FIRE HISTORY AND ECOLOGY OF REMNANT FOREST PATCHES IN THE SUB-BOREAL PINE-SPRUCE ZONE OF CENTRAL BRITISH COLUMBIA

by

Paula Vera

B.Sc., University of Alberta, 1998

A THESIS SUBMITTED IN PARTIAL FULFILLMENT

OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

in

THE FACULTY OF GRADUATE STUDIES

THE FACULTY OF FORESTRY

We accept this thesis as conforming

to the required standard

THE UNIVERSITY OF BRITISH COLUMIA
APRIL 2001

Department of FOREST SCIENCES

The University of British Columbia
Vancouver, Canada

Date April 24/01

ABSTRACT

When a fire burns a substantial area of forest, it often leaves patches unburned. No published study appears to have addressed the question of whether or not there are patches that have never been burned by fires within the last few hundred years in British Columbia. Published studies have only partially addressed the question of whether or not there are some landscape factors that prevented fire from killing trees within the unburned patches.

To address these questions, a project commenced in 1999 in the SBPSxc biogeoclimatic subzone with 2 main objectives – to determine (1) if there are some forest patches within lodgepole pine forests in this subzone in central B.C. that have not burned during the last 200-300 years, and (2) if forest patches within these lodgepole pine forests that did not burn at the time when the surrounding forests were most recently burned, have some characteristics that caused them not to burn.

It was determined that in 24 of 26 patches studied, the most recent fire within the patch was the same one that established the surrounding forest. All patches had burned within the last 200-300 years. It is not completely certain why trees in the study patches escaped being killed during the fire that established the surrounding forest. It appears that lower tree density and basal area within the patches at the time of the fire may have been important. Other factors such as topographic features, soil moisture, and crown fuels do not appear to have been important.

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ACKNOWLEDGEMENTS

Financial support for this study was provided by the Canadian Interagency Forest Fire Centre - Fire Science and Technology Fund and the University of British Columbia. I was supported by a National Science and Engineering Research Council scholarship and fellowships from the Faculty of Forestry. The support of all these agencies is gratefully acknowledged.

I thank Dr. Michael Feller, my supervisor, for giving me the opportunity and support required to conduct this research. Dr. Feller's knowledge and advice were instrumental in the completion of this thesis. Evidently, I managed to complete my fieldwork without really breaking anything.

Thank you to the members of my supervisory committee, Dr. Peter Marshall and Dr. Karel Klinka, for their comments, suggestions and resources. The support provided by Ray Coupe from BC Ministry of Forests in Williams Lake is also appreciated.

Emily Heyerdahl shared her enthusiasm and knowledge of dendrochronology with me at a time when I needed it most. Thanks Emily!

I would also like to thank all the people who assisted me in the field: Greg Adams, Linda Draude, Theresa Gulliver, and my dad. Special thanks to the "Klinkoids" for providing never ending humor and advice in the office. And of course I could not end without thanking my mom, she has always been there for me, providing a never ending supply of "whatever you do - be careful out there!"

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1.0 INTRODUCTION

Land managers and the scientific community in disciplines related to forest management are now expected to maintain biological diversity, sustainable ecosystems, and sustainable industries. Historically, the protection of wilderness areas and areas relatively unaffected by resource extraction was assumed adequate to sustain natural ecological functioning and biodiversity (DeLong and Tanner 1996). Public criticism of past practices and better understanding of natural systems have resulted in the emergence of new ideas about forest management (DeLong 1998). Currently, it is expected that as many activities as possible be carried out sustainably and still maintain biodiversity in all areas rather than just in those designated as protected areas.

In forestry, the current approach towards maintaining biological diversity is to pattern forest management practices after those of natural disturbances (DeLong and Tanner 1996). Part of the British Columbia Forest Practices Code is based on the principle that the more managed forests resemble the forests established by natural disturbances, the greater the probability that all native species and ecological processes will be maintained (Stuart-Smith and Hendry 1998). Natural disturbances maintain plant and animal diversity over time and space by maintaining structural complexity within stands, and by influencing the size, distribution, edge characteristics, and dispersion of stands across the landscape. Hence, an understanding of how the forested landscape was affected by natural disturbance is needed to develop alternative management systems that more closely approximate natural disturbances in their effects (DeLong 1998).

1.1 FIRE

Natural disturbances range from benign to catastrophic; common forest disturbances include fires, wind, insects, and avalanches (Agee 1998). Fire is a disturbance process that has interacted with vegetation in the landscape since the evolution of forest assemblages approximately 30 to 12 million years before present (Weber and Taylor 1992). Before the advent of humans on the North American continent, fire was an important process in most of the forested areas of Canada, such that most of our forests have evolved adaptations to fire (Duchesne 1994). Fire developed into an integral process in the forest landscape, responsible for the maintenance of the complexity of the mosaic of stand ages and stand compositions.

The acquisition of fire by humans, and the subsequent movement of humans across the globe, had profound effects upon the nature of fire (Pyne 1993). For many years, fires were something feared and to be prevented at all costs. Today we have a better understanding of what fire does for the forest. Forest fires allow for species diversity by burning understory vegetation and providing for new species to emerge. Some species, such as ponderosa pine (*Pinus ponderosa*), have evolved to become resistant to fire and actually use fire for seed dispersal. Fire maintained ecosystems that have an open canopy of mature, nearly fireproof trees, such as ponderosa pine, or larch (*Larix* spp.), have an abundant ground cover of grasses, forbs and shrubs (Gayton 1996). These forests provide excellent habitat for grazing species of wildlife and cattle, as well as for many species of birds.

Fires maintain fruiting shrub communities such as buffaloberry (*Shepherdia canadensis*). Buffaloberry is a known food source for grizzly bears (*Ursus arctos horribilis*) which can live in forests dominated by lodgepole pine (*Pinus contorta*) (Hamer and Herrero 1987). Forests that burn frequently show more evidence of fruiting shrubs compared to forests that do not burn as frequently.

Fire may reduce the risk of insect infestation. In the absence of fire, some forests can become ingrown which increases the likelihood of a forest pest outbreak because trees begin to compete for resources and become stressed (Gayton 1996). Once an outbreak occurs, the increased fuel loading from dead and dying trees means that catastrophic fire may follow (Lotan 1976).

1.2 RESEARCH ON FIRE HISTORY

Fire history is important for management planning because it provides detailed information on how the vegetative complex of an area has been shaped (Arno 1980). Fire history provides information for evaluating change in plant communities where fire is, or was, a significant ecological factor (Dieterich and Swetnam 1984). As a result, the study of fire history has become increasingly popular. Many fire history studies have been completed in the United States (e.g. Agee 1991, Agee et al. 1990, Arno 1980, Baisan and Swetnam 1990, Brown and Swetnam 1994, Brown et al. 1999, Dieterich 1980, Everett et al. 2000, Henry and Swan 1974, Heyerdahl et al. 1993, Murray et al. 1998, Swetnam 1993). Studies in Canada include those by Tande (1979), Hawkes (1983), Wein and Moore (1979) and Dansereau and Bergeron (1993).

Tande (1979) examined the fire history and vegetation pattern of coniferous forests in Jasper National Park, Alberta. He found that stands varied from even-aged-to multiple-age-classes intermingled over short distances. Multiple-aged stands dominated lower elevations and were maintained by frequent removal, by fire, of low organic matter accumulations. Large, continuous, even-aged forests occurred at mid to high elevations where wetter moisture regimes allowed greater fuel accumulations, and consequently, more intense fires during droughts (Tande 1979).

Wein and Moore (1979) looked at fire history and rotation periods in Nova Scotia. They noted that vegetation types in the Acadian Forest have had widely different fire rotation periods. They found that the vegetation of Cape Breton Island has experienced almost no fires, whereas the vegetation type with the shortest fire rotation period (in the interior of western Nova Scotia) had been subjected to fire rotation periods as low as 65 years at the turn of the century.

Dansereau and Bergeron (1993) examined fire history in the southern boreal forest of northwestern Quebec. Their compilation of data concerning area burnt per type of surficial material confirmed that the physical environment exerted a strong control on the delimitation of smaller fires.

1.3 RESEARCH ON REMNANT FOREST PATCHES

Although stand-replacing fires dominate in sub-boreal ecosystems, burned landscapes typically contain patches of forest that did not burn (Delong and Kessler 2000). Research on remnant patches remaining after fires in North America is currently limited to research in the boreal forest, Cascade Mountains and a preliminary study in the Nelson Forest Region (e.g. Eberhart and Woodard 1987, Camp et al. 1997, Stuart-Smith and Hendry 1998). Some work has also been completed on other continents (e.g. Hornberg et al. 1998, Van Wilgen et al. 1990).

Eberhart and Woodard (1987) analyzed fire size and shape, number and size of islands of residual vegetation, amount of edge, and distances to residual vegetation for 69 fires in the boreal forest of Alberta. The study focused on potential for natural reforestation and benefits to some wildlife habitats as fire size increases. They found that fires in the smallest size class (20-40 ha) did not contain any islands of unburned vegetation, and that the number of unburned islands was highest for the third and fourth largest fire size classes (201-400 and 401-2000 ha).

Delong and Tanner (1996) looked at managing the harvest pattern of sub-boreal forests in British Columbia to mimic wildfire. They examined the current pattern of regularly dispersed clearcuts and discussed how the spatial characteristics of different forest age classes were drastically different from those historically created by wildfire. Wildfire created a more complex landscape pattern with greater range in patch size and more irregular disturbance boundaries. Delong (1998) looked at the size and distribution of fires in northern British Columbia. He concluded that maximum allowable harvested areas in the current guidelines are lower than the maximum natural disturbance size.

