Forested Area ha	7265	7290	2860	11695	1210	5640	14560
Burned Area ha[2]	13110	12010	5620	19500	2490	8885	25120
NFR yrs[3]	416	455	382	450	364	476	435

1/Aspect stratafied into north and east-facing slopes as north facing and south and west-facing slopes as south-facing.

2/Area burned over the entire 750 year period reconstructed.

3/NFR calculated as by Heinselman (1973) by the following formula:

$$NFR = \frac{\text{Forested Area}}{\text{Burned Area/750 years}}$$

Table 7. Van Wagner's (1978) Fire Cycle for the Whole Park and by Drainage.

Region	Total Forested Area	C 1/ yrs	r^2	Slope 2/
Ohanapecosh Drainage	12052 ha	723	0.06	-
Cowlitz Drainage	5109 ha	303	0.57	-
Nisqually Drainage	6856 ha	559	0.26	-
Puyallup Drainage	4466 ha	322	0.72	-
Mowich Drainage	3824 ha	-200	0.56	+
Carbon Drainage	5509 ha	178424	0.01	+
West White Drainage	3156 ha	-547	0.01	+
White Drainage	11853 ha	592	0.15	-
Whole Park	53030 3/ ha	306	0.72	-

1/ Van Wagner (1978) calculates C as the inverse of p in the following equation: $f(x) = pe^{-px}$ where f(x) is the percent of the area covered at the present time by an age class with midpoint x and p is the probability that any one stand will burn in any one year. The fire cycle, C, is defined as the inverse of p and is calculated by fitting the linear regression: $\ln (f(x)) = \ln p - px$ to find p.

2/ If the slope of the line is negative, the forested area generally follows the negative exponential relationship between f(x) and x postulated by Van Wagner. If the slope is positive, older age classes occupy more of the forested area than younger age classes; just the opposite of the predicted model.

3/ Includes avalanche areas.

to fit the negative exponential curve is that the exercise shows that fires in the Park's forest are not randomly located, periodic events.

Mean fire return interval also seems to poorly describe the frequency of fires at Mount Rainier (Table 5). Tande (1977) used fires which had burned over 50 percent of his study area in calculating a mean fire return interval of 66 years. Reconstructed fire episodes at Mount Rainier all burned less than 50 percent of the area. In fact, by adjusting the percent of area burned cut-off level, widely variable mean return intervals can be calculated. For this reason, the mean fire return interval index seems to be of limited use in comparing fire frequency of different areas.

An important question posed by these fire frequency calculations is whether fire frequency is a valid concept at Mount Rainier National Park. Do fires occur with some cyclical pattern over time or are they triggered by some non-cyclical force such as climatic shifts? Can a frequency even be realistically calculated where only two or three episodes have occurred in 1000 years, as is the case in nearly 30 percent of the Park's forests? Considering the close correspondence between major fire episodes and major drought discussed earlier, it seems likely that fire episodes are not inherently cyclical at Mount Rainier and do not, therefore, possess a discernable frequency. Of course, droughts may result from some yet unknown climatic cycle and, if fire episodes indeed link with major drought, fire episodes may be cyclical in an indirect sense.

Relative Importance of Disturbance Types

Fires are by far the most important forest catastrophic disturbers at Mount Rainier National Park. On a Park-wide basis, 90 percent of the existing stands have developed following fires, seven percent following avalanches and two percent following lahars. Avalanches are the most frequent major disturber, occurring yearly to decadally, while large fires occur once every century or so somewhere in the Park and lahars even less often.

Other types of forest disturbances are important, especially wind and pathogens (insects, root-rot, etc.). Wind has been a major forest disturber in the Coast, Olympic and Cascade Ranges (Lynott and Cramer 1966). The Columbus Day storm of 1962 blew down more than eleven billion board feet of timber in Oregon and Washington. Only small disturbances at Mount Rainier definitely date from this storm. After 50 to 100 years, 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). In addition, windthrow can be augmented by root-rot or insect killed trees. In any case, neither wind nor pathogens show up as major, stand-wide destructive forces at Mount Rainier National Park.

Implications for Managers

Coniferous forests at Mount Rainier National Park bear little resemblance, in terms of fire frequency, to most of those in the Sierra-Nevada and Rocky Mountains or in the north central United States where fire frequencies are about 8 years, 20 to 25 years, and up to 100 years, respectively (Kilgore 1973, Habeck 1976, Heinselman 1973). Given the long period between fires over much of Mount Rainier's forests, the effects of fire suppression, if it has indeed reduced fire occurrence, in altering the composition and structure of the Park's forest vegetation might appear only after centuries of fire exclusion. Forests on upper slopes and southern exposures which support stands of Douglas-fir and noble fir less than about 250 years old will probably change relatively rapidly as some of the comparatively short-lived early seral species drop out. Even this change involves time scales of about 100 years. Other habitats on wetter, more protected sites often have experienced only one or two fires during the last 1000 years and there is no reason to suppose that they would have burned during the past 70 years or during the next two or more centuries. The problem of fuel buildup leading to holocaustic fires, as has been experienced in other areas, naturally occurs at Mount Rainier and has probably not been increased under present fire suppression programs.

Wildfire has been an important natural force at Mount Rainier and must be included in a program to maintain natural forest conditions, even though changes from pre-modern man structure and composition will not be immediate. Naturally ignited fires should be allowed to burn wherever possible. If fires and drought are closely linked, as this study indicates, most fires will be small except during infrequent periods of prolonged drought. During protracted droughts, extensive, holocaustic fires might occur. Conflagrations of the size and apparent intensity of those which occurred in the past could be extremely destructive to life and property. Present fire suppression techniques might well be ineffective in controlling such fires.

Lahars also present a potentially significant danger to life and property, mainly as a consequence of their destruction in valley bottoms, which are among the most intensely developed areas in the Park. Lahars might also extend a long distance outside the Park's boundaries, potentially affecting populated areas in the lowlands around the park.

CONCLUSIONS

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

1) Catastrophic disturbances played an important role in shaping the Park's existing forest mosaic. The most important disturbing agent studied is fire, followed by avalanches and lahars.

2) Wildfires at Mount Rainier have been large and infrequent with a natural fire rotation of more than 350 years.

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

4) Episodes of major fire may correspond to periods of prolonged drought.

5) Complete regeneration of forests after a catastrophic disturbance often requires more than 75 years.

6) Modern man's influences on the natural fire regime at Mount Rainier have probably been negligible except for possibly limiting the size of fires during the 1917 to 1934 drought.

7) Extensive, holocaustic fires and large lahars, while infrequent, may potentially be very destructive to lives and property both within and outside of the Park's boundaries.

8) Wildfire has been very important in the recent history of the Park's forests and as a result, must be included as an active factor in the forest ecosystems if they are to be maintained in a natural state.

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