FIRE KNOWLEDGE for MANAGING CASCADIAN WHITEBARK PINE ECOSYSTEMS

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ACKNOWLEDGEMENTS

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DELIVERABLES

Item	Date
Manuscript of project	In preparation
Workshop at each Study Unit including oral presentation, delivery of digital data, and dendrochronology samples	Spring 2006
Oral Presentation – Annual JFSP Workshop, 2005	(Declined by JFSP)
*The following are **additions** to the original proposed list of deliverables.*	
Invited Oral Presentation: Restoration Ecology Seminar, University of Washington, Seattle	January 2006
Invited Oral Presentation: American Assoc. for Advancement of Science, Western Division Meeting, Southern Oregon University., Ashland.	June 2005
Invited Oral Presentation: Mixed Severity Fire Regime Conference, Spokane, WA	November 2004
Poster Presentation: Annual Meeting of Ecological Society of America, Portland, OR	August 2004
Poster Presentation: Annual Wildflower Show, Shady Cove, OR	May 2004
Invited Oral Presentation: Kirlin Lecture Series, Southern Oregon University, Ashland	April 2004
Invited Oral Presentation: Northwestern Oregon Federal Ecologists Working Group, Sandy, OR	April 2004

SUMMARY

Whitebark pine (*Pinus albicaulis)* is an ecologically significant component of high elevation forest and woodland ecosystems in the Cascade Mountain Range of Oregon and Washington. Its importance is noted as whitebark pine is recognized as a keystone species. The objectives of this study are to 1) gain an understanding of fire frequency and severity associated with whitebark pine forests, and 2) describe historic and current stand conditions and estimate potential ecological effects of fire exclusion policies. By applying standard field techniques (scar and core sampling) we compiled a dataset that describes fire's role in these timberline forests. We report on 55 fire history sites located in the Cascade Range. Incidence of fire was documented throughout the whitebark pine ecosystem in the Cascades, indicating that fire is a significant disturbance agent. Whitebark pine ecosystems appear to burn in a broad spectrum of severity and frequency. Fire return intervals ranged from 9 to 314 years. This broad range indicates that fire regimes in whitebark pine forests are site-specific more than species-specific. From stand reconstruction techniques, we estimate that since the 1920s, volume for all tree species including whitebark pine began to increase dramatically. Late-seral species have increased at greater rates, indicating fire exclusion as a causal agent facilitating and possibly driving changing forest conditions.

Managers can reintroduce fire as a natural element of Cascadian whitebark pine forests. Because fire regimes vary greatly among these forests, it's recommended that site-specific targets for severity and frequency, rather than general range wide prescriptions be incorporated into burn plans. We provide guidelines for each of three study units with the goal to achieve burning conditions which are within the natural and historic regimes of these unique and threatened forests.

TABLE OF CONTENTS

Part 1: Fire Regimes

Part 2: Historic Stand Conditions

Appendices

Part 1: Fire Regimes

INTRODUCTION

It is well established that fire is a key natural disturbance that regulates ecosystems and forest dynamics in the Pacific Northwest (Weisberg and Swanson 2003; Everett et al 2000; Agee 1994; Agee et al 1990). Fire regimes have been studied throughout the Pacific Northwest and Intermountain West (Agee 1993). The United States Forest Service recognizes the importance of understanding localized fire regimes and has recently embarked on an ambitious project to identify fire regime reference conditions for forest types (www.frcc.gov). Knowledge of fire regimes enables forest managers to make informed decisions when considering fire management questions. This research attempts to guide management decisions where whitebark pine is part of the ecosystem.

Subalpine woodlands of western North America commonly consist of whitebark pine (*Pinus albicaulis*), which is a valuable resource for wildlife. Its seed, the largest of all subalpine trees, is a nutritional prize. In the southern Cascades several mammals and at least a dozen birds are known to forage on the seeds (Tomback and Kendall 2001) with an additional variety of woodpeckers, raptors, nuthatches, jays, and grouse commonly occupying habitat (personal observations). The bird most often associated with whitebark pine is the Clark's nutcracker *(Nucifraga columbiana)* which collects seeds and buries them in the ground for later retrieval. Seeds not reclaimed by the birds can germinate – thus a mutually beneficial relationship is recognized (Tomback 2001).

Whitebark pine is a poor competitor with other tree species and maintains itself well at sites prone to disturbance or where natural elements are too harsh for its competition. In the northern Cascades, whitebark pine is most often associated with Engelmann spruce (*Picea engelmannii*), subalpine fir (*Abies lasiocarpa*), lodgepole pine (*Pinus contorta murrayana*), and subalpine larch (*Larix lyalli*), and is less frequently associated with Douglas-fir (*Pseudotsuga menziesii*) and yellow cedar (*Chamaecyparis nootkatensis*). Common timberline associates in the southern Cascades are mountain hemlock (*Tsuga mertensiana*), Shasta red fir (*Abies magnifica x shastensis*), and lodgepole pine.

During the past two decades knowledge has been gained on the role of fire within whitebark pine ecosystems. Low severity (non-stand replacing) fire frequency was first studied in mixed whitebark pine – subalpine fir – lodgepole pine stands of the Bitteroot Mountains, Montana (Arno and Petersen 1983; Arno 1976) where intervals were found to occur between 2 and 78 years. Morgan and Bunting (1990) found similar results (13 – 46 years) in mixed stands of the Shoshone National Forest, Wyoming. Barrett (1994) discovered longer fire intervals (66 – 204 years) in Yellowstone National Park which was comparable to Murray's (1996) findings in the West Big Hole Range of Montana and Idaho (Table 1). Because forest stands were encountered with no evidence of fire (charcoal, scars, distinct age cohorts), Murray (1996) noted that fire intervals could be greater than 256 years in the same stand. The disparity in interval lengths between the first two and second two studies is possibly a reflection of the extremely high timberline sites sampled in the later studies.

Table 1. Fire intervals of whitebark pine forests, Rocky Mountains, USA.

Range of Fire Intervals (years)	Reference
<u>Low – Mixed Severity</u>	
2 – 78	Arno 1976; Arno and Petersen 1983
13 – 46	Morgan and Bunting 1990
56 (mean)	Brown and others (1994)
66 – 204	Barrett 1994
42 – 256+	Murray 1996
<u>High Severity</u>	
180 (mean)	Brown and others (1994)
300 – 400	Renkin and Despain 1992
338 (MAFI)	Barrett 1994

High severity (stand-replacing) fires are not easy to document in whitebark pine forests due to typically long intervals. There is a tendency for fire scarred trees to be lost to attrition during the long fire-free period or be consumed by the most recent fire. Nevertheless, estimates of high severity fires can be offered using the MAFI (mean area fire interval) method (Barrett and Arno 1988). For the whitebark pine type of Yellowstone National Park, estimates are 300 – 400 years (Renkin and Despain 1992) and a MAFI of 338 years (Barrett 1994).

Whitebark pine forests appear to experience a spectrum of fire severity. Arno (1976) indicated that fires commonly burned less intensively at the upper subalpine zone. Barrett (1994), Brown and others (1994), and Murray (1996) found evidence for all classes of severity in whitebark pine forests they sampled. The variety of fire effects is likely a strong reflection of complex topobiological controls, especially aspect, slope, and fuel contagion. In the upper subalpine zone these parameters often vary greatly at a relatively small spatial scale driving complex fire behavior. Therefore, whitebark pine forests are an excellent example of mixed-severity regimes (Arno 2001).

Cascadian whitebark pine forests have been noticeably overlooked in scientific research. In the Pacific Northwest, the limited fire history research has typically regarded subalpine forests to burn severely but infrequently (Schellhaas et al 2001; Agee 1998; Agee 1994). However, Agee (1993) compiles data from numerous sources, concluding whitebark pine forests burn much more frequently than subalpine fir, subalpine larch, and mountain hemlock.

No formal documentation of whitebark pine fire regimes has been offered for the Cascade Mountains. In general, Cascadian whitebark pine forests support more conifer species, endure a maritime climate, and tend to be more isolated into smaller stands than Rocky Mountain populations.

Fire has been a primary disturbance agent for at least 10,000 years in the Cascade Mountains; charcoal sediments found in lake cores sampled throughout the Pacific Northwest and Cascades Mountains confirm these observations (Pritchard et al 2005; Long et al 1998). Numerous fire histories have been completed in the Cascade Mountains. Hemstrom and Franklin (1982) completed a fire history study in Mount Rainier National Park which documented infrequent, wide spread high severity fires. They concluded that fire frequency in Mount Rainier is most infrequent in valley bottoms and increases in frequency on higher elevation slopes. Agee and others (1990) documented fires on Desolation Peak, North Cascades National Park Complex. They found that mean fire return intervals varied based on forest community types, with intervals ranging from 52-137 years. Everett and others (2000) working on lowland forests in the Okanogan and Wenatchee National Forest found that the mean fire free interval of 7 years for the time period of 1700-1860. These studies conducted research in close proximity to the study area for this research, but typically in lower elevation sites.

Fire history research in the whitebark pine zone poses unique challenges. Identifying whitebark pine fire regimes on a coarse scale from aerial photographs does not work particularly well (Barrett 1994). Whitebark pine fire scars sampled from as close as 50 m from other fire scars exhibited unique fire regimes, events, and intervals (Barrett and Arno 1994). It has been observed that fire in the whitebark pine zone commonly only burns a few trees and does not readily spread to adjacent stands (Fischer and Clayton 1983). Studies in the greater Yellowstone area have come to similar conclusions. Whitebark pine exhibits a very localized and patchy burn pattern (Barrett 1994). These findings have been corroborated by observations of fire in the whitebark pine forest at Crater Lake National Park in recent years (Murray personal communication).

METHODS

Study Area

The study area straddles the crest of the Cascade Mountains in Washington and Oregon. Stretching from its northernmost extent at Tiffany Peak, Methow Valley Ranger District, Okanogan National Forest south to Pelican Butte, Klamath Ranger District, Fremont-Winema National Forest, the study area represents the central portion of the Cascades (Figure 1). Included in the field work were three National Parks, and four National Forests. Plots occurred between elevations of 1675 m (5500 ft) at Little Bald Mountain, in Washington to nearly 2700 m (9000 ft) at Mt. Scott in southern Oregon.

For ease of analysis the study area was divided into three units based on proximity. The Southern Oregon Unit encompassed sites at Crater Lake National Park, Fremont-Winema National Forest, and Deschutes National Forest. The Mount Rainier Unit consists of sites at Mount Rainier National Park and the Wenatchee National Forest. The North Cascades Unit consists of sites at Lake Chelan National Recreation Area (administered as North Cascades National Park Complex), Okanogan National Forest and Wenatchee National Forest.