Delong and Kessler (2000) conducted a study to develop a better understanding of the ecological significance of unburned forest remnants in successional sub-boreal landscapes created by fire. They characterized remnant patches and compared them to matrix forest in young, mature and old age classes. It was found that remnant patches could be discriminated from matrix forest types based on variables relating to tree overstory and snag density.

Stuart-Smith and Hendry (1998) determined the amount, type and distribution of live residual trees left within fires, and how this varied by biogeoclimatic subzone for a limited number of fires in the East Kootenay of British Columbia. Residual vegetation was separated into four classes: veterans, clumps, islands and skips. Veterans were defined as single, widely scattered live trees within the fire boundary. Clumps were identifiable clusters of single live trees too small to be typed out by forest cover inventory. Islands were typed out forest cover polygons within the fire that were classified as having burned underneath, while skips were forest cover polygons within or predominantly within the fire that were classified as not having burned. They found that the total number of live residual trees increased with the size of the fire. However, the average size of clumps, islands, and skips did not change with fire size.

Kushla and Ripple (1997) examined the role of terrain in a fire mosaic of a temperate coniferous forest in Oregon. They found that vegetation and terrain variables accounted for more variation in forest survival within individual physiographic areas than across the entire study area. Significant topographic variables differed among individual physiographic areas, and included ridgeline proximity, elevation, stand age and aspect. Foster (1983) concluded that remnants often formed downwind of fuel breaks, including lakes, streams and peatlands in the boreal forest of southeastern Labrador.

In Sweden, Hornberg et al. (1998) examined boreal swamp forests. Some of these forests have never actually burned. They hypothesized that it is probably because they are situated in lowlands, where the risk of ignition by lightning is low and where wet conditions make the build-up of fuel less important than in drier sites.

Vegetation structure and fuel chemistry may contribute to excluding some patches from fire. Sylvester and Wein (1981) found extreme differences in the flammability of many arctic plant species. Some areas may not burn because the species present do not favour burning. Van Wagner (1967) found that trees with high foliar moisture content produced less radiant heat, which could prevent crowning.

Bottorff (2001) classified the understory plant communities of remnant patches in the upper foothills – subalpine region of northwestern Alberta. He found that larger (greater than 1.5 ha) remnant patches represented unique communities on the landscape and may supply understory plant species to the burned area as succession continues.

1.4 FACTORS INFLUENCING FIRE BEHAVIOR AND WHETHER OR NOT AN AREA WILL BURN

Fire behavior is the product of the environment in which the fire is burning. Topography, fuel, weather, and the fire itself are the interacting influences that make up the fire environment (Pyne et al. 1996). The changing states of each of the environmental components – fuel, topography and weather – and their interaction with each other and with the fire itself determine the characteristics and behavior of a fire at any given moment (Pyne et al. 1996). The study of each of the above factors on fire behavior is detailed. What follows below is a brief description of each factor. It should be noted that although the factors are discussed under separate headings, many of them interact with one another, creating many unique fire environments. Further details on fire behavior and the factors that influence it can be found in Pyne et al. (1996) and Chandler et al. (1983); the following discussion is based on both.

1.4.1 Topography

Topography includes the elements of elevation, slope steepness and aspect. Variations in topography can cause dramatic changes in fire behavior as a fire progresses over the terrain (Pyne et al. 1996). Differences in elevation greatly influence the general climate and thereby affect fuel availability. Length of fire season and fuel vary with elevation due to differences in amount of precipitation received, snow melt dates, and greenup and curing dates (Pyne et al. 1996). Temperature and relative humidity also vary with position on the slope. Slope steepness affects the radiation intensity and fuel moisture. Slope steepness has a direct affect on flame length and rate of spread of a fire. Connected to slope is aspect – the direction a slope is facing. Aspect affects fire behavior through variations in the amount of solar radiation and wind that different aspects receive.

Topography can influence whether or not certain areas burn and others do not. For example, lower-elevation sites that have a north aspect (in the northern hemisphere), moist gullies and depressions may have ecosystems that are wetter and cooler than surrounding ecosystems, making them less favorable for fire. Alternatively, depending on the time of year that the fire occurs, higher-elevation sites with late-lying snow will be less suitable for fire compared to lower elevations that experience higher daytime temperatures as a result of aspect.

1.4.2 Weather

Weather influences fire in two ways: (1) by influencing fuels – temperature, relative humidity, and precipitation affect fuel moisture, and (2) by influencing fire behavior – wind speed and direction strongly influence fire behavior. Lightning can also act as an ignition source for fire.

The diurnal fluctuation of temperature and relative humidity affects fire behavior. During daylight hours, temperature is generally higher (providing less of a gradient between fuel temperature and ignition temperature) humidity is lower, and winds are often stronger. As it becomes dark, temperature generally decreases and humidity increases, while wind speed declines, often providing a less suitable environment for fire. This diurnal change can cause a change in the type of fire. A fire burning in the crowns of trees during the day can become a surface fire at night – leaving some patches of forest without crown damage.

Differing latitudes, topography and position relative to large bodies of water all influence weather. The amount of moisture in any forest fuel is critical in determining flammability of that fuel. In turn, the amount of moisture in dead forest fuels depends highly on atmospheric moisture. Forests near coastal areas or large bodies of water may be less flammable due to increased humidity.

Wind is one of the most variable and most important of the weather factors influencing forest fires (Chandler et al. 1983). Wind assists in drying fuels by providing a means of carrying off the evaporated moisture. Wind also supports and increases combustion by ensuring a continued supply of air, by increasing radiation through the tilting of flames toward unburned fuel in advance of the flame front, and by carrying burning embers to ignite spot fires ahead of the main fire (Chandler et al. 1983). Slope affects wind. During the day as the surface of a slope warms, the warmed air flows upslope; during the night as the surface cools, the cooled air flows downslope. A knowledge of the local winds can be a considerable benefit when dealing with forest fires.

Cumulus clouds are significant to forest fire weather in that they are indicative of air turbulence and instability. Cumulus clouds or, cumulonimbus clouds when fully developed are often formed by convective lifting during warm weather. Cumulonimbus clouds commonly produce lightning, rain and strong winds and are nature's primary forest fire ignition source (Chandler et al. 1983).

1.4.3 Fuels

Fuel is necessary for fire. Understanding fuel is important for all aspects of wildland fire, including fire suppression, fuel management, smoke management, wildland/urban interface, forest health and ecosystem management, and global climate change (Pyne et al. 1996). Wildland fire fuels can be classified as follows:

(1) Ground fuels: include duff, roots and rotten buried logs. These fuels are generally quite compact causing fire spread to be slow.

(2) Surface fuels: most wildland fires ignite in, and are carried by, the surface fuels. Surface fuels include small trees, shrubs, herbaceous vegetation, forest floor litter, and downed woody material.

(3) Crown fuels: overstory trees and large shrubs. Even when the canopy is not included in the fire, it affects the behavior of the fire in the surface fuel (Pyne et al. 1996). Stands with open canopies, for example, usually have a faster spreading surface fire than closed stands.

Fuels change over time – from the diurnal change in moisture content to changes as the forest ages. As forests age, vegetation growth, decay and litter all increase. Older forests may have more extreme fire behavior because the quantity and arrangement of fuel favour fire. Seasonal changes in moisture content also occur. Chrosciewicz (1985) examined foliar moisture content variations in four coniferous species of central Alberta. It was determined that seasonal patterns of variation in the mean moisture content of foliage occurred throughout the sampling period. Typical declines of moisture in the spring were followed by recoveries in the summer.

Each type of fuel (ground, surface, or crown) can be described according to various properties. Intrinsic fuel properties (heat content, chemical content) vary according to each individual particle burned. Physical properties that affect the way a material burns include quantity, size, compactness, and arrangement.

Fuel quantity is how much fuel there is at a particular site. For surface fuels this is often expressed as a unit of mass divided by unit area occupied. Crown fuel quantity is expressed as foliage mass per unit area.

It is clear that small fuels ignite and sustain combustion easier than large pieces of fuel. This is because less heat is required to remove fuel moisture and raise a small particle to ignition temperature (Pyne et al. 1996). Thus, it is the fine fuels that carry the flaming fire front.

Compactness can be thought of as the spacing between fuel particles. The closeness and physical arrangement of the fuel particles affect both ignition and combustion (Pyne et al. 1996). In most cases, slower spread rates occur when fuels are compacted. Bulk density, the mass per unit volume of a fuel complex, is an appropriate measure of porosity of a fuel complex.

The way fuel particles are arranged has a great influence on fire behavior (Pyne et al. 1996). Both the horizontal and vertical continuity of fuelbeds are important to fire behavior; however, they are extremely difficult to quantify (Chandler et al. 1983). The combination of live versus dead fuel is also part of fuel arrangement.

Many variables relating to fuels could be responsible for why certain areas burn and others do not. A challenge is finding variables that can be measured post-burn and reconstructed to the time of the fire.

1.5 STUDY OBJECTIVES

There are two objectives of this thesis. They are to determine: (1) if there are some forest patches within drier lodgepole pine forests in central B.C. that have not burned during the last 200-300 years; and (2) if forest patches within these lodgepole pine forests in central B.C. that did not burn at the time when the surrounding forests were most recently burned, have some characteristics that caused them not to burn.