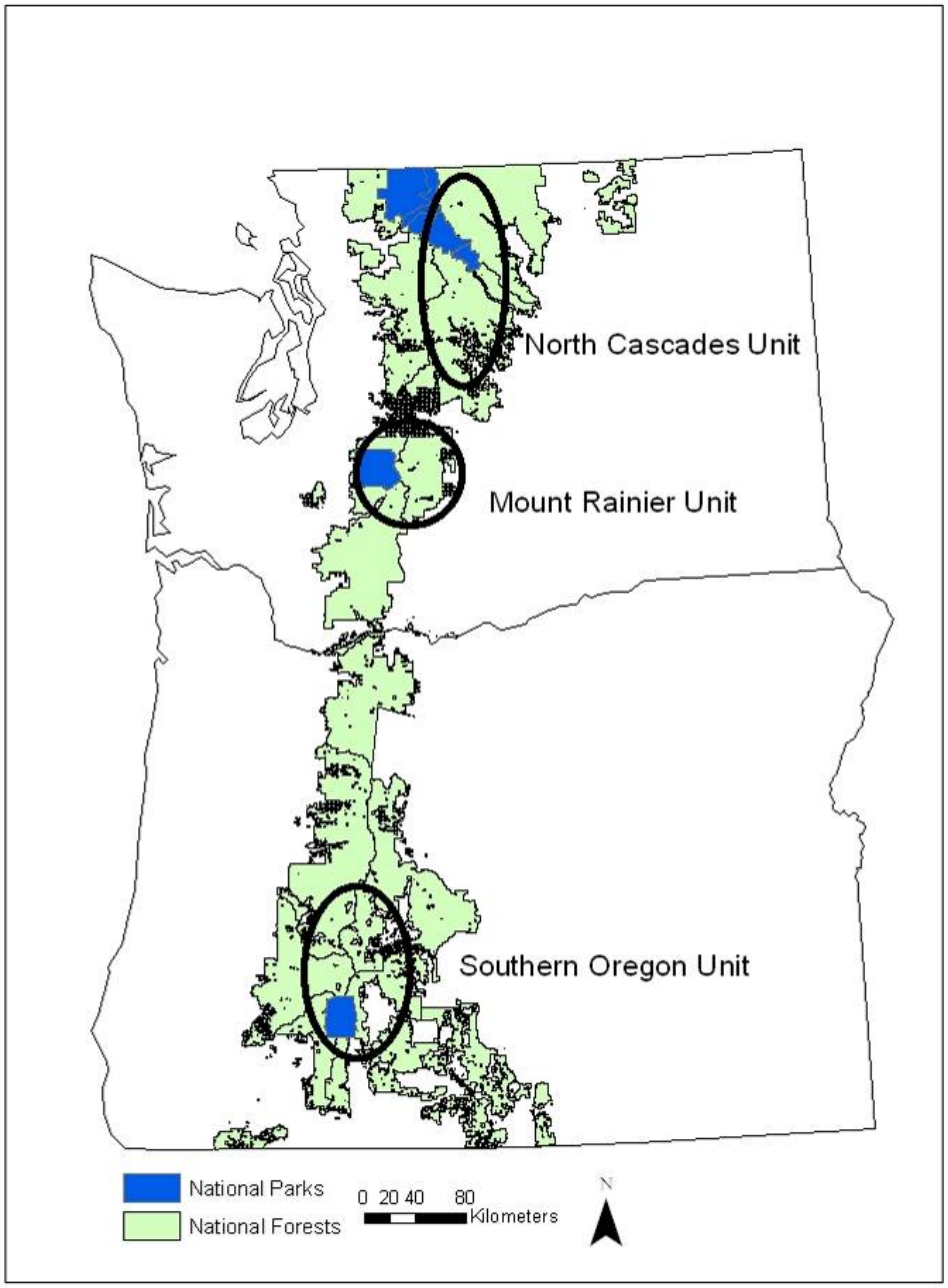

Figure 1. Three study units located on the Cascade Range.

Site Selection

Whitebark pine stands were identified using existing maps, personal correspondence with local experts, and topographic analysis of the expected range of whitebark pine. Stands were eligible for sampling when 25% or greater canopy coverage of whitebark pine was observed in relation to other tree species. Plots were selected to best represent overall characteristics of stands. Once in the vicinity of a whitebark pine stand, time was spent attempting to locate fire evidence (i.e. fire scars, charcoal, distinct age cohorts). Typically, even if no fire evidence was found a plot was installed. More often fire evidence was found and a plot(s) were installed in a representative part of the stand in the same vicinity of the fire evidence.

Field Methods

Fire history sampling methodology was adapted from Arno and Sneck (1977) and involved evaluating stand structure and tree fire scars. Exposed fire scars are triangular, with the wound beginning at or below ground level (Gutsell and Johnson 1996; Barrett and Arno 1988). The scar is typically found on the leeward or uphill side of trees where heat concentrates during a fire event and flame heights are greater due to less wind dispersing the heat from the passing fire (Gutsell and Johnson 1996). Fire scars can be identified by having uniform margins, in contrast to scars left by beetles which often exhibit irregular and furrowed patterns along the edges of the scar face (Barrett and Arno 1988). During fieldwork extreme care was taken to differentiate between fire scars and scars left behind from other agents such as mountain pine beetle, porcupine, bear, bole scrapes or other types of mechanical injury. Only scars that exhibited the highest degree of probability were sampled and consequently used in analysis of fire intervals.

Fire scars were sampled according to standard methods using a chainsaw (Arno and Sneck 1977). This technique entailed extracting a partial cross section. Heyerdahl and McKay (2001) indicated that sampling living fire-scarred trees with partial cross sections is an effective non-lethal means of obtaining valuable fire history data In the event a downed snag was found to be scarred a complete stem cross section was sampled.

Fire scars in Cascadian whitebark pine communities are rare when compared to other forest communities. All fire scars on all tree species in the whitebark pine stands were sampled. The vast majority of fire scars sampled were whitebark pine and lodgepole pine, however when less fire tolerant species were found to have scars and they were in a whitebark pine stand, they were also sampled. For each fire scar location, a GPS waypoint and a digital photograph were taken. Additionally, characteristics such as diameter at breast height (DBH), description of site, basic tree pathology, and other information that may help with future analysis (i.e. char on scar face) were documented in the field notes for each tree sampled.

To complement sampled fire scars and when scars were unavailable, stands were sampled using increment borers. Stands were sampled based on several factors; their proximity to fire scars, if a particular site had fire evidence (typically charcoal), or if no fire evidence was found. Trees were cored based on standard dendrochronological principles (Stokes and Smiley 1968). Two trees, per species for each 400 m² plot were sampled for each size class. Size classes were defined as DBH of; ≤ 4 inches, 4-8 inches, 8-12 inches, and 12 inches and greater. Trees were cored at 40 cm (16 inches) above the ground. This measurement corresponds to the length of the handle of the Swedish Increment Corer which greatly facilitates measuring the core height. Whenever possible, trees were sampled from the side-slope to ensure standard sampling protocol which may allow future dendroclimatic analysis to be completed on the existing dataset. If sampling protocol could not be completed, any deviations from the norm were noted in the field notes. An age to coring height correction was added to the age of each tree. This correction factor was based on sampling a 40 cm tall seedling at ground level and aging the tree for each species at each site.

The presence or absence of charcoal was documented for each site. In the absence of fire scars, the presence of charcoal records that fire has occurred, though it can be difficult to determine severity or the age of the fire from charcoal records alone (Lorimer 1984). The average tree height and height to live crown (crown ratio) was estimated per species for dominant trees. The percent cover of dominant ground cover (i.e. herbaceous plants, rock, gravel, litter duff etc.) was also noted. The dominant species in the understory was established and documented. Since whitebark pine plant communities and associations are poorly documented in the Cascades, the dominant understory species was used along with the dominant overstory trees (typically whitebark pine) to establish a plant association which then in turn was used to establish a fuel type for each specific plot. All trees less than 2 m in height were regarded as seedlings, and were counted per quarter plot. A down and dead inventory was completed. All trees with their base originating in the plot were considered for the down and dead survey. Down and dead trees were measured at breast height, assigned a rot class, and based on the rot class a time since death was estimated. Fire intensity was classified as high severity (stand replacing) or low severity (non-stand replacing) based on qualitative field observations for each plot. If there were more than one tree that survived an apparent fire within a 400 m² plot, the fire regime was considered low severity. Every tree in each plot was categorized according to its pathology (living, sick, or dead). If an individual tree was identified as sick, an attempt was made to identify and document the cause of sickness (i.e., white pine blister rust (*Cronartium rubicola*), dwarf mistletoe (*Arceuthobium campylopodum*), mountain pine beetle (*Dendroctonus ponderosae*). If an individual tree was dead and standing, an estimate of death date and cause of death were included in the field notes.

Lab Methods

Partial cross sections and increment core samples were sanded and processed according to standard dendrochronological procedures (Stokes and Smiley 1968). Sampled cores and partial cross sections were analyzed to determine the approximate ages of fire events and dates of tree establishment. If a sample did not reach the pith, a simple pith locator was used to estimate the number of rings missed (Villalba and Veblen 1997; Applequist 1958). This estimate to pith along with an estimate to core height provided the presumed age of the tree. Though research has shown that estimating a core height relationship is not completely accurate (Desrochers and Gagnon 1997; Johnson et al 1994), this method still provides a nondestructive method of accurately estimating many tree ages in a particular study area.

Partial cross sections sampled from dead trees were cross-dated using various methods to assign a calendar date of death and fire event (Grissino-Mayer 2001; Yamaguchi 1991; Stokes and Smiley 1968). Partial cross sections were cross-dated against existing regional chronologies of whitebark pine. Chronologies were obtained from the International Tree Ring Databank (http://www.ncdc.noaa.gov/paleo). Whitebark pine chronologies submitted by Brubaker and Graumlich (1986) for the Mount Rainer area and by Peterson (1993) for the North Cascades Unit were used for cross-dating. Since no whitebark pine chronologies were available from Crater Lake National Park a simple localized chronology was built from locally available whitebark pine cores. Increment cores for stand establishment data and living sampled fire scars were not crossdated for several reasons. The stand establishment data was analyzed at a coarse temporal scale of ten years where dendrochronological precision is not required (Morgan and Bunting 1990). Since the trees sampled were intended for stand establishment analysis and not dendroclimatic reconstructions the trees often displayed complacent ring patterns which is problematic for cross-dating as is often indicative of a tree that does not have any ring anomalies (Yamaguchi 1991). In ecosystems with intervals greater than 30 years, dendrochronological techniques are less critical than in ecosystems where fire is ubiquitous (Agee et al 1990; Mandany et al 1982). Fire regimes which have longer fire return intervals are not as sensitive to a missing or a false ring (Agee et al 1990). Barrett and others (1997) determined that for noncross-dated fire scars dates, the events are accurate to a resolution of ±2 years of the actual ring count. Therefore, noncross-dated fire scars collected for this study have a resolution of five years.

Data Analysis

The ages of the stands were extrapolated and estimated based off the 2 trees per species, per size class that were sampled. The trees in each plot were aged independently based on the specific age-growth curves determined from the sampled trees at that plot. If the r^2 values of the age growth relationship exceeded .6 than ages of non-cored trees in the plot were estimated based on a linear age growth relationship. The estimated ages for the stand were placed in cohorts (bins) of 10 years for further analysis (Morgan and Bunting 1990). Infrequently, the r^2 value did not reach this level. This indicated that the age of the tree and radius of the tree was independent of each other. This is likely the result of whitebark pine’s tendency to establish in clumps. In these cases tree ages were estimated based on clumps. If a sampled tree was rotten, then another tree in the same species and size class was selected as a replacement. Difficulties arose from older rotten trees where no suitable replacement was present. Ages of these trees were estimated based on measuring the diameter of the tree and estimating the number of missing rings based on the density (rings/inch) available from the core fragments that were salvaged from the rotten tree.

Typically, an even aged stand structure is often indicative of a forest disturbance event (Barrett and Arno 1998). It is important to note, that an un-even aged stand does not necessarily indicate that the stand developed in the absence of disturbance (Lorimer 1984). This may be especially true since Rocky Mountain whitebark pine forests often reestablish slowly after a disturbance event (Tomback et al 2001a; Tomback et al 1993). However, in British Columbia data suggests that whitebark pine reestablish rapidly following fire (Campbell and Antos 2003). Tomback and others (1995) notes that areas where whitebark pine seed sources have been negatively impacted by blister rust and mountain pine beetle will have a longer lag in reestablishment.

The Multiple Site Average Fire Interval (MSAFI) method of analysis was used to compute fire intervals (Barrett and Arno 1988). Barrett and Arno (1988) contend that this is an ideal strategy for dealing with fire history datasets that encompass distinct geographically sampled sites, and incorporates both age class and fire scar components of fire history sampling.

RESULTS

A total of 60 plots were inventoried. If plots displayed a similar fire history and were in the same stand then they were consolidated into a fire history site. These 60 plots produced 55 distinct “fire history” sites. Of the 55 fire history sites, no conclusive fire history dates were deduced from 12 sites (Table 2). Additionally, 15 sites produced only one fire date. Of the 55 distinct fire histories, 28 sites contained fire intervals that were in turn used for the calculations of MSAFI (Barrett and Arno 1998). Fifty seven partial cross sections were sampled from fire-scarred trees (Figure 2). Approximately 700 increment cores were taken as part of the age class component of the research. The resulting 101 fire dates represent events taken from fire-scarred trees, events interpreted from age class sampling, and field verified historical events that took place in proximity to sampled sites. Of the 101 fire events, 57% were from fire scar data and were often reinforced by stand reconstruction, while 37% were from stand reconstructions that had no corresponding data from fire scars. The remaining 6% of the fire events were from historical sources verified by field observations.

Table 2. Summary of fire history sites investigated for this study.

	# of sites	% of total
No Fire Dates	12	22%
One Fire Date	15	27%
2 or more Fire Dates	28	51%
Total	55	100%

Charcoal

The presence of charcoal was noted for each plot. Charcoal is often regarded as the most fundamental indicator that fire has been present in an ecosystem (Agee 1993; Lorimer, 1984). Eighty-eight percent of all plots in the study area that were inventoried had charcoal (Table 3).

Table 3. The presence of charcoal was documented for each plot.

	Number of Plots	Plots with Charcoal	% Plots with Charcoal
Southern Oregon Unit	28	23	82%
Mount Rainier Unit	15	13	87%
North Cascades Unit	17	17	100%
Totals	60	53	88%

Intervals

Fire intervals varied widely throughout the study area with at least one fire event found in every 10-year interval class up to 160-9 years (Figures 2 & 3). Intervals obtained from fire scar and age class data ranged from 9 years to 314 years, with an average interval of 67 years, and a standard deviation of 57 (Table 4). The Standard Deviation for Multiple Site Average Fire Interval (Barrett and Arno 1988) remains high, which may be an indication that the interval data is not explained by a single variable.

Interval data was analyzed both by overstory and understory plant associations since whitebark pine plant associations have not been formally developed for the entire study area (Table 4, Table 5). Each method of classification provides a useful means of displaying the complex response to fire in the whitebark pine zone.

The whitebark pine/pine grass (*Calamagrostis rubescens)* community type appears to burn the most frequently. No fire intervals were detected from the whitebark pine/mountain hemlock or the minimal vegetation community types and therefore we conclude that these communities burn the most infrequently of any forest community types investigated.

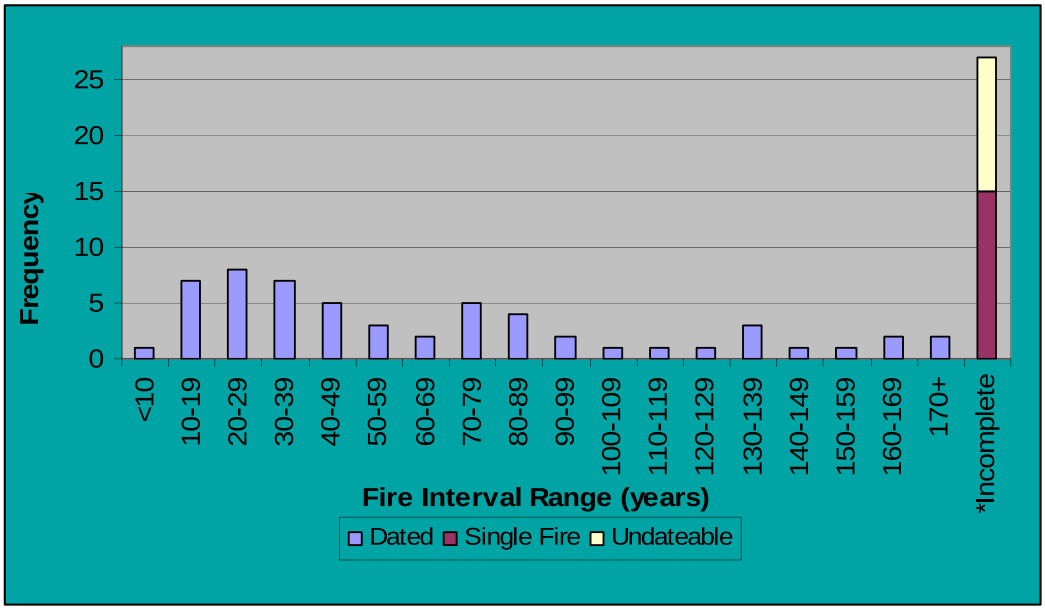

Figure 2. Distributional frequency of fire intervals from plots. Last bar denotes : 1) incomplete intervals – due to only a single fire detected, and 2) undateable plots which had no dendrochonological evidence of fire.

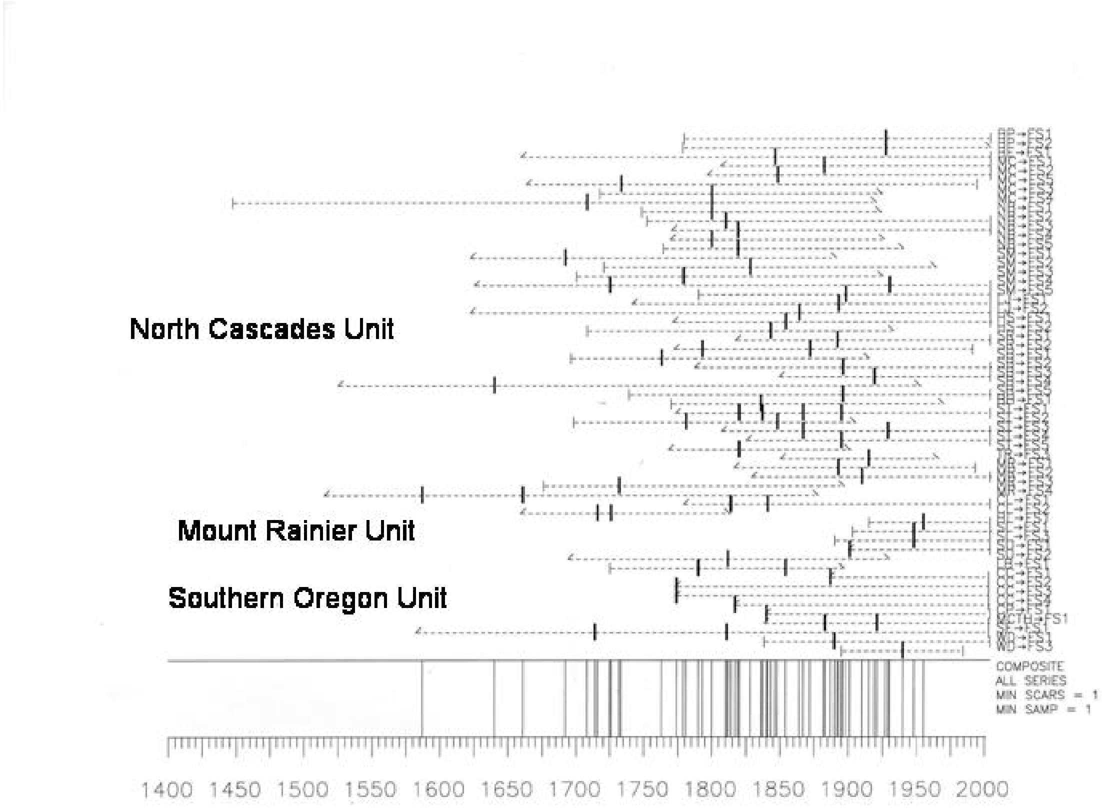

Figure 3. Master fire chronology for fire scar dates from all sites studied for the entire study area. Horizontal lines represent time span for individual trees sampled as partial cross sections. Short dark vertical lines depict fire scar dates. Composite fire graph represents all fire scars dates from all individuals from the entire study area.

The whitebark pine forest communities are a fire regime that burns with considerable variability. Sometimes it burns with high severity, which may destroy all evidence of previous low severity events. These high severity events are reconstructed using the age class techniques and appear to occur about every 100-200 years. Low severity fires appear to be occurring as frequently as every nine years, but range as long as 70 years.

Table 4. Comparison of fire intervals for the entire study and for each forest community type using observed overstory observations as selection criteria.

Overstory Community	No. of Sites	No. of intervals	MSAFI* (years)	Standard Deviation (Intervals)
PIAL/PSME	2	10	47 (11-161)	46
PIAL/ABLA-ABSH	22	30	67 (11-64)	43
PIAL/PIEN	3	3	72 (9-196)	108

PIAL/PICO	8	13	73 (12-314)	79
Pure PIAL	10	3	96 (38-153)	58
PIAL/TSME	10	0	?? >250 years	??
Entire Study	55	59	67 (9-196)	57

* Multiple Site Average Fire Interval (Barrett and Arno 1988)

Table 5. Comparison of fire intervals for each forest community type based on dominant understory.

Dominant Understory Vegetation	No. of Sites	No. of intervals	MSAFI* Years (range)	Standard Deviation (of the intervals)
PIAL/CARU	3	9	44 (11-134)	39
PIAL/VASC	20	25	55 (9-196)	48
PIAL/JUCO	3	5	64 (33-140)	44
PIAL/FEVI	5	9	84 (11-164)	57
PIAL/Dryland Grass	12	10	93 (13-120)	86
PIAL/ARNE	4	1	130	-
Minimal Vegetation	8	0	>250 years	-

*Multiple Site Average Fire Interval (Barrett and Arno 1988)

Severity

Estimations of severities were based on the 55 distinct fire history sites. Forty four percent of the most recent fire events for each site were low severity events (Table 6). Of the 101 total fire events in the study 54% of events were low severity. This subtle increase to 54% indicates that high severity events often destroy the evidence of previous low severity events.

Table 6. Observed severity of most recent fire event for each Unit.