1.6 STUDY AREA

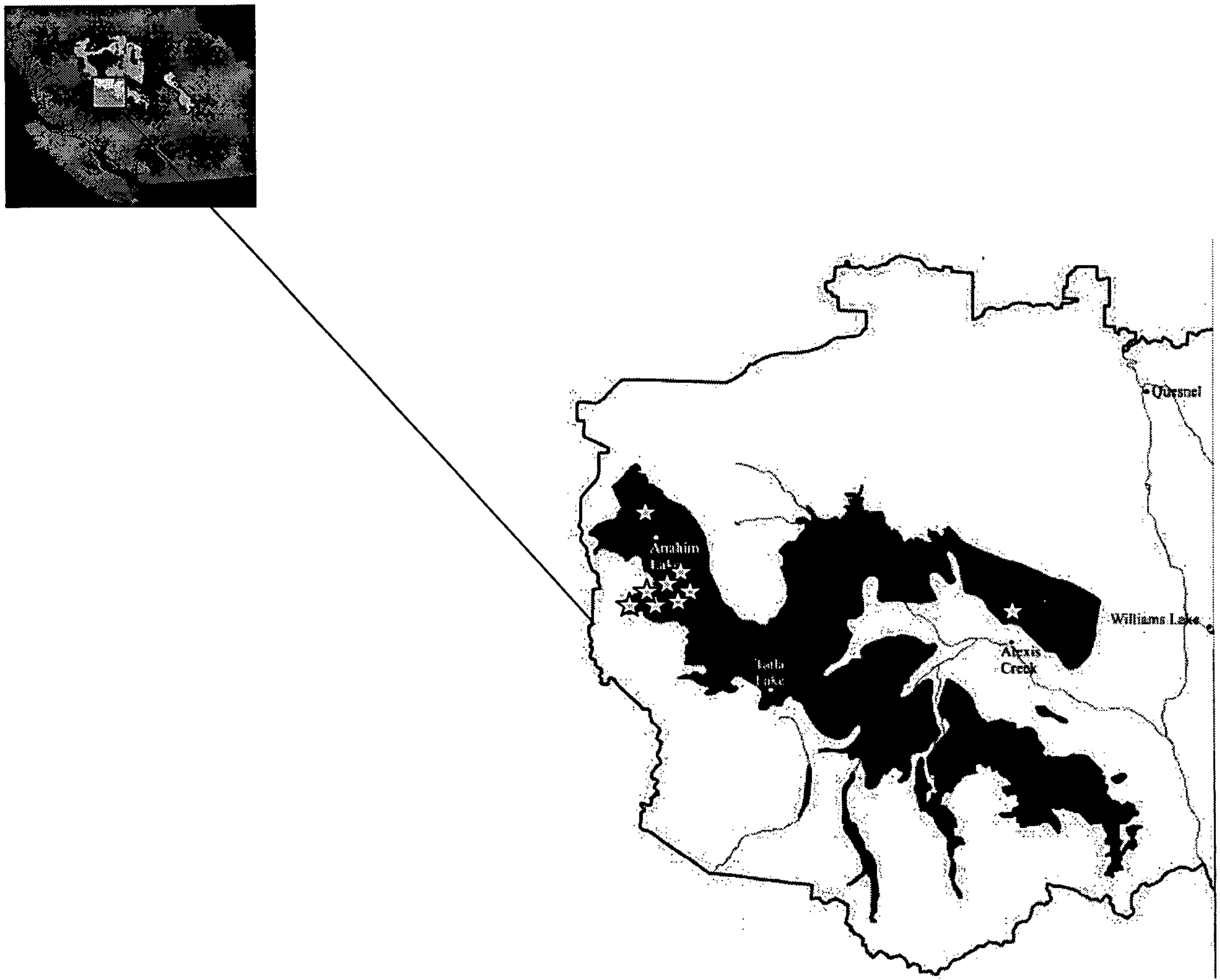
The study area was located within the Sub-Boreal Pine-Spruce biogeoclimatic zone (SBPS). The SBPS biogeoclimatic zone was chosen as the study area for this project for several reasons. SBPS is known to be a zone in which fires occur frequently. The zone has favourable terrain for research and relatively good access. Although there are four subzones in the SBPS, this study focused on the SBPSxc (very dry cold) because it has the best road access and covers the largest area (approximately 10 900 km^2) when compared to the other subzones (Steen and Coupe 1997). Characteristics for the SBPS zone are given below as found in Meidinger and Pojar (1991).

The SBPS is a montane zone that occurs on the high plateau in the west central interior of British Columbia (Figure 1). It lies south and west of the Sub-Boreal Spruce zone in the rainshadow of the coast mountains. The SBPSxc occurs in the southwest part of the zone in an arc along the inside of the Coast Mountains as far north as the Rainbow Range. Macro topography in the SBPSxc subzone is gently rolling.

Elevations in the southern and western parts of the zone, near the Coast Mountains, range from 1100-1500 metres. The SBPS generally occurs at elevations above the Interior Douglas-fir zone and below the Montane Spruce, Sub-Boreal Spruce, and Engelmann Spruce-Subalpine Fir zones on the Fraser Plateau.

The climate of the SBPS is continental and characterized by cold, dry winters and cool dry summers. The cool, dry growing season of the SBPS results in large part from its position in the strong rainshadow of the Coast Mountains

Figure 1. Map to the upper left shows the distribution of the SBPS zone in British Columbia. Larger map shows relative plot locations (stars) (adapted from Steen and Coupe 1997).



and its relatively high elevations. Mean annual temperatures in the SBPS range from 0.3 to 2.7°C with a mean of 1.9°C. Mean annual precipitation ranges from 335 to 580 mm, of which 30-50% falls as snow.

Lodgepole pine (*Pinus contorta* var. *latifolia*) is by far the most common tree species and large areas of forest contain no tree species other than lodgepole pine. Due to their extensive fire history, the pine trees generally form young, even-aged, very dense stands. White spruce (*Picea glauca*) and trembling aspen (*Populus tremuloides*) are also common in the SBPS.

White spruce is the theoretical climatic climax tree species over most of the SBPS. In the very dry southwestern part of the zone, the abundance of pine regeneration and virtual absence of spruce regeneration on zonal sites suggests that lodgepole pine may be an edaphic or fire climax tree species. In the remainder of the zone, the dominance of pine on zonal sites has been maintained by recurrent wildfires, and pine is considered a persistent fire-climax species.

Understory vegetation in the SBPSxc is comprised of low to moderate (5-50%) cover of Buffaloberry (*Shepherdia canadensis*), common juniper (*Juniperus communis*) and prickly rose (*Rosa acicularis*) in the shrub layer. The herb layer is dominated by pinegrass (*Calamagrostis rubescens*) and kinnikinnick (*Arctostaphylos uva-ursi*). Other common species are dwarf blueberry (*Vaccinium caespitosum*), twinflower (*Linnaea borealis*), fireweed (*Epilobium angustifolium*) and wild strawberry (*Fragaria virginiana*).

1.6.1 Lodgepole pine and fire

On most sites where lodgepole pine grows, fire is necessary for the species' continued dominance (Fischer and Bradley 1987). Successional trends are frequently interrupted by fire and original stands are replaced with essentially pure stands of lodgepole pine (Lotan et al. 1985).

Lodgepole pine's key fire survival attribute is cone serotiny (closed cones) (Fischer and Bradley 1987). Seeds remain viable in serotinous cones for several years, providing a reserve that disperses the first year following a burn (Nyland 1998). Most viable lodgepole pine seeds germinate within the first season after dispersal (Nyland 1998). Nyland (1998) noted that high-intensity fires that consumed most of the litter layer and exposed the mineral soil created a favourable surface for lodgepole pine establishment.

Many species, such as larches and pines are often referred to as "fire resistant". This term implies some characteristic that allows the trees to resist being killed by fire. Thick bark provides an insulating layer between the fire and tree cambium. Van Wagner (1973) noted that in pine species, the principle cause of mortality following fire is crown scorch rather than damage to the cambium. To die by cambial damage alone, a tree must be completely girdled, and any fire intense enough to girdle a tree is usually intense enough to scorch all of its foliage as well (Van Wagner 1973).

1.6.2 Fire in the SBPS

In the SBPS biogeoclimatic zone, fire is one of the most common forest disturbances. The British Columbia Biodiversity Guidebook (B.C. Environment 1995) has divided all of the biogeoclimatic zones and subzones into Natural Disturbance Types (NDT). These disturbance types characterize areas with different natural disturbance regimes. All of the subzones in the SBPS are in NDT 3, ecosystems with frequent stand-initiating events. Historically, these forest ecosystems experienced frequent wildfires that ranged in size from small spot fires to conflagrations covering tens of thousands of hectares. The largest fires in British Columbia occur in this NDT, often exceeding 100 000 ha and sometimes even 200 000 ha. Natural burns usually contained patches of mature forest that were untouched by fire. Consequently, these forests produced a landscape mosaic of even-aged regenerating stands with mature forest remnants (BC Environment 1995).

Parminter (1992) described the typical historic patterns of wildfire disturbance by biogeoclimatic zone. For the SBPS he noted that there was low data quantity and quality. Fire types are generally medium to high intensity surface and crown fires with a mean fire return interval between 100 and 250 years. Parminter (1992) estimated fire size in the SBPS to be on average 50-500 hectares.

1.7 SAMPLING OF PATCHES

For this study patches were defined as an area of older age class forest surrounded by a younger age class forest. Potential study fires were initially delineated by looking at all forest cover maps of the SBPSxc subzone. Potential study fires had to meet the following criteria: (1) accessible – did not require more than a 2 kilometre walk from vehicle access and; (2) had a minimum of 1 patch identified on the forest cover map. A patch was defined as such, when it differed in age from surrounding forest by a minimum of two age classes (see Table 1).

Table 1. Age limits for inventory forest age classes used by the Ministry of Forests in British Columbia (Delong and Tanner 1996).

Age class	Age limits (years)
1	1-20
2	21-40
3	41-60
4	61-80
5	81-100
6	101-120
7	121-140
8	141-250
9	>250

Several days were spent checking some of the potential fires on the ground to ensure that what was on the maps could be found on the ground. In some cases it was necessary to look at air photos of the fires to determine the differences in ages at a more detailed level because not all patches remaining within a fire were typed out on the forest cover maps. Some fires were excluded from the list of all possible because ground checking found that roads were deactivated or sites had been logged since the maps were updated.