Unit	High Severity	Low Severity
Southern Oregon Unit	10 (56%)	8 (44%)
Mount Rainier Unit	6 (75%)	2 (25%)
North Cascades Unit	8 (47%)	9 (53%)
Totals	24 (56%)	19 (44%)

Size

The vast majority of fires in the whitebark pine zone appear to be small local isolated events, occurring on a sub-stand level. Sub-stand level events typically only burn a small percentage of a larger whitebark pine stand. Fires larger than the sub-stand level were documented in several cases. Estimates of average area for fire in the whitebark pine zone are beyond the scope of this study.

The largest documented fire was found in Mount Rainer National Park in the Crystal Lake basin. The fire in the Crystal Lake basin displayed varying severity over its range. It is estimated that it burned several hundred hectares of whitebark pine habitat and in the process burned the entire stand except isolated trees along the perimeter of the fire. Additionally a large fire was documented from the fire history sites at Mt. McCay and North Baldy Pass on the Methow Valley Ranger District. This fire was document with 3 different fire scars on two plots. Though an exact area of this fire is also unknown it can be assumed to be at least on the order of several hundred hectares.

Conversely, the majority of 101 fires occurred on the sub-stand level. Five plots were inventoried within a total area of approximately 250 hectares on Mt. Scott in Crater Lake National Park. A fire event was documented from a living fire-scarred tree, which took place in 1921, on the flanks of Mt. Scott. None of the four adjacent plots documented the same fire event.

Estimating the area of fires in the whitebark pine zone is complicated by numerous factors. Often fire scars are only found in specific and limited locations. It is difficult to extrapolate the area of a fire from point location data. Also whitebark pine severity can vary dramatically making documentation of the area of the events more complicated.

Change in fire frequency from 1800-1900 and 1900-2000

The amount of fire on the landscape is diminishing. The period of 1800-1900 experienced 51 fire events for areas investigated for this study. The period of 1900-2000 displayed only 22 fire events that were reconstructed from fire scars and age class. This significant difference ($X^2 = 10.73$, $p=0.01$) suggests management and/or climate may be playing a role in lessening fire frequency. Few recent fires (post-1950) were documented in this study.

DISCUSSION

No known study attempts to document fire history in the whitebark pine zone of the Cascade Mountains. Schellhaas and others (2001) conclude that subalpine forests of north-central Washington burn in a high severity fire regime on the order of every 100-200 years. This is partially supported by the conclusions put forth in this study.

Burning patterns typically become more complex in the whitebark pine zone than in lower elevation forest types (Barrett 1994). For each site it is important to remember that the older the fire, the less reliable the dates and severity of that fire become. The wide range of intervals and high standard deviation found throughout the study area and for all community types investigated indicate that fire in the whitebark pine zone is a complex phenomenon.

The Southern Oregon Unit displayed the lowest percentage of sites with charcoal. In this area whitebark pine often grows in close association with mountain hemlock, which infrequently burns (Lertzman and Krebs 1991). Whereas the North Cascades Unit plots were typically in the rainshadow of the crest of the Cascades Mountains and were therefore drier and more fire prone.

The whitebark pine/Engelmann spruce forest community type showed the highest degree of interval variability. The long interval of 196 years for one plot is a unique case. The specific plot is adjacent to a very expansive lodgepole pine forest that appears to burn with high severity about every 200 hundred years, this site may be influenced by the lodgepole pine fire regime. Sites where whitebark pine and mountain hemlock co-dominate displayed very little evidence of fire. These sites are characterized by having rock, gravel, pumice, or sand as the dominant ground cover component, and were on the Cascade crest at Crater Lake National Park where the maritime climate exhibits its strongest influence. No intervals were detected for this forest community type.

Pure whitebark pine community types were found at ten sites ranging the breadth of the study area. The fact that only three intervals were detected from 10 sites indicates that pure whitebark pine sites are not as fire prone as it might appear. Pure whitebark pine sites are often sparse and take on the appearance of woodland instead of a forest. In this woodland there often is insufficient fuel to carry a fire. Individual trees may be surrounded by areas with little are no vegetation. Fire could be much more frequent in pure whitebark pine communities than this study indicates since the fires likely do not grow and therefore leaves little evidence behind.

As vegetation gets less dense, the fire intervals become longer. The intervals, in fact, become longer to the point that they are not detectable with dendrochronological techniques. The grouse whortleberry *(Vaccinium scoparium)* vegetation type often grows in slightly wetter and cooler environments; it often forms a dense and continuous mat of vegetation. When conditions become favorable grouse whortleberry aids in the spread of surface fires by increasing the flammability of litter through preheating (Alexander, 1978). Sites with dense grasses were the most fire prone.

Several methodological issues have arisen from completing the analysis. Nearly half all sites (49%) were unable to produce a fire interval (Table 2). Fire intervals are likely greater than 150 years for these sites. Whether an interval of 150 years or greater is natural or a result of fire suppression is not known. Many of these sites had only one fire event that was detectable. From one event no interval can be deduced, though it is still clear that fire is present in the ecosystem just not detectable in a quantitative fashion. It is likely, that for the 15 sites that had only one detectable date per site, fire suppression is altering natural fire intervals. The Multiple Site Average Fire Interval MSAFI (Barrett and Arno 1988) is not applicable to sites that exhibit only one fire event. No known methods can be used to infer or deduce intervals from sites with only one interval (Agee personal communication). These 27 sites with estimated intervals of >150 years would greatly increase the average interval computed from this study if the data was incorporated into the MSAFI computed for sites with intervals.

Cascadian whitebark pine forests have typically burned in both high and low severity events and at a sub-stand, stand, and watershed scales. It appears site specific controls are primarily responsible for severity and area of fires. In this manner Cascadian whitebark pine fire regimes are similar to Rocky Mountain whitebark pine (Murray 1996; Morgan and Bunting 1990).

Typically fire historians have divided their studies into pre-historic, pre-settlement and settlement eras (Everett et al 2000). How effective were suppression efforts in the whitebark pine zone during the time period of 1910-1935? This time period is regarded as the onset of active suppression in western forests (Agee 1993) however it also corresponds to the cold/wet phase of the Pacific Decadal Oscillation (Gedalof and Smith 2001). The cold wet phase historically appears to have notably decreased overall fire activity in the Pacific Northwest (Hessl et al 2004; Mote et al 1999). Whether this decrease in fire can be attributed solely to fire suppression remains unclear. Most likely regional climate patterns worked in conjunction with local land manager to suppress fires in the Pacific Northwest during the time period of 1910-1935.

MANAGEMENT RECOMMENDATIONS

Brown and others (2004) argue that there is broad consensus to participate in active forest management through thinning and the reintroduction of fire. They concede that the debate continues on how and when to implement active management. Low severity fire regimes are in the most need of active forest management (Brown et al 2004). The National Park Service is mandated to maintain and restore forest conditions and processes to those present during the pre-settlement period (USDI 1988), while the Forest Service’s mission is to sustain the health, diversity, and productivity of the land it oversees (USDA 2004). The reintroduction of fire would ensure that mandates and missions are met with regards to the future of whitebark pine ecosystems.

Blister rust, mountain pine beetles, fire exclusion, and climate change appear to be having a disastrous effect on whitebark pine throughout the Northern Rockies (Tomback et al 2001b). Keane and others (2003) conclude that in the Rocky Mountains whitebark pine will become locally extinct if current management practices continue. Keane (2000) concluded that for Rocky Mountain populations of whitebark pine the key to conservation lays in allowing fire to return to its’ natural place in the ecosystem. The majority of whitebark regeneration occurs because of the seed caching of Clark's Nutcracker. It has been shown that there is a preference to cache seeds in recently burned areas (Tomback et al 1990). Furthermore, without forest openings, there will be few places for naturally rust resistant trees to be cached, and in turn grow rust resistance whitebark pine stands (Keane 2000). Active forest management techniques are being used as restoration treatments in the Bitterroot Mountains of Idaho and Montana as part of the Restoring Whitebark Pine Ecosystems projects (Keane and Arno 2001; Keane and Arno 1996). Techniques such as prescribed fire and silviculture cuttings are being employed in a scientific and measured manner to assess effects on whitebark pine conservation. Forest managers have the difficult task of attempting to restore balance to an ecosystem that is in trouble.

Southern Oregon Unit

The Southern Oregon Unit is the least fire prone area of the study. Where whitebark pine often grows in close association with mountain hemlock fire is infrequent. Mountain hemlock is recognized as having some of the longest fire-free periods of any conifers that grow in the subalpine forest with intervals often exceeding 1500 years (Lertzman and Krebs 1991). Where whitebark pine grows in pure stands and with lodgepole pine fire becomes more common. These stands typically occur in the eastern side of the southern Oregon Cascades.

Natural fire should be pursued at Crater Lake National Park. Recent fires in the whitebark pine zone clearly demonstrate that fire is a natural and manageable part of the ecosystem. The pumice soils, lack of surface and fine fuels in subalpine areas, along with a late-laying snowpack prevent the large scale spread of wildland fires in whitebark pine ecosystems of Crater Lake. The accessibility of the whitebark pine at the Park would allow managers to easy manage wildland fires within park boundaries.

Sites investigated on National Forest land in southern Oregon were drier and less maritime-influenced. These sites did not yield any fire scars. Charcoal, however, was ubiquitous at these sites. Whitebark pine and lodgepole pine communities were frequently encountered on the National Forest sites investigated for this study. The community type in this Unit appears to burn approximately every 200 years in a high severity manner which would explain the lack of dateable fire scars. It is assumed that the fires burned at a stand or watershed level. Dates from stand establishment indicate that most stands burned during the late 1700's and early 1800's. No fires were evident from the modern fire suppression era.

Fire in this area should be managed carefully because of the high severity nature of the fire regime. Though fires on National Forest land appear to be larger and more severe than fires at Crater Lake National Park, the evidence remains unequivocal; fire is the primary disturbance agent and should be allowed to return to these sites to maintain whitebark pine. Fires on these sites whether naturally ignited or prescribed, should be allowed to grow to be either high or mixed severity. Pretreatments or other silviculture techniques should not be necessary at these sites in the event of a prescribed burn, except when fir species are numerous as ladder fuels that would aid the widespread torching of mature whitebark pine.

North Cascades Unit

Fire is common in the North Cascades Unit. All sites investigated displayed evidence of fire. The majority of sites in this area were well east of the Cascade crest and therefore in the rainshadow. These hot and dry sites appear to burn the most frequently of any in the study. Fire intervals in the Lake Chelan area approach 20 years- burning with a frequent low severity. At higher and more mesic sites whitebark pine in this Unit grows in association with Engelmann spruce, which has been decimated by spruce beetle (*Dendroctonus rufipennis*) outbreaks. Because of this, the whitebark pine Engelmann spruce forests north of Winthrop, WA appear to be ripe for a large scale catastrophic fire. Historically, this area has been prone to large fires (Schellhaas et al 2001). Any large scale fires that occur in the spruce-fir belt will likely spread upward in elevation and have significant negative impacts on whitebark pine.

The North Cascades Unit is unique in that the all adjacent forest communities to the whitebark pine zone are fire prone. There is no equivalent to the whitebark pine/mountain hemlock community or open sparsely fueled subalpine meadows growing in pumice soil that would limit fire spread. There are no fuel types that could act as refugia to prevent fires from decimating whitebark pine populations. A fire in a whitebark pine stand could theoretically grow in all directions to all forest types in this Unit. Therefore, extreme care should be considered when managing fires in whitebark pine stands in the North Cascades Unit.

Management in this Unit needs to incorporate different scales and recognize that the fire regime is often localized. Frequent (20-40 years) low severity burns should be allowed to burn if naturally ignited. In areas adjacent to the spruce forest which are tinder dry due the spruce beetle outbreaks, efforts should be taken to protect a very hot and severe wildfire from decimating many isolated stands of whitebark pine that grow in association with the spruce.

Mount Rainier Unit

The Mount Rainer Unit displayed the widest variety of fire regimes in the study area. Sites displayed high severity, mixed severity, low severity, and no evidence of fire. Along the eastern boundary of the Mount Rainier National Park in the Crystal Lake area fire appears to be occurring on an average every 50 years over the past 200 hundred years. Conversely, very little evidence of fire was discovered in close proximity to Mount Rainier itself. Site specific strategies for fire management need to be weighed heavily when making management decisions in the Mount Rainier Unit.

Fire in whitebark pine habitat in and around the mountain itself should be considered infrequent and managed as such. Extreme fire spread is unlikely unless conditions are ideal in the subalpine meadows around Mount Rainier. Currently, there is intense discussion regarding the impacts of frequent historical Native American burning in the upper subalpine meadows communities of Mount

Rainier (Kurth personal communication). No evidence was found in this study from whitebark pine stands that would corroborate this hypothesis or indicate that these burns impacted whitebark pine communities.

The rainshadow whitebark pine stands (Crystal Lakes, Deadwood Lakes) should be managed differently than their analogs on the flanks of Mount Rainier. Whitebark pine growing along the easternmost border of the park should be considered to have a unique fire regime. Because of the recent fires here (~1930) this area could be considered a whitebark pine area that has not been significantly impacted by successful fire exclusion. This area provides a unique challenge and opportunity for managers. Allowing naturally occurring fires to burn would maintain this area as a fire history site that has continued in a natural state. All types of severity were observed here making this a mixed severity fire regime. Future burning in this area should target a mixed severity. As such, forest management techniques such as reducing fuel loads to lessen fire severity would not be recommended to achieve natural conditions.

Overall, fire should only be reintroduced in a measured and scientific manner in the whitebark pine forest. Brown and others (2004), argues that fire and other restoration treatments need to be viewed as steps in a restoration process and should be considered on a site specific strategy.

CONCLUSIONS

The whitebark pine ecosystem is recognized as a mixed-severity fire regime in the Rocky Mountains, however, until now, little has been known from the Cascade Mountains. The 55 investigated sites from this study indicate that whitebark pine fire regimes vary throughout the Washington and Oregon Cascades Mountains. The 55 sites examined here illustrate the variable and complex nature of fire regimes of Cascadian whitebark pine forests.

- Fire is an integral part of the Cascadian whitebark pine forest.
- Fire regimes in whitebark pine forests are site specific more then species specific.
- Local climate, aspect, slope, fuel contagion, and stand structure appear to have pronounced and complex influences on fire in the upper subalpine zone.
- Cascadian whitebark pine sites exhibit all types of fire severity.
- The whitebark pine/mountain hemlock forest community type is the least fire prone forest community investigated in this study.
- Fire should be carefully reintroduced in National Forests and National Parks of the Pacific Northwest which manage whitebark pine.

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Part 2: Historic Stand Conditions

INTRODUCTION

Whitebark pine (*Pinus albicaulis*) is recognized as being a keystone species in subalpine ecosystems of western North America (Tomback and others 2001). The goal of this objective is to describe historic and current stand conditions and estimate potential ecological effects of fire exclusion policies.

Fire exclusion policies since the early part of the 20th century, are hypothesized to change stand structure by allowing less fire-resistant late seral species to out compete whitebark pine. Research of whitebark pine forests in the Rocky Mountains supports this hypothesis – providing evidence of marked volume increases of late successional trees with a corresponding decrease in whitebark pine, exacerbated by blister rust disease and mountain pine beetle epidemics (Keane and Arno 1993; Morgan and Bunting 1990; Murray and others 2000; Skovlin and others 2001).

High elevation forests of the Cascade Mountains offer an ideal barometer of which to quantify ecosystems response to disturbances. Because of the remoteness of these forests they are often less modified and altered when compared to their low elevation counterparts.

METHODS

Study Area

The study area and sampling plots chosen are from the fire regime study described in Part 1 (Figure 1).

Field Sampling

Whitebark pine stands were identified using existing maps, collaboration with local experts, and topographic analysis of the expected range of whitebark pine. Stands were eligible for sampling when 25% or greater canopy coverage of whitebark pine was observed in relation to other tree species. Plots were selected to best represent overall characteristics of stands. Trees were cored based on standard dendrochronological principles (Stokes and Smiley 1968). Two trees, per species for each 400 m^2 plot were sampled for each size class. Size classes were defined as DBH of; ≤ 4 inches, 4-8 inches, 8-12 inches, and 12 inches and greater. Trees were cored at 40 cm (16 inches) above the ground. This measurement corresponds to the length of the handle of the Swedish Increment Corer which greatly facilitates measuring the core height. Whenever possible, trees were sampled from the side-slope to as a standard. If sampling protocol could not be completed, any deviations from the norm were noted in the field notes. A core-height correction was applied to the age of each tree. This correction factor was based on sampling a 40 cm tall seedling at ground level and aging the tree for each species at each site. Core samples were not taken from dead standing or downed trees. These trees were given an estimate of their death date based on rot class and had their circumferences measured at DBH so that they could be incorporated into the stand reconstruction

Stand Reconstruction

Measuring volume, by species, can be an appropriate metric for quantifying forest composition (Oliver and Stephens 1977). To do this, we used cores collected from each plot corresponding to 10 cm size class of every species. Cores were prepared for analysis and measurement according to standard dendrochronological methods (Stokes and Smiley 1968). To determine stem radius back through time the distance from the pith to the each 20th year was measured using a velmex sliding stage. This technique provides the associated growth and radius of the stem at 20-year intervals for each tree cored. These measurements were then extrapolated to the uncored trees in the plot. To compute this average, growth distances were calculated for each cored species and its respective size class for every 20-year interval. These average growth distances were then applied to corresponding uncored trees (same species and size class) on the plot by subtracting each matching 20-year growth distance, beginning with the sampled (current) year, back in time. These techniques created a matrix which lists the size of all trees on the plot every twentieth year. These values were then summed for each plot to get the volume for each species on each plot. The values were then averaged among all plots to summarize estimated trends in forest structure and composition.

RESULTS

A total of 60 plots were inventoried. Total volume is greater now than at any time since 1804. Starting in circa 1924 total volume for all species began to increase dramatically. The trends displayed represent average volume for each species (Figure 4). Between the time-period of 1884-1924 whitebark average volume remained nearly constant. Conversely, from the time period of 1924-2004 average whitebark pine volume increased by 280%. Late seral species such as Shasta red fir increased by 4200% and subalpine fir increased by 2800% during the time period of 1924-2004.

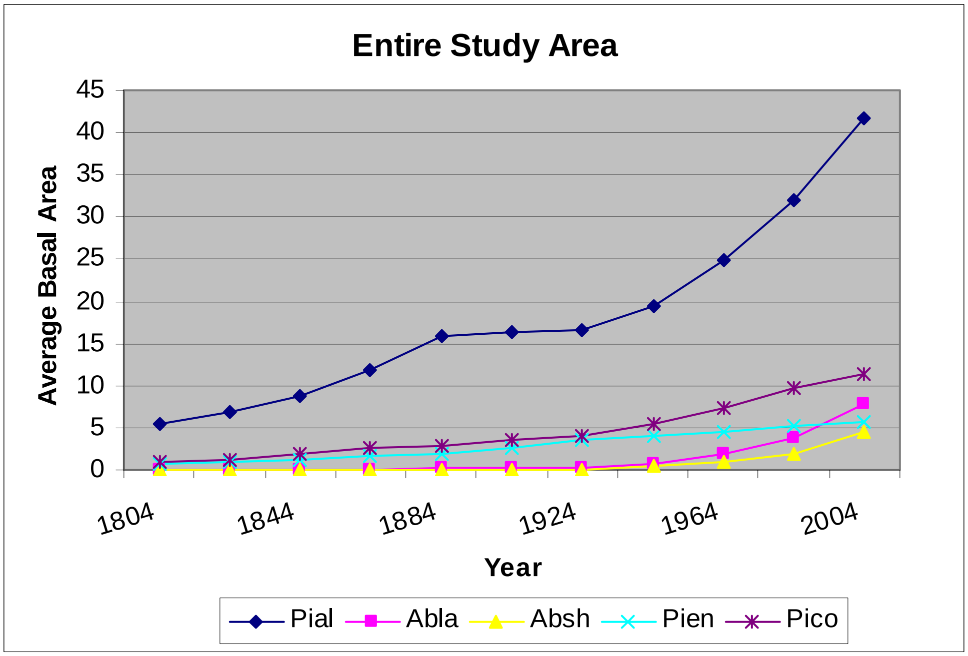

Figure 4. Changes in average volume (m²/ha).

DISCUSSION

The dramatic increase in average volume in the study area for all species can potentially be attributed to several different factors. Since 1924 a dramatic “invasion” of shade tolerate late seral trees has occurred. The increases in the volume of subalpine fir and Shasta red fir may be attributed to fire exclusion. Pre-1900 treeline forests in our study area were nearly exclusively whitebark pine while post-1900 forests have significant numbers of late seral trees species (Figure 4). The amount of fire on the landscape is diminishing over the time period 1800-2004 (see Part 1). During the time period of 1800-1900 the study area experienced 51 fire events. The period of 1900-2000 displayed only 22 fire. This represents a decrease of approximately 57%. Few recent fires (post-1950) were documented in this study.

The increases in volume noted in this study are similar to findings in the northern Rocky Mountains where the changes were attributed to fire exclusion. A reduction of fire frequency and fire size were noted as potential causal agents in the Rocky Mountain study.

It is possible that that our results underestimate volume in the past due to the natural decay of evidence especially downed logs (Morgan and others 1994). Additionally, plots were preferentially chosen to be used in a corresponding fire history study. This could have created a sampling bias in that many plots exhibited evidence of fire disturbance and the overall increase in volume could be at least partly attributed to ecosystem response after fire.

In the absence of disturbance it is expected that late-seral species will eventually overtake whitebark pine in abundance. Whitebark pine decline could be synergistically impacted by the outbreaks and mortality caused by white pine blister rust (*Cronartium rubicola*), dwarf mistletoe (*Arceuthobium campylopodum*), and mountain pine beetle (*Dendroctonus ponderosae*), and continued fire exclusion.

CONCLUSIONS

- Volume for all tree species began to increase dramatically circa 1924.
- Late-seral species' volumes have increased at greater rates than whitebark pine.
- Fire exclusion is likely a causal agent of the observed increase in volume.