Nine fires were randomly selected to carry out field observations from a total of 25 possible fires. All possible fires were given numbers and the numbers were placed in a hat. Nine were selected for study based on the amount of time available for fieldwork. Eight fires were in the Anahim Lake area and one fire was located north of Alexis Creek (Figure 1). Twenty six out of 64 (40.6%) remnant patches, identified from forest cover maps within the possible fires, were sampled (Table 2).

Table 2. Remnant forest patch plot locations.

Fire	Plot	UTM*	Site Series**	Elevation (m.a.s.l.)	Slope (%)	Aspect (degrees)
4	04-O1	483188 5794492	01	1131	4	238
	04-O2	483169 5794490	02	1160	5	300
	04-O3	483260 5794450	02	1149	2	232
6	06-O1	340217 5825579	01	1090	3	246
	06-O2	340121 5825975	01	1070	0	0
10	10-O1	347315 5808610	02	1031	2	18
	10-O2	347563 5808460	02	1053	0	0
	10-O3	347241 5808398	02	1087	1	340
11	11-O1	342507 5812419	01	1138	1	327
	11-O2	342428 5812227	02	1159	2	248
	11-O3	342795 5812430	01	1165	0	0
13	13-O1	337157 5814346	02	1157	1	86
	13-O2	337056 5814554	02	1179	1	269
	13-O3	337049 5814482	02	1223	3	273
20	20-O1	342400 583007	02	1211	0	0
	20-O2	343298 5803045	02	1240	3	3
	20-O3	342262 5802713	02	1252	90	72
21	21-O1	342203 5794907	02	1322	2	40
	21-O2	342170 5794930	04	1319	0	0
	21-O3	342288 5795033	04	1295	2	360
26	26-O1	349192 5796816	02	1192	2	267
	26-O2	349134 5796952	02	1203	1	36
	26-O3	349104 5796643	02	1183	0	0
27	27-O1	335505 5790526	02	1448	5	160
	27-O2	335398 5790466	02	1375	6	168
	27-O3	335469 5790761	02	1402	3	160

*Universal Transverse Mercator **Site series are all sites within a subzone that are capable of producing the same climax vegetation unit. Zonal site units are always numbered 01. Non-zonal forested site series are numbered from 02 to 09 sequentially in order of increasing moisture regime and secondarily in order of increasing nutrient regime (Steen and Coupe 1997).

At each fire, 6 plots were established. Three plots were randomly located in the young forest surrounding the remnant patches (henceforth called the matrix) and three plots were located within the remnant patches. Due to the difficulty in finding remnant patches on the ground, the first three remnant patches found were used for the study provided that the patch was large enough to establish a plot. One study plot was established in each remnant patch. Different plot sizes were used because of variability in stand density (933-16250 trees ha^{-1}) (e.g. Taylor and Skinner 1998). In the matrix forest 20m by 20m plots were used and in the remnant forest 30m by 30m plots were used.

Plots within remnant patches were located at least two tree lengths from the edge of the patch to avoid any edge effect that may have been present. The starting point of each plot was determined by blindly tossing an object into the patch. Orientation of all plots was established using a random bearing from a compass. (e.g. Nyland 1998).

Plots in the matrix forest were located by adding 100 to a random compass bearing to determine the distance (101-460 m) from the starting corner of the remnant plot. The direction from the remnant patch was also determined using a random compass bearing.

2.0 FIRE HISTORY OF REMNANT PATCHES

2.1 INTRODUCTION

The study of fire history provides important information for evaluating change in plant communities where fire is, or was, a significant ecological factor (Dieterich and Swetnam 1984). The frequency of fire is documented when fire passes through a forest, leaving scars on surviving trees and these scars are precisely dated (Waring and Schlesinger 1985). When fires are frequent, they are confined to the ground surface, killing only very small trees or those with very thin bark. Conversely, when fires burn at less frequent intervals, sufficient fuel accumulates to permit fires to kill nearly all trees (Waring and Schlesinger 1985).

A fire scar is a result of partial cambial death at the base of a tree (Gutsell and Johnson 1996). Gutsell and Johnson described four observations associated with the formation of fire scars on trees: (1) when a fire passes by a tree (either a head or backing fire) it increases in height on the leeward side of the tree (relative to the wind direction); (2) fire scars are found only on the leeward side of trees; (3) small trees rarely have fire scars; and (4) fire scars are usually triangular in shape, becoming narrower with height. Trees survive fire and leeward fire scars form because the cambium is not completely killed around the tree. In most cases the residence time and temperature of the passing flames are high enough to kill the cambium only on the leeward side of the tree (Gutsell and Johnson 1996, Smith and Sutherland 1999, Brown and Sieg 1996). Many researchers have determined dates and frequency of historical fires by analyzing and dendrochronologically crossdating fire scars on trees (e.g. Brown and Sieg 1996, Dieterich and Swetnam 1984, Murray et al. 1998, Tande 1979, Veblen et al. 1999).

One objective of this thesis is to examine the hypothesis that there are some remnant patches in drier lodgepole pine forest that rarely, if ever, burn and have not burned in the last 200-300 years. Evidence of charcoal, burnt stumps and logs and fire scars were used to determine if patches burned. A master tree-ring chronology was constructed to dendrochronologically cross-date fire scarred trees. In addition, pith dates adjusted for coring height were used to determine surrounding forest establishment dates. This type of information is needed to both understand the historical role of fire and to provide land managers with guidelines and justification for prescribed burning (Brown and Sieg 1996).

2.2 METHODS

A description of the study area and the methods used for the sampling of patches can be found in Chapter 1.

2.2.1 Evidence of fire

Within each plot, a visual check for evidence of fire was conducted. I looked for burned logs, fire scars, and charcoal in the soil. Evidence of burned logs and charcoal on the soil surface were important factors in determining that scars present on the trees were in fact from fire. Mountain pine beetle is present in the SBPS zone and often scars left by beetles can be confused with fire scars.

Stuart et al. (1983) reported that in south-central Oregon scars resembling fire scars (wide at the base and tapering up the bole) were formed following recent non-lethal bark beetle attacks. In order to distinguish beetle scars from fire scars the following beetle scar characteristics from Stuart et al. (1983) were considered. Beetle scars may have: (1) bark retention on the face of the scar; (2) spiral scars; (3) beetle emergence holes; (4) blue stain fungus; and (5) mountain pine beetle galleries.

2.2.2 Fire Scars

Criteria used to identify fire scars, taken from Brown and Swetnam (1994), were: (1) substantial cambium mortality; (2) presence of charcoal ring boundary; and (3) ring separations. If fire scars were found, cross-sections of fire scarred trees were extracted from the height that best displayed the fire scars.

Cross sections were taken to overcome the problems inherent when using increment cores, or partial cross sections (Madany et al. 1982). Problems associated with fire scar dendrochronology include considerable variability in ring sequences as a result of distortion caused by proximity to the scarred face. These distortions occasionally obscure the ring patterns and make cross dating with master chronologies difficult (Madany et al. 1982).

The presence of fire scars was an indication that the old patch had experienced a fire that did not kill all of the trees. If no fire scars were visible in the old patch, 3 of the largest trees were felled to obtain cross sections and check for fire scars not visible on the outside of the tree. When fire scars were visible the number of fire scarred trees sampled per site varied between 5 and 7. If possible, fire scars were cut from trees that were dead and on the ground. If scars could not be found on fallen trees, standing trees were felled after obtaining a Free Use Permit from the Ministry of Forests Chilcotin Forest District. A total of 126 trees were sampled, of which 28 were live trees. Choosing trees to sample involved identifying those trees in the stand which: (1) were scarred by fire; (2) were most easily and safely sampled; and (3) exhibited the longest record of historical fire possible (i.e. multiple fire scars and /or total tree age) (e.g. Murray et al. 1998).

In the laboratory, cross-sections were dried and sanded with a belt sander and increasingly finer sandpaper (600 grit) until individual cells could be distinguished. The very fine surface resulting from sanding made it possible to view individual cell walls and also helped in identifying fire scars and determining their location within a given annual ring (Dieterich and Swetnam 1984). Each fire scarred sample was counted and cross-dated with the master chronology to determine the exact year of fire scar occurrence.

2.2.3 Charcoal

Evidence of charcoal was examined by looking at 10 small soil pits in each plot that exposed the surface approximately 20 cm of mineral soil. At each pit the thickness of forest floor was recorded along with the presence or absence of charcoal on the surface or in the soil. Evidence of visibly burnt coarse woody debris was recorded for each plot.

2.2.4 Tree-ring master chronology

Within each plot 10-12 of the dominant and co-dominant lodgepole pine trees were cored at 50 cm above ground to obtain tree age and develop a tree ring chronology. Cores were labeled and stored in drinking straws. In the evening, the cores were dried and mounted with wood glue in wooden core mounts. In plots where other canopy species were present, up to ten individuals of each species were cored to determine tree age.

All pine cores taken were mounted in core trays and sanded using progressively finer sandpaper to 600 grit. Cores were counted to obtain tree age. To develop a master chronology, 40 cores were chosen from all of the cores taken in the remnant plots (approximately 300 cores). Cores for the chronology were selected using the following criteria: (1) length of time tree would contribute to chronology; (2) evidence that the tree was not being influenced by any other factor than climate (i.e. not experiencing suppressed growth due to competition within the stand) (E. Heyerdahl Pers. Comm.); and (3) quality of the core.