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Summary of Scientific Names

Appendix A

Scientific Code	Scientific Name	Common Name
ABLA	*Abies lasiocarpa*	Subalpine fir
ABSH	*Abies magnifica var. shastensis*	Shasta red Fir
ACOC	*Achnatherum occidentale ssp. californicum*	California needlegrass
ARNE	*Arctostaphylos nevadensis*	Pinemat manzanita
ARTR	*Artemisia tridentate*	Big sagebrush
CABR	*Carex brainerdii*	Brainerd's sedge
CARO	*Carex rossi*	Ross' sedge
CARU	*Calamagrostis rubescens*	Pinegrass
CAST	*Cassiope stelleriana*	Alaskan mountain heather
CHNO	*Chamaecyparis nootkatensis*	Alaska cedar
ELEL	*Elymus elymoides*	Squirreltail grass
FEVI	*Festuca viridula*	Green fescue
LUAN	*Lupinus andersonii*	Anderson's lupine
LUHI	*Luzula glabrata var. hitchcockii*	Hitchcock’s woodrush
LUPE	*Luetkea pectinata*	Partridge foot
JUCO	*Juniperus communis*	Common juniper
JUDR	*Juncus drummondii*	Drummond's rush
PEDA	*Penstemon davidsonii*	Davidson's penstemon
PIAL	*Pinus albicaulis*	Whitebark pine
PICO	*Pinus contorta*	Lodgepole pine
PIEN	*Picea engelmannii*	Engelmann spruce
PSME	*Pseudotsuga menziesii*	Douglas-fir
TSME	*Tsuga mertensiana*	Mountain hemlock
VASC	*Vaccinium scoparium*	Grouse whortleberry

Fire History Statistics: North Cascades Unit

Appendix B

Methow Valley Ranger District, Okanogan National Forest.

Plot Name (Plot Code)	GPS (UTM NAD 27, Zone 10)	Dominant Overstory	Dominant Understory	Elevation (feet)	Aspect	Fire Scar Fire Years	Stand Replacing Fire Years#	MFRI* (years)
Baldy Pass (BP)	5386553 N 725063 E	PIAL/PIEN	VASC	7085	NW	1926	~1730	196
Bernhardt Mine (BE)	5393033 N 726054 E	PIAL/PIEN	VASC	7030	W	1846	-	N/A
Clark Ridge (CR)	5391353 N 725531 E	PIAL/PICO	LUAN	7183	SW	-	~1870, ~1730	140
Freezeout (FO)	5393913 N 724597 E	PIAL	FEVI	7150	S	-	-	N/A
Mt. McCay (MC)	5388966 N 727323 E	PIAL/ABLA	JUCO	7285	S	1882, 1848, 1800, 1700	~1733	46
North Baldy Pass (NB)	5387420 N 726046 E	PIAL/PIEN	VASC	6658	N	1819, 1810, 1800	-	10
Starvation Mountain (SM)	5379289 N 725630 E	PIAL/PICO	VASC	6724	SW	1918, 1898, 1828, 1779, 1725, 1692	-	40

#Stand replacing fire years are considered approximate and are denoted with the symbol ~.
*Mean Fire-Return Interval (Agee 1993)

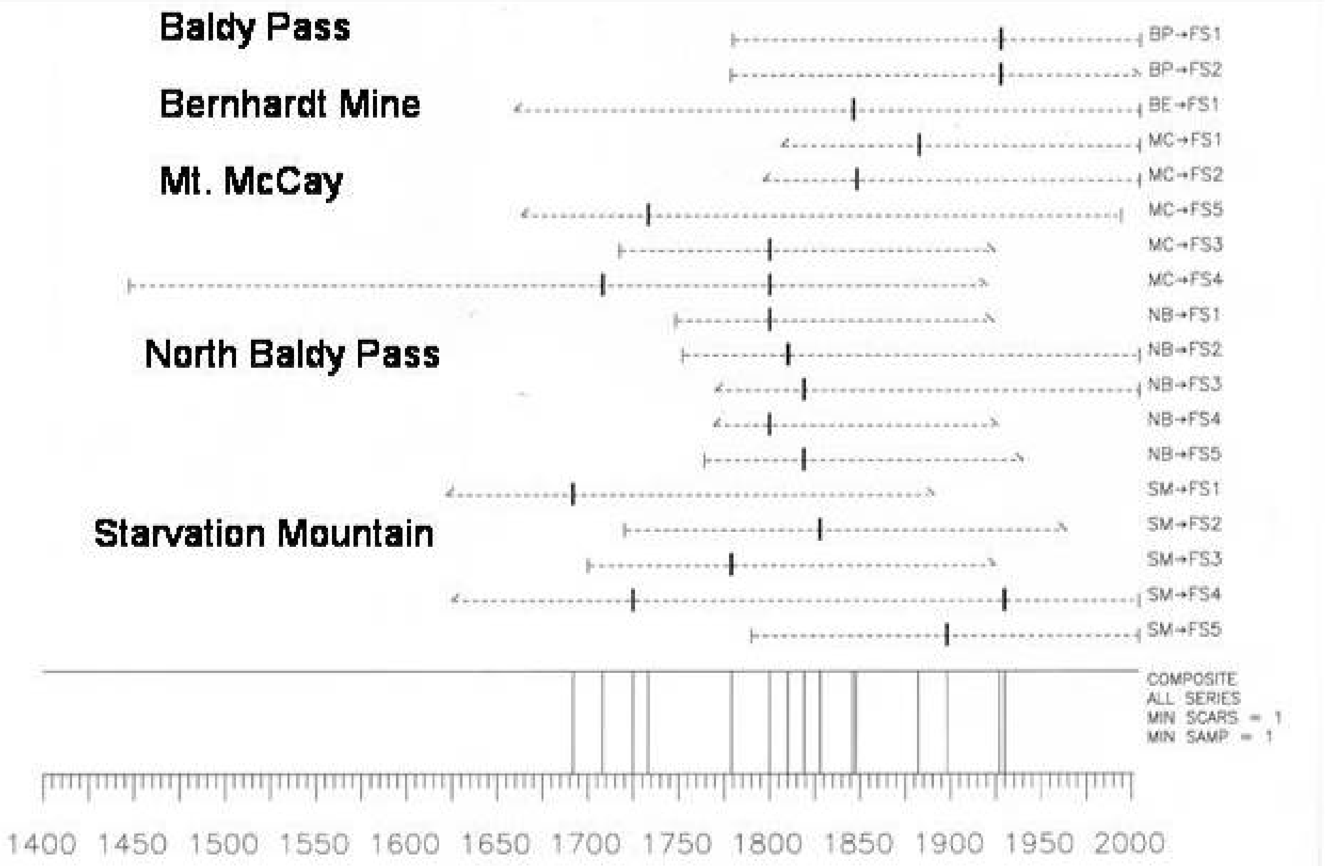

Figure 1. Master fire chronology for fire scar dates from all sites studied on the **Methow Valley Ranger District**, Okanogan National Forest. Horizontal lines represent time span for individual trees sampled as partial cross sections. Short vertical lines depict fire scar dates. Composite fire graph represents all fire scar dates from all individuals on this ranger district.

Lake Chelan National Recreation Area, North Cascades National Park Complex

Plot Name	GPS (UTM NAD 27, Zone 10)	Dominant Overstory	Dominant Understory	Elevation (feet)	Aspect	Fire Scar Fire Years	Stand Replacing Fire Years#	MFRI* (years)
Lake Juanita (LJ)	5353415 N 681059 E	PIAL/ABLA	VASC	7166	SW	1893,1864	~1840	27
Triplett Lake (TL)	5352305 N 681482 E	PIAL	LUAN	7185	SW	-	~1890	N/A

#Stand replacing fire years are considered approximate and are denoted with the symbol ~.
*Mean Fire-Return Interval (Agee 1993)

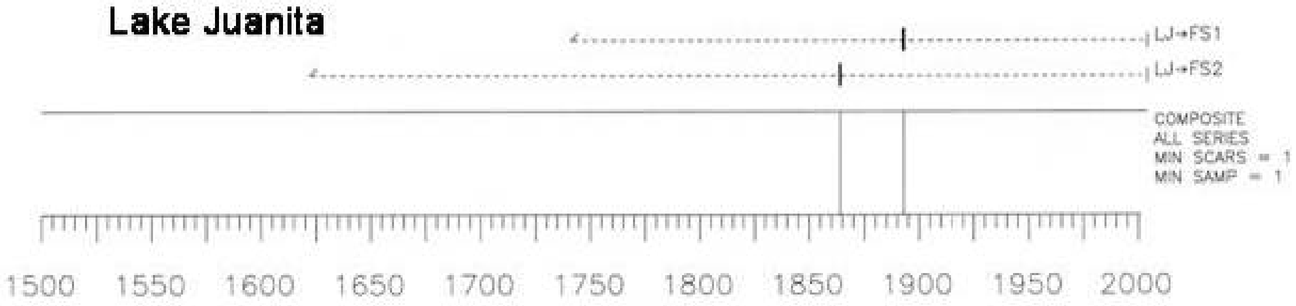

Figure 2. Master fire chronology for fire scar dates from all sites studied on the **Lake Chelan National Recreation Area**, North Cascades National Park Complex. Horizontal lines represent time span for individual trees sampled as partial cross sections. Short vertical lines depict fire scar dates. Composite fire graph represents all fire scar dates from all individuals on this specific administrative unit.

Chelan Ranger District, Wenatchee National Forest

Plot Name (Plot Code)	GPS (UTM NAD 27, Zone 10)	Dominant Overstory	Dominant Understory	Elevation (feet)	Aspect	Fire Scar Fire Years	Stand Replacing Fire Years#	MFRI* (years)
Handy Springs (HS)	5315609 N 693060 E	PIAL/ABLA	FEVI	6820	NE	1854, 1843	2004$ (field observations), ~1890	54
Junior Point (JP)	5318431 N 693716 E	PIAL/ABLA	FEVI	6756	SW	-	2004$(field observations), ~1840	164
Sawtooth Ridge (SR)	5331030 N 705126 E	PIAL/ABLA	LUAN	6396	NE	1892, 1872	~1850	21
South Navarre (SN)	5332585 N 697909 E	PIAL/ABLA	VASC	6527	SW		1995$ (field observations) ~1900	95
Summer Blossom (SB)	5333651 N 700380 E	PIAL/ABLA	LUAN	7019	S	1919, 1896, 1763, 1640	-	93

#Stand replacing fire years are considered approximate and are denoted with the symbol ~.

$ Fire years denoted as based on “field observations” indicate that a stand clearing fire event took place recently and the event can be dated precisely based on historical data. Plots were installed in refugia (areas that did not burn in close proximity to the previous stand clearing event) and therefore a more complete picture of fire history is presented.

*Mean Fire-Return Interval (Agee 1993)

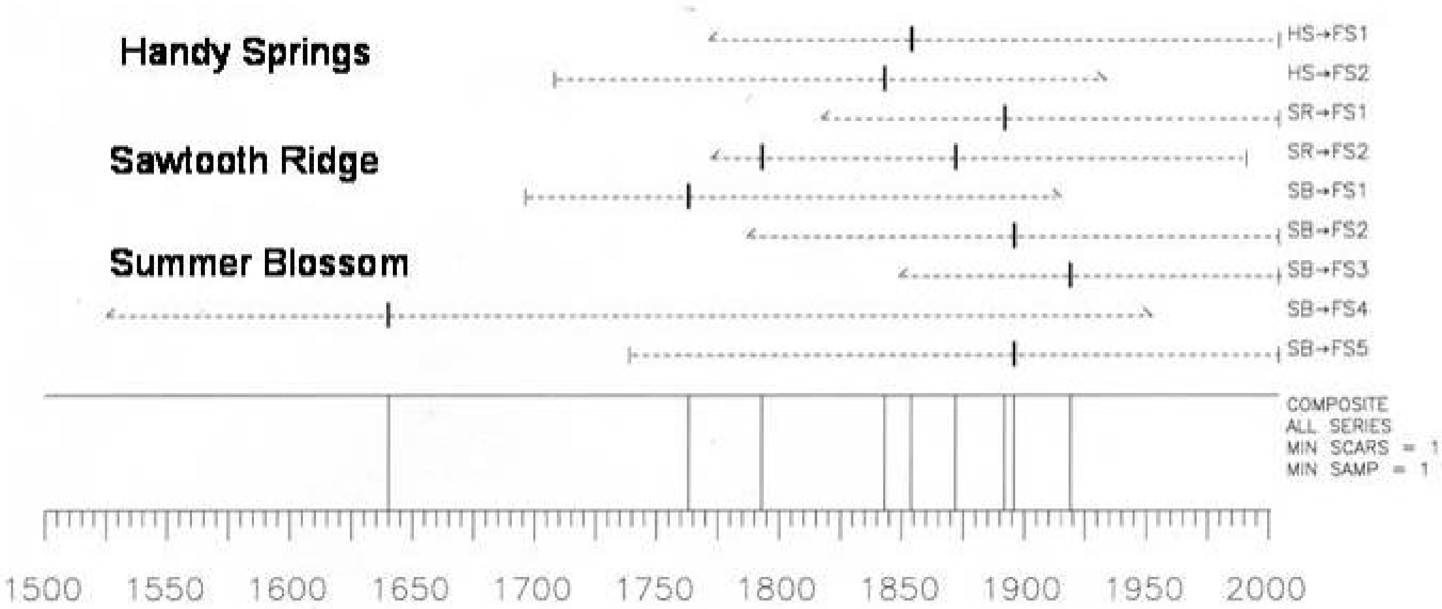

Figure 3. Master fire chronology for fire scar dates from all sites studied on the **Chelan Ranger District**, Wenatchee National Forest. Horizontal lines represent time span for individual trees sampled as partial cross sections. Short vertical lines depict fire scar dates. Composite fire graph represents all fire scar dates from all individuals on this specific ranger district.

Entiat Ranger District, Wenatchee National Forest

Plot Name (Plot Code)	GPS (UTM NAD 27, Zone 10)	Dominant Overstory	Dominant Understory	Elevation (feet)	Aspect	Fire Scar Fire Years	Stand Replacing Fire Years#	MFRI* (years)
Big Hill (BH)	5321134 N 686311 E	PIAL/ABLA	CARU	6789	SW	1836	1970$ (field observations)	134
Stormy Mountain (ST)	5307035 N 698942 E	PIAL/PSME	CARU	6264	SW	1929,1895, 1867,1848, 1837, 1820, 1781	-	25
Tyee Ridge (TR)	5304309 N 688339 E	PIAL/ABLA	LUAN	6445	SW	1915	1994$ (field observations), ~1880	57

#Stand replacing fire years are considered approximate and are denoted with the symbol ~.

$ Fire years denoted as based on "field observations" indicate that a stand clearing fire event took place recently and the event can be dated precisely based on historical data. Plots were installed in refugia (areas that did not burn in close proximity to the previous stand clearing event) and therefore a more complete picture of fire history is presented.

*Mean Fire-Return Interval (Agee 1993)

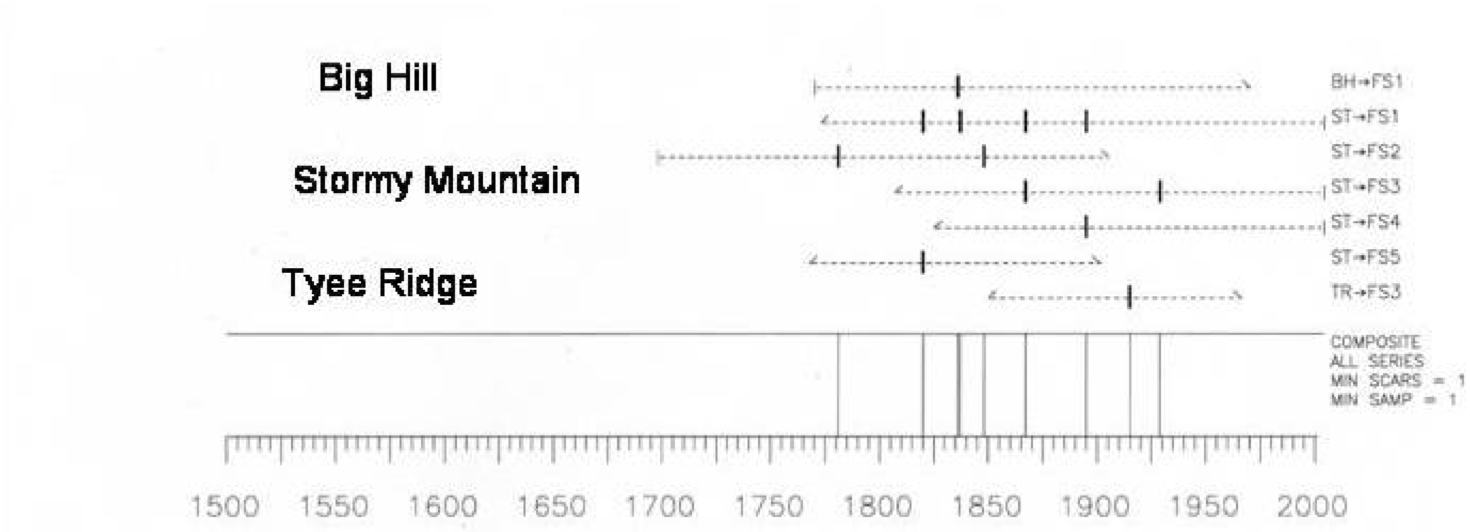

Figure 4. Master fire chronology for fire scar dates from all sites studied on the **Entiat Ranger District**, Wenatchee National Forest. Horizontal lines represent time span for individual trees sampled as partial cross sections. Short vertical lines depict fire scar dates. Composite fire graph represents all fire scar dates from all individuals on this specific ranger district.

Wenatchee River Ranger District, Wenatchee National Forest

Plot Name (Plot Code)	GPS (UTM NAD 27, Zone 10)	Dominant Overstory	Dominant Understory	Elevation (feet)	Aspect	Fire Scar Fire Years	Stand Replacing Fire Years#	MFRI* (years)
Mission Ridge (MR)	5238665 N 694324 E	PIAL/PSME	VASC	6642	SW	1910, 1893, 1732, 1661, 1587	-	81

#Stand replacing fire years are considered approximate and are denoted with the symbol ~.
*Mean Fire-Return Interval (Agee 1993)

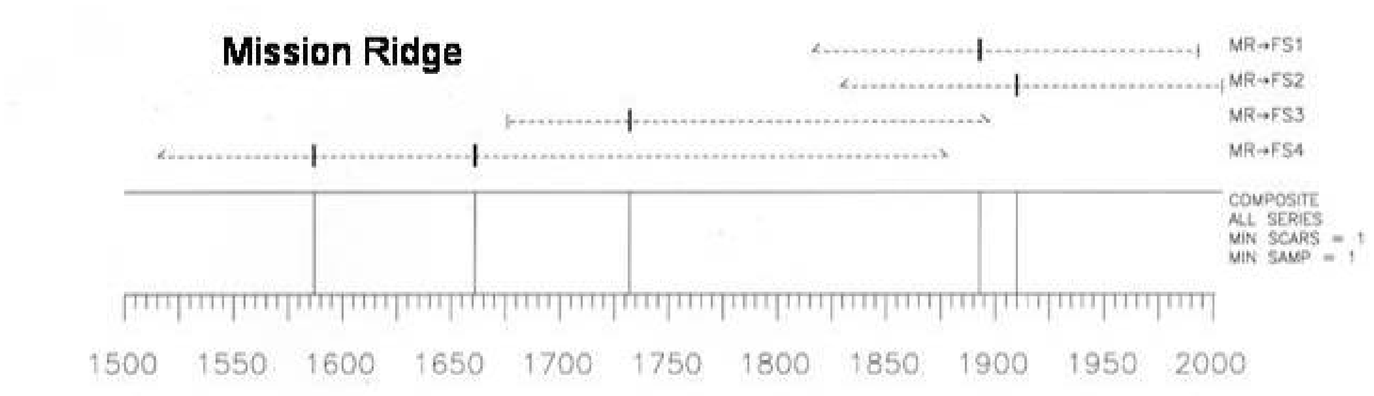

Figure 5. Master fire chronology for fire scar dates from all sites studied on the **Wenatchee River Ranger District**, Wenatchee National Forest. Horizontal lines represent time span for individual trees sampled as partial cross sections. Short vertical lines depict fire scar dates. Composite fire graph represents all fire scar dates from all individuals on this specific ranger district.

Fire History Statistics: Mount Rainier Unit

Appendix C

Mount Rainier National Park

Plot Name (Plot Code)	GPS (UTM NAD 27, Zone 10)	Dominant Overstory	Dominant Understory	Elevation (feet)	Aspect	Fire Scar Fire Years	Stand Replacing Fire Years#	MFRI* (years)
Burroughs Mountain (BM)	519509 N 601765 E	PIAL/ABLA	VASC	6396	SW	-	-	N/A
Crystal Lake (plots 1,2,3) (CL)	5196302 N 613717 E	PIAL/ABLA	VASC	6527	SW	1841, 1814, 1726, 1716	~1930	54
Hidden Lake (HL)	5199565 N 606828 E	PIAL/ABLA	VASC	6201	SW	1955	~1900	55
Mystic Pass (MP)	5195761 N 593918 E	PIAL/ABLA	CAST	6330	SE	-	-	N/A
Shadow Lake (plots 1 and 2) (SL)	5196121 N 603260 E	PIAL/ABLA	CARO	5969	SW	1948	~1840	108
Skyscraper (SK)	5197225 N 598987 E	PIAL/ABLA	LUHI	6690	SW	-	-	N/A
Sunrise (plots 1 and 2) (SU)	5196114 N 604378 E	PIAL/ABLA	VASC	6199	SW	1901, 1812	-	89
Throne (TH)	5197067 N 613722 E	PIAL/ABLA	VASC	6593	SW	-	~1830	N/A

#Stand replacing fire years are considered approximate and are denoted with the symbol ~.