Cores selected for the chronology had ring widths measured using a scanner and WIN-DENDRO II software, an automatic tree ring measurement system that uses computerized image processing and analysis techniques (Guay et al. 1992). COFECHA (Grissino-Mayer et al. 1994) was used to statistically crossdate the samples and maintain accuracy in the assignment of calendar years. Cores were also checked visually. Visual recognition of specific patterns of tree rings, such as the 1952-1957-1958 pattern of narrow rings, or the 1923 narrow ring followed by the 1926-1932 rings with thick late wood, were used for cross-dating.

2.2.5 Age vs. Height correction of cores

To determine the number of years for trees to reach coring height (50 cm), site index equations for lodgepole pine in British Columbia were consulted. Hegyi et al. (1979) determined the age of lodgepole pine trees growing on low to good sites. The heights of the trees (Appendix 1) in the remnant patches were used to determine what age correction to apply. Low sites were corrected by 7 years, poor sites by 5 years and medium sites by 4 years.

2.3 RESULTS AND DISCUSSION

2.3.1 Charcoal

Table 3 displays the average forest floor thickness in remnant and matrix plots in each fire. Presence (✓) or absence (×) of charcoal on the soil surface or in the soil or burnt coarse woody debris of the 3 plots per fire is indicated using the first mark for plot 1, the second for plot 2, and the third for plot 3.

Table 3. Evidence of charcoal and burnt CWD.

Plots	Average LFH depth(cm)	Charcoal on soil surface	Charcoal in soil	Burnt CWD
Fire 4 Remnants	2.9	✓✓✓	✓✓✓	✓✓✓
Fire 4 Matrix	2.9	✓✓✓	✓✓✓	×✓✓
Fire 6 Remnants	2.7	✓✓✓	✓✓✓	✓✓✓
Fire 6 Matrix*	3.5	✓✓	✓✓	✓✓
Fire 10 Remnants	2.3	✓✓✓	✓✓✓	✓✓✓
Fire 10 Matrix	2.4	✓✓✓	✓✓✓	✓✓✓
Fire 11 Remnants	1.9	✓✓✓	✓✓✓	✓✓✓
Fire 11 Matrix	2.0	✓✓✓	✓✓✓	✓✓✓
Fire 13 Remnants	4.0	✓✓✓	✓✓✓	✓✓✓
Fire 13 Matrix	2.7	✓✓✓	✓✓✓	✓✓✓
Fire 20 Remnants	3.3	✓✓✓	✓✓✓	✓✓✓
Fire 20 Matrix	2.8	✓✓✓	✓✓✓	✓✓✓
Fire 21 Remnants	3.9	✓✓✓	✓✓✓	✓✓✓
Fire 21 Matrix	2.4	✓✓✓	✓✓✓	✓✓✓
Fire 26 Remnants	2.1	✓✓✓	✓✓✓	✓×✓
Fire 26 Matrix	1.8	✓✓✓	✓✓✓	✓✓✓
Fire 27 Remnants	3.4	✓✓✓	✓✓✓	✓✓×
Fire 27 Matrix	2.6	✓✓✓	✓✓✓	✓✓✓

* Fire 6 has two matrix plots.

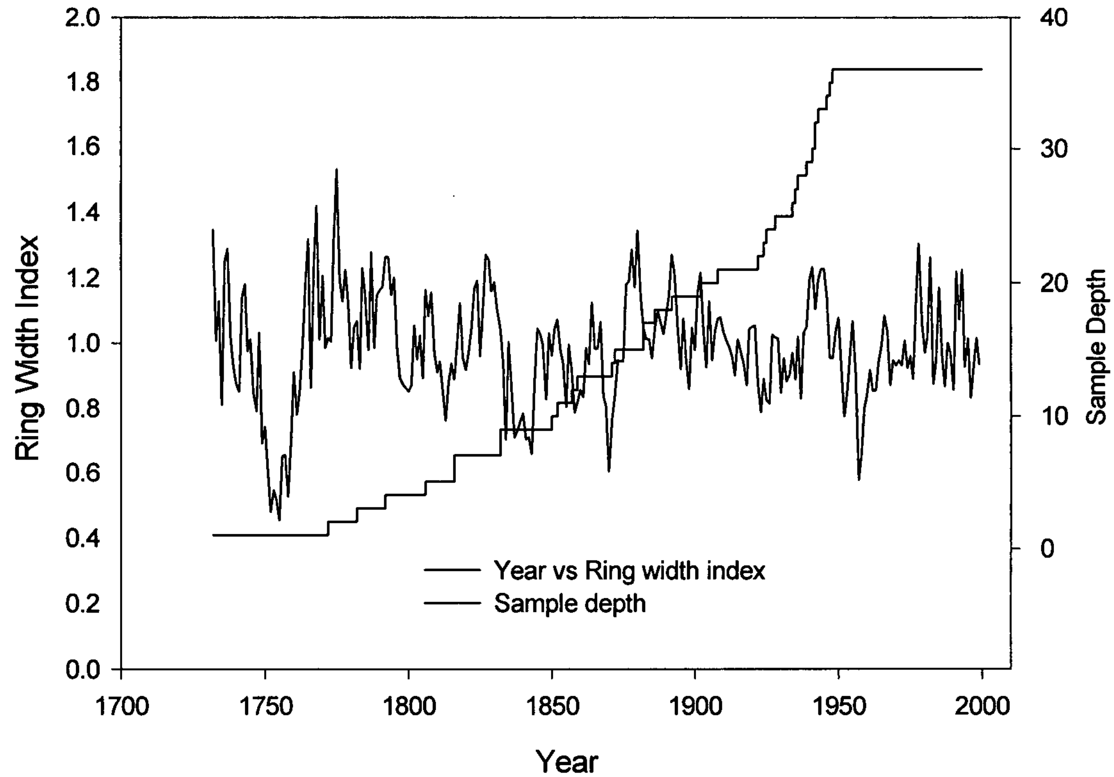
Surface and soil charcoal were found in all remnant patches. Three plots did not have any evidence of burnt CWD within them. One possible reason that these 3 plots did not have any burnt CWD is that the fire did not partially consume any large fuels, so there was no remaining evidence. Any smaller fuels consumed by the fire would be hard to detect approximately 90 years post burn.

2.3.2 Dendrochronology

A 267 year long chronology was built. The sample depth (number of cores spanning the same time period) varied from 1 to 36 cores. Figure 2 shows the master ring width chronology and sample depth. 1923, 1957 and 1958 are 3 easily identifiable pointer years.

For the fire-scared samples, cross-dating confidently identified scars on 113 out of 126 samples. Nine samples could not be dated. Although the master chronology extended back to 1732, between 1732 and 1772 the sample depth is one. This posed a problem when four samples had scars occurring in or close to this time period. These samples could not be confidently cross-dated. Instead samples were assigned a year determined by counting backwards from the last cross-dated ring found on the disc.

Figure 2. Master tree ring chronology with sample depth.



To test the accuracy of my chronology (AL), I compared it to 9 lodgepole pine chronologies (WLP02, WLP03, WLP04, WLP05, WLP06, WLP07, WLP08, WLP09 and WLP13) and a Douglas-fir chronology (WLDF) constructed by Dobry et al. (submitted) in the Williams Lake area.

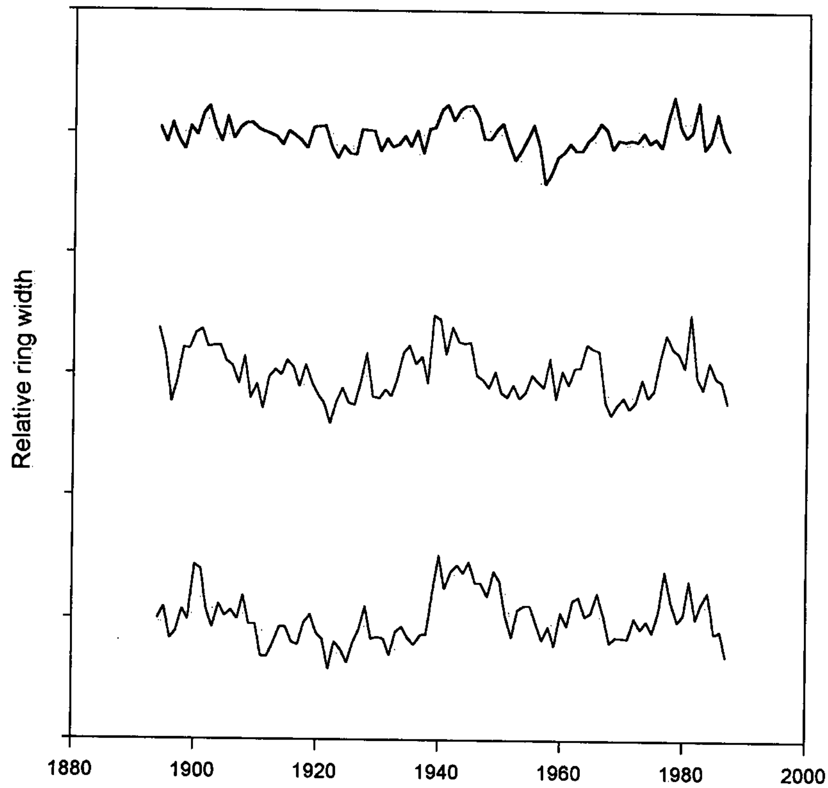
The above standard chronologies were tested for similarity in the period between 1894 and 1988 (n = 95) for which ring widths in all chronologies were available.

Table 4. Matrix of correlation coefficients (p-values in parentheses) of standard chronology tree ring widths between the constructed chronology (AL) and 10 others in the Williams Lake area.

Chronology	WLP02	WLP03	WLP04	WLP05	WLP06	WLP07	WLP08	WLPO9	WLP13	WLDF	AL
WLP02	1.00 (0.00)										
WLP03	0.35 (0.00)	1.00 (0.00)									
WLP04	0.49 (0.00)	0.54 (0.00)	1.00 (0.00)								
WLP05	0.74 (0.00)	0.43 (0.00)	0.65 (0.00)	1.00 (0.00)							
WLP06	0.75 (0.00)	0.23 (0.03)	0.56 (0.00)	0.82 (0.00)	1.00 (0.00)						
WLP07	0.72 (0.00)	0.32 (0.00)	0.50 (0.00)	0.68 (0.00)	0.72 (0.00)	1.00 (0.00)					
WLP08	0.64 (0.00)	0.35 (0.00)	0.71 (0.00)	0.81 (0.00)	0.82 (0.00)	0.74 (0.00)	1.00 (0.00)				
WLP09	0.69 (0.00)	0.33 (0.00)	0.60 (0.00)	0.75 (0.00)	0.82 (0.00)	0.73 (0.00)	0.83 (0.00)	1.00 (0.00)			
WLP13	0.61 (0.00)	0.22 (0.04)	0.18 (0.07)	0.51 (0.00)	0.61 (0.00)	0.47 (0.00)	0.45 (0.00)	0.50 (0.00)	1.00 (0.00)		
WLDF	0.57 (0.00)	0.22 (0.03)	0.33 (0.00)	0.53 (0.00)	0.60 (0.00)	0.46 (0.00)	0.48 (0.00)	0.41 (0.00)	0.53 (0.00)	1.00 (0.00)	
AL	0.30 (0.00)	0.19 (0.07)	0.16 (0.13)	0.39 (0.00)	0.26 (0.01)	0.49 (0.00)	0.33 (0.00)	0.31 (0.00)	0.27 (0.00)	0.13 (0.21)	1.00 (0.00)

The AL chronology was most similar to the WLP07 (r = 0.49) and WLP05 (r = 0.39). . Figure 3 is a graphical comparison of the AL, WLP07 and WLP05 chronologies. Although the r-values were quite small, the WL chronologies came from plots over 300 km away, in the Interior Douglas-fir biogeoclimatic zone – a warmer zone than the SBPS. Individual site variation inherent in each of the individual chronologies may also contribute to low r-values.

Figure 3. Comparison of similar chronologies.



Top series: AL chronology constructed in this study
Middle series: WLP05 chronology constructed by Dobry et al (submitted)
Bottom series: WLP07 chronology constructed by Dobry et al (submitted)

Marker years with particularly narrow rings, common to all 3 chronologies were 1923, 1957, and 1958. The wide ring of 1982 was also present in all three.

2.3.3 Fire history

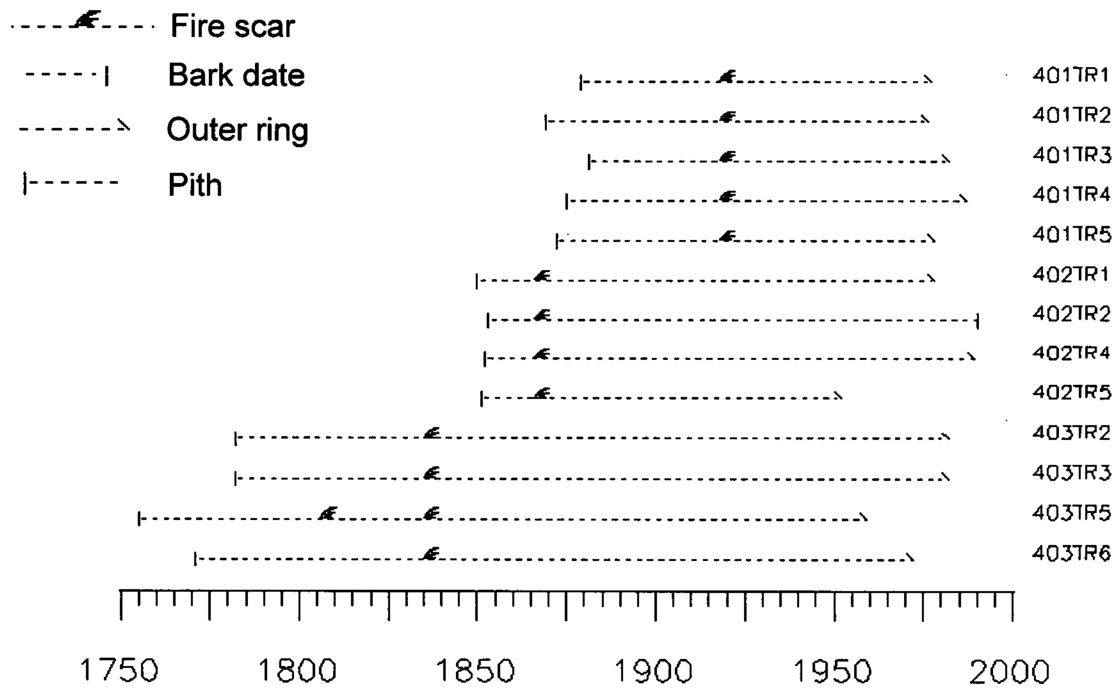
Twenty-six plots were established in remnant patches. One plot in Fire 6 was mistakenly established as a remnant patch. Examination of tree cores determined the plot to be part of the matrix forest. Twenty-four of 26 patches were found to have been burned by the most recent fire in such a way that not all of the trees were killed. To determine the dates of the fires in each patch, 113 fire scars were cross-dated. Outer ring dates on samples ranged from 1945 (remnant sample) to 1999 (live sample).

Figure 4 shows the fire chronologies of each fire sampled. Diagrams were created using Grissino-Mayer's (2000) FHX2 – software for the analysis of fire history from tree rings. Seven of the 9 fires had patches containing fire scars whose dates matched the initiation date of the surrounding matrix forest. Fire 4 and Fire 27 had patches that did not record the fire that initiated the matrix forest. Samples taken from two of the plots in Fire 4 did not record the most recent fire.

Remnant patches surrounded by the same forest matrix but with different fire scar dates (each remnant within the same matrix had a different fire scar date) can be explained. Fire scar analysis is not exact, as every fire may not scar a sampled tree, and a previous fire scar may be lost from subsequent fires or by weathering (Brown and Swetnam 1994; Brown and Sieg 1996). Each fire creates a new vegetation disturbance "patch" or "patches" that overlay previous vegetation "patches" (Everett *et al.* 2000). Scars in lodgepole pine forests may be found in remnant patches that have survived more than one stand replacing fire. A scar may represent a surface fire of very small extent that did not significantly affect either the remnant patch or the matrix (Kipfmueller and Baker 1998). Since most samples were taken from trees that were on the ground, these trees could be remaining from previous fires and were not scared by the most recent fire. Similarly, remnant sample trees may have actually been killed by the most recent fire and outer rings removed by decomposition. Remnant sample trees may have also died from old age, insect attack or disease.

Figure 4a. Fire chronology of trees within remnant patches of Fire 4.

ring



Fire chronology of trees sampled within each patch. 4O1TR1, for example, is the first tree (TR1) sampled from Fire 4 in the first remnant patch (O1) examined.

Figure 4b. Fire chronology of trees within remnant patches of Fire 6.

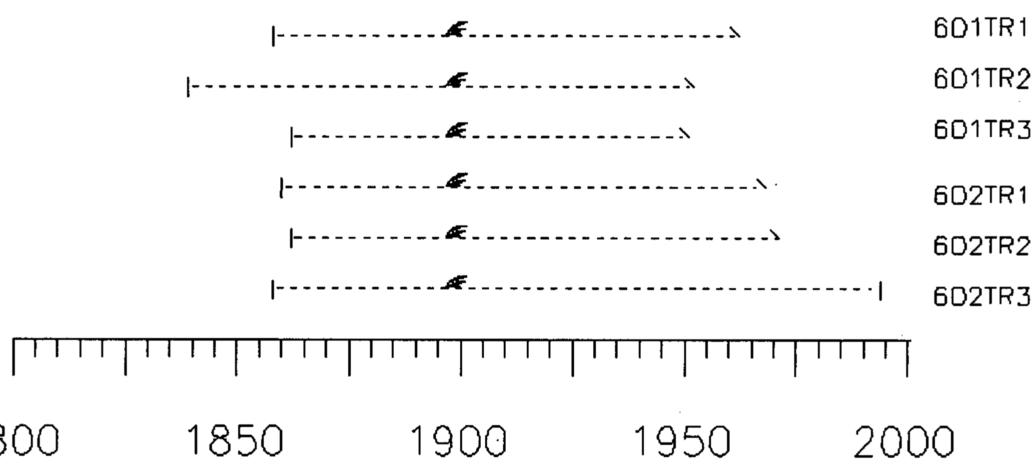


Figure 4c. Fire chronology of trees within remnant patches of Fire 10.

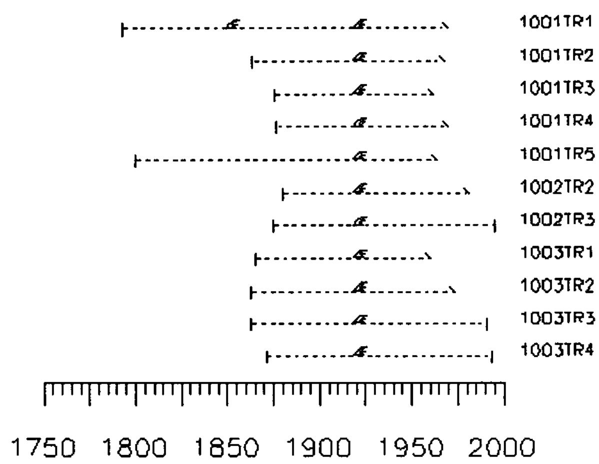


Figure 4d. Fire chronology of trees within remnant patches of Fire 11.