*Mean Fire-Return Interval (Agee 1993)

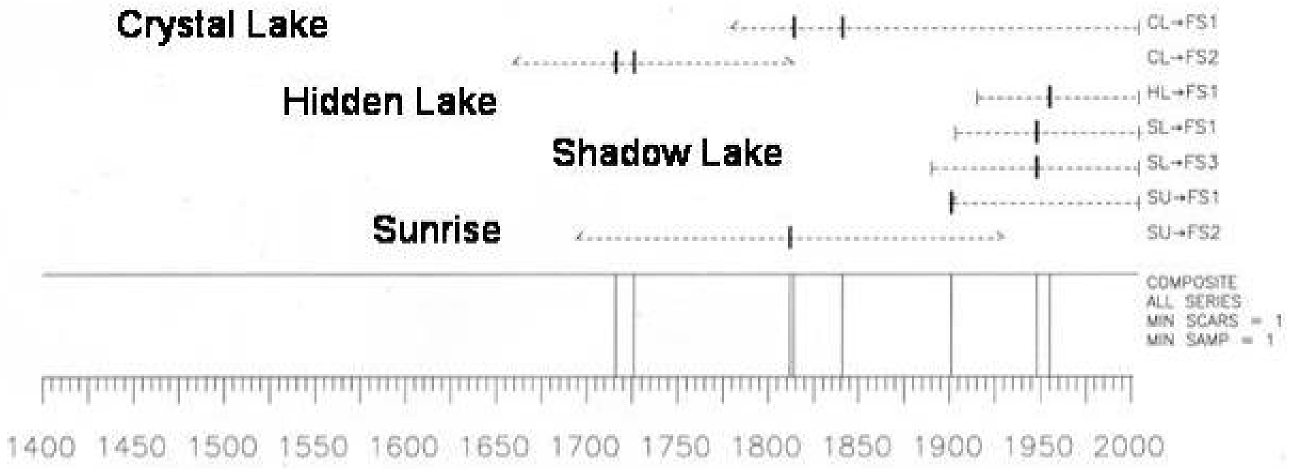

Figure 6. Master fire chronology for fire scar dates from all sites studied for **Mount Rainier National Park**. Horizontal lines represent time span for individual trees sampled as partial cross sections. Short vertical lines depict fire scar dates. Composite fire graph represents all fire scars dates from all individuals for this specific administrative unit.

Naches Ranger District, Wenatchee National Forest

Plot Name (Plot Code)	GPS (UTM NAD 27, Zone 10)	Dominant Overstory	Dominant Understory	Elevation (feet)	Aspect	Fire Scar Fire Years	Stand Replacing Fire Years#	MFRI* (years)
Clover Springs (CS)	5192707 N 637106 E	PIAL/ABLA	VASC	6363	SE	-	~1890	NA
Little Bald Mountain (LB)	5195789 N 639891 E	PIAL/ABLA	ARTR	5822	SE	1854, 1790	~1900	55
Section Three Lake (STL)	5158427 N 629568 E	PIAL/ABLA	LUPE	6232	E	-	~1890	NA

#Stand replacing fire years are considered approximate and are denoted with the symbol ~.
*Mean Fire-Return Interval (Agee 1993)

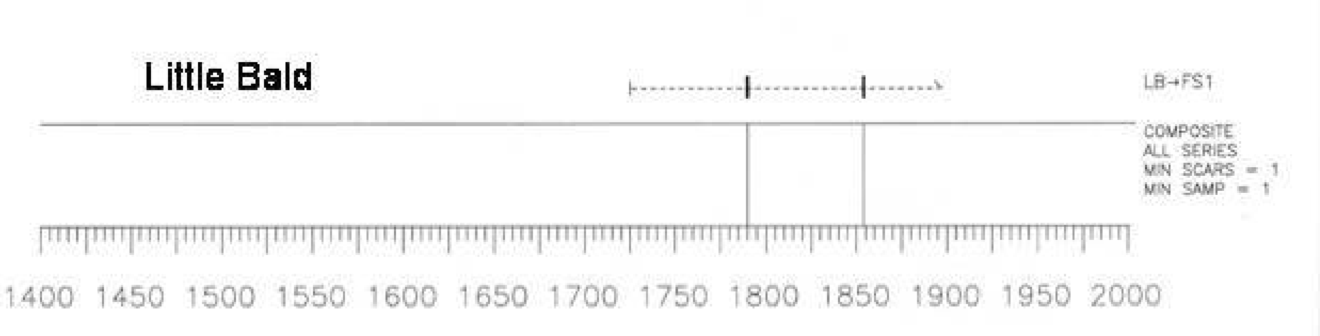

Figure 7. Master fire chronology for fire scar dates from all sites studied on the **Naches Ranger District**, Wenatchee National Forest. Horizontal lines represent time span for individual trees sampled as partial cross sections. Short vertical lines depict fire scar dates. Composite fire graph represents all fire scar dates from all individuals on this specific ranger district.

Fire History Statistics: Southern Oregon Unit

Appendix D

Crater Lake National Park

Plot Name (Plot Code)	GPS (UTM NAD 27, Zone 10)	Dominant Overstory	Dominant Understory	Elevation (feet)	Aspect	Fire Scar Fire Years	Stand Replacing Fire Years#	MFRI* (years)
Cloud Cap (Plot “3” and Plot “Big”) (CC)	4753720 N 577904 E	PIAL/PICO	JUDR	7885	NW	1887, 1817, 1774	~1460	142
Cloud Cap South (CCS)	4753190 N 578212 E	PIAL/PICO	JUDR	7985	S	-	~1700	N/A
Crater Peak (CP)	4744275 N 573634 E	PIAL/ABLA	CABR	7183	W	1840	~1760	80
Dutton Ridge 1 (DR1)	4749578 N 574989 E	PIAL	ACOC	7740	W	-	~1820	N/A
Dutton Ridge 2 (DR2)	4748834 N 575114 E	PIAL	ACOC	7298	SW	-	~1860	N/A
Grouse Hill (GH)	4760102 N 571785 E	PIAL/TSME	CABR	7347	SE	-	-	N/A
Hilman (HI)	4755737 N 567442 E	PIAL/TSME	PEDA	7740	SW	-	-	N/A
Llao Rock (LR)	4757957 N 570686 E	PIAL	LUHI	7937	NW	-	~1700	N/A
Mt. Scott Cairn	4752601 N 579343 E	PIAL/TSME	LUHI	7740	SW	-	~1760	N/A

(MSC)								
Mt. Scott East (MSE)	4752365 N 580430 E	PIAL/TSME	PEDA	8741	SE	-	~1850	N/A
Mt. Scott SW (MSSW)	4752080 N 580148 E	PIAL	PEDA	8823	SW	-	-	N/A
Mt. Scott TH (MSTH)	4753024 N 579076 E	PIAL	CABR	7511	SW	1921, 1883	~1730	96
Mt. Scott 3 (MS3)	4752163 N 579453 E	PIAL/TSME	ARNE	8101	SW	-	~1800	N/A
Phantom Ship Overlook (PS)	4752458 N 576861 E	PIAL/PICO	ELEL	7380	SE	-	-	N/A
Red Cone (RC)	4760726 N 568247 E	PIAL	ARNE	7298	S	-	-	N/A
Red Cone Flat (RCF)	4759473 N 569227 E	PIAL/TSME	CABR	6100	NW	-	-	N/A
Stump Flat (SF)	4754853 N 578251 E	PIAL	ACOC	7380	SE	1811, 1714	-	97
Timber Crater (TC)	4765912 N 576108 E	PIAL/PICO	CABR	7380	SW	-	~1933, ~1873	60
Watchman (WA)	4754580 N 567562 E	PIAL/TSME	PEDA	7888	SW	-	-	N/A
West Dutton (WD)	4747933 N 574880 E	PIAL/PICO	LUAN	6448	SW	1940, 1890	~1870	39
Williams (WI)	4755886 N 567247 E	PIAL/TSME	PEDA	7396	S	-	-	N/A

#Stand replacing fire years are considered approximate and are denoted with the symbol ~.
*Mean Fire-Return Interval (Agee 1993)

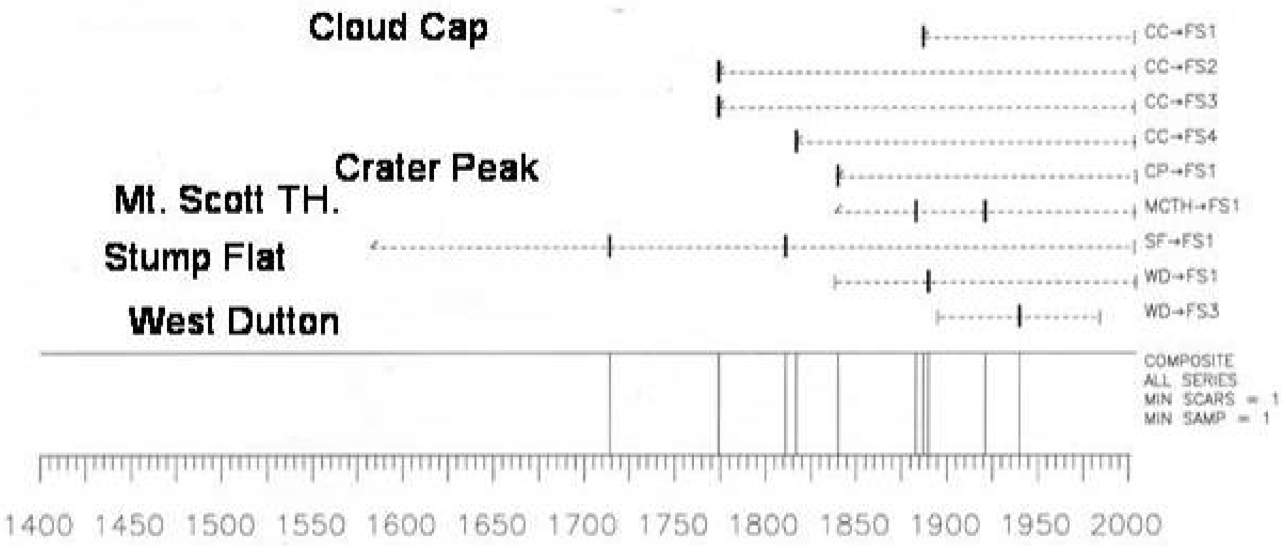

Figure 8. Master fire chronology for fire scar dates from all sites studied at **Crater Lake National Park**. Horizontal lines represent time span for individual trees sampled as partial cross sections. Short vertical lines depict fire scar dates. Composite fire graph represents all fire scar dates from all individuals on this specific administrative unit.

Bend-Fort Rock Ranger District, Deschutes National Forest

Plot Name (Plot Code)	GPS (UTM NAD 27, Zone 10)	Dominant Overstory	Dominant Understory	Elevation (feet)	Aspect	Fire Scar Fire Years	Stand Replacing Fire Years#	MFRI* (years)
Paulina Peak	N/A	PIAL/PICO	ARNE	7610	W	-	~1840	N/A

#Stand replacing fire years are considered approximate and are denoted with the symbol ~.
*Mean Fire-Return Interval (Agee 1993)

Klamath Ranger District, Fremont-Winema National Forest

Plot Name (Plot Code)	GPS (UTM NAD 27, Zone 10)	Dominant Overstory	Dominant Understory	Elevation (feet)	Aspect	Fire Scar Fire Years	Stand Replacing Fire Years#	MFRI* (years)
Pelican Butte (plots 1 & 4)	4706845 N 570299 E	PIAL/ABLA	ARNE	7987	SW	-	~1800, ~1670	130
Pelican Butte 2	4707192 N 570004 E	PIAL	PEDA	7790	W	-	~1740	N/A
Pelican Butte 3	4707363 N 569883 E	PIAL/TSME	PEDA	7872	W	-	~1750	N/A
Pelican Butte 5	4707363 N 569883 E	PIAL/TSME	PEDA	7675	W	-	~1765	N/A

#Stand replacing fire years are considered approximate and are denoted with the symbol ~.
*Mean Fire-Return Interval (Agee 1993)