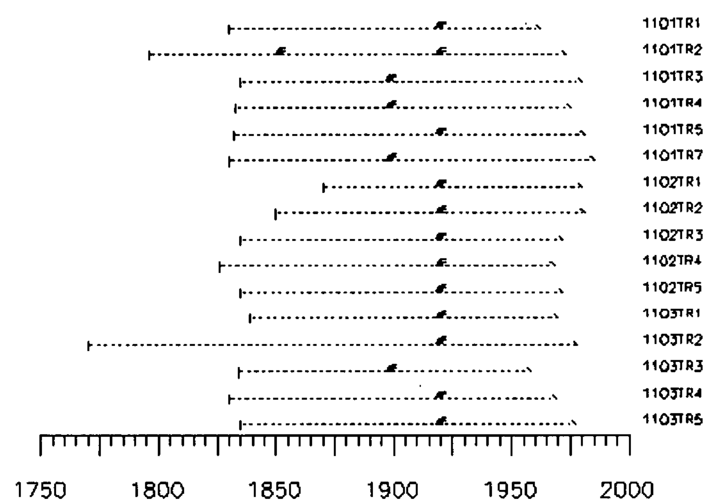


Figure 4e. Fire chronology of trees within remnant patches of Fire 13.

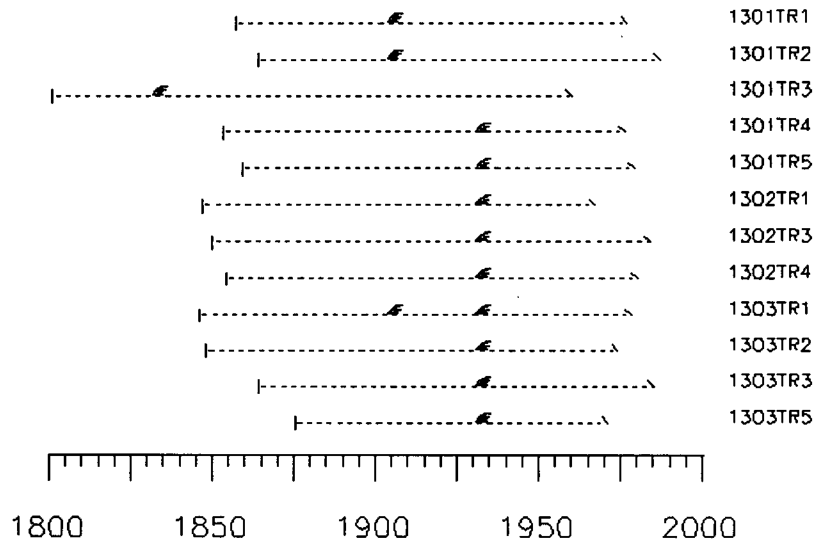


Figure 4f. Fire chronology of trees within remnant patches of Fire 20.

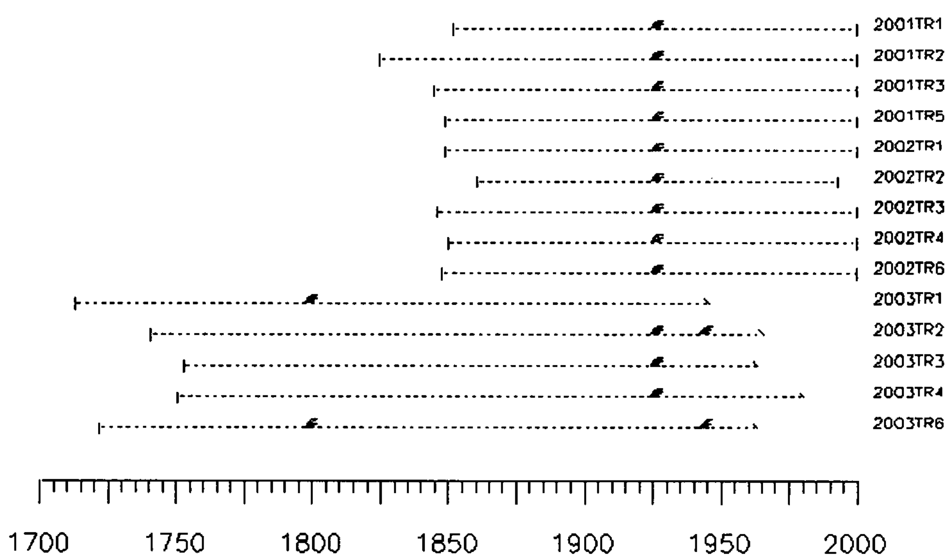


Figure 4g. Fire chronology of trees within remnant patches of Fire 21.

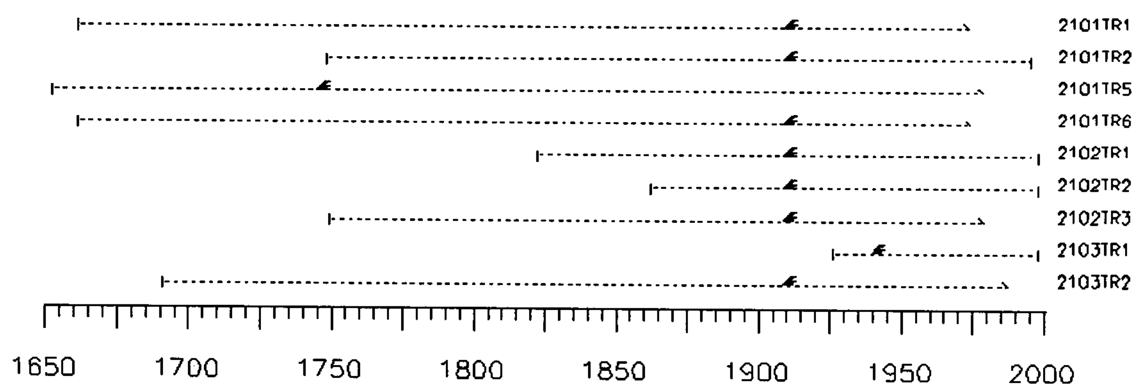


Figure 4h. Fire chronology of trees within remnant patches of Fire 26.

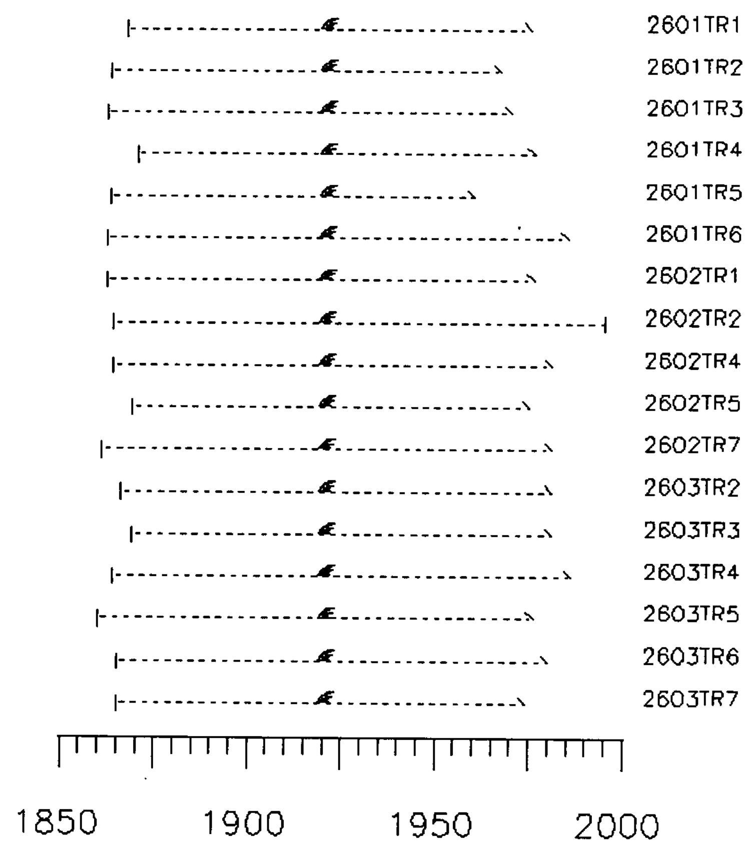
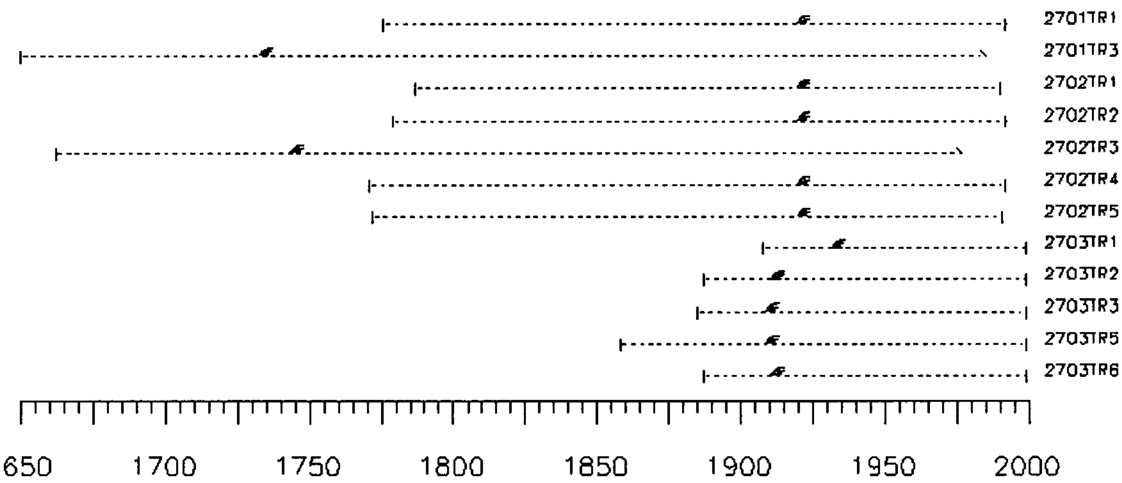


Figure 4i. Fire chronology of trees within remnant patches of Fire 27.



2.3.4 Initiation of forest matrix

Plots established in the forest matrix had tree cores taken to determine forest age and approximate year of stand initiation. It was found that generally the surrounding forest started growing between 0 and 10 years after a fire had been recorded in a remnant patch. Barth (1970) noted that in lodgepole pine forests, seedlings typically become established the year after the fire. Alternatively, Nyland (1998) found that following the Yellowstone National Park fires in 1988, some plots had no seedlings 8 years after the fires. He commented that since lodgepole pine seedlings succumb so readily to interference and competition to grasses, many seedlings that initiate on dominantly herbaceous micro-sites may not survive beyond early seedling stages. Tande (1979) found that lodgepole pine in Jasper National Park established on recently burned areas 1-20 years after a fire, averaging 4 years. Results of this study (establishment 0-10 years after fire) are within the ranges reported in the literature.

Table 5. Fire scar dates determined within each patch. Sample depth is the number of samples recording the same fire scar date.

Fire	Patch	Sample Pith Dates (range)	Fire Scar (dates)	Sample Depth	Estimated Matrix Initiation Year
4	1	1869-1881	1920	5	
	2	1850-1853	1868	4	1929
	3	1755-1782	1837	4	
6	1	1839-1862	1899	3	1908
	2	1858-1862	1899	3	
10	1	1793-1877	1922	5	
	2	1875-1880	1922	2	1922**
	3	1863-1871	1922	4	
11	1	1796-1835	1899, 1920	3,3	
	2	1826-1870	1920	5	1925
	3	1770-1839	1899, 1920	1,4	
13	1	1799-1862	1832, 1904, 1931	1,2,2	
	2	1845-1852	1931	3	1931**
	3	1844-1873	1904, 1931	1,4	
20	1	1824-1851	1926	4	
	2	1845-1860	1926	5	1926
	3	1712-1752	1799*, 1926, 1944	2,3,2	
21	1	1653-1749	1748*, 1912	1,3	
	2	1750-1863	1912	3	1916
	3	1692-1927	1912, 1943	1,1	
26	1	1862-1870	1921	6	
	2	1861-1869	1921	5	1922
	3	1860-1869	1921	6	
27	1	1650-1776	1735*, 1922	1,1	
	2	1662-1787	1746*, 1922	1,4	1912
	3	1858-1908	1911, 1913, 1934	2,2,1	

* indicates samples in which scar years were not dendrochronologically cross-dated.
**indicates the estimated matrix initiation year was overestimated by the height correction (see text).

Table 5 summarizes the fire scar years and estimated year of stand initiation for each fire. The estimated height correction was added to the age of the oldest tree cored in the surrounding matrix forest plots. In two of the fires (Fire 10 and Fire 13) the estimated year of stand initiation was calculated to be prior the fire. Fire 10 was calculated to have initiated in 1919, 3 years prior to the fire in 1922, and Fire 13 was calculated to have initiated in 1929, 2 years prior to the fire in 1931. At these two sites it is possible that cores taken from the trees may have mistakenly been taken below 50 cm, causing the 50 cm height correction to be incorrectly applied. Alternatively, or in addition, the tree heights used to determine the height correction may have been measured incorrectly, again causing the incorrect height correction to be applied.

2.4 CONCLUSION

Dendrochronological dating techniques supplemented with stand origin data determined the fire years in each remnant patch. The hypothesis that there are some remnant patches of lodgepole pine forest that rarely, if ever, burn and have not burned in the last 200-300 years was found to be false for the SBPSxc subzone. All patches had been burned by past fires. Twenty four of the 26 patches were burned by the most recent fire after which the matrix forest was established. The other two patches were burned by a previous fire, but not the one that caused the initiation of the matrix. This discovery provides a reference point for developing and conducting prescribed burning programs aimed at emulating natural occurrence. There are patches of forest that burn, but not as severely as the matrix. The following chapter explores the possible differences between the matrix forest and the remnant patches.

3.0 REMNANT PATCH CHARACTERISTICS

3.1 INTRODUCTION

Natural disturbances maintain plant and animal diversity over time and space by maintaining structural complexity within stands, and by influencing the size, distribution, edge characteristics, and dispersion of stands across the landscape. An understanding of how the forested landscape was affected by natural disturbance is needed to develop alternative management systems that more closely approximate natural disturbances and their effects (DeLong 1998).

Although stand-replacing fires dominate in sub-boreal ecosystems, burned landscapes typically contain patches of forest that did not burn (Delong and Kessler 2000). Several authors have hypothesized why remnant patches occur on the landscape. Hornberg et al. (1998) speculated that swamp forests in boreal Sweden have escaped fire because they were situated in lowlands, where the risk of ignition by lightning is low and where wet conditions make the build-up of fuels less important than in drier sites. They also noted that the occurrence of species less susceptible to fire may further reduce the likelihood of fire. Foster (1983) studied fire patterns in the boreal forest of southern Labrador. He found that remnants tended to form downwind of fuelbreaks such as lakes, streams and peatlands.

Fuel characteristics have also been examined. Snyder (1984) discussed Mutch's (1970) hypothesis that communities that burn readily or frequently were more flammable than communities that do not. Sylvester and Wein (1981) studied fuel characteristics of arctic plants and found that some plant communities may not burn because the species present did not favour being burned.

Van Wilgen et al. (1990) studied the role of vegetation structure and fuel chemistry in excluding fire from forest patches in the fynbos shrublands of South Africa. They postulated that the inability of some forest patches to burn could be due to one or more of the following factors: (1) a higher moisture content in the live foliage of forest trees when compared to fynbos shrubs and herbs; (2) a higher portion of crude fats in fynbos compared to forest plants; (3) higher heat yields in fynbos than in forest plants; and (5) differences in the packing ratios of plant (fuel) parts, and the ratio of live to dead material.

Recently, Delong and Kessler (2000) characterized remnant forest patches in successional sub-boreal landscapes and compared them to matrix forest in young, mature and old age classes. They determined that remnant patches could be discriminated from matrix forest types based on variables relating to tree overstory and snag density.

The objective of this chapter is to examine the hypothesis that remnant patches of lodgepole pine in the SBPSxc have some characteristic(s) that cause(s) them not to burn as frequently as the surrounding forest. Topographic features, soil moisture, overstory forest structure and fuels were examined.

3.2 METHODS AND ANALYSIS

A description of the study area and the methods used for the sampling of patches can be found in Chapter 1.

3.2.1 Topographic Features

In each plot, elevation, slope and aspect were measured. Elevation was measured with an altimeter calibrated each day at the Anahim Lake airport. Slope was measured in percent with a clinometer. Aspect was measured in degrees with a compass and divided into four categories (Table 6).

Table 6. Aspect categories based on compass degrees.

Aspect Category	Degrees
North	> 315, ≤ 45
East	> 45, ≤ 135
South	> 135, ≤ 225
West	> 225, ≤ 315

Analysis of variance (ANOVA) was used to test for significant differences in elevation and slope between the remnant and matrix plots.

Significant differences in aspect between remnant and matrix plots were determined using Chi-squared (X^2) independence tests (Bluman 1997):

$$X^2 = \sum (O-E)^2/E \qquad [1]$$

Where: O = observed frequency, and E = expected frequency. The calculated test statistic was compared to a critical X^2 value ($\alpha = 0.05$) with (rows-1)(columns-1) degrees of freedom.

3.2.2 Soil Moisture

Soil moisture was selected as the edaphic characteristic to be examined in this study. Hornberg et al. (1998),Foster (1983) and Spence et al. (1999) all suggested that wetter sites are less likely to burn.

Soil moisture regime (SMR) refers to the average annual amount of soil water available to plants (Green and Klinka 1994). An estimate of relative SMR was inferred from selected physiographic and soil features. The key to relative SMR from the Field Guide to Forest Site Identification and Interpretation for the Cariboo Forest Region (Steen and Coupe 1997) was used.

Significant differences in relative SMR between remnant and matrix plots were also determined using a X^2 independence test and displayed in a contingency table.

3.2.3 Overstory Forest Structure/Stand Reconstruction

In order to determine if stand structure could explain why a remnant patch experienced a fire that did not kill all the trees, several stand characteristics were measured. Within each remnant and matrix plot the species and diameter at breast height (dbh) of all standing trees were recorded to the nearest tenth of a centimeter. In remnant plots, the dbh's of fallen trees (trees on the ground) were also recorded. Depending on the amount of disintegration and the year of the most recent fire, fallen trees were either assumed to have died as a result of the most recent fire or died prior to the fire. Heavily disintegrated trees with evidence of fire consumption were assumed to have been on the ground at the time of fire, and therefore not part of the overstory stand structure at the time

To recreate an approximation of each remnant plot at the time of the most recent fire, diameters of standing overstory trees were reduced by their post-fire radial growth (x 2 = diameter), measured on increment cores (e.g. Arno et al. 1995). Diameters of fallen trees assumed to be standing at the time of the most recent fire were reduced in the same way.

The ages of each remnant patch at the time of the most recent fire varied. As a result, the ages of the remnant patches at the time of the most recent fire were classified into the following categories: (1) 50-years-old at the time of fire; (2) 85-years-old at the time of the fire; and (3) 150+-years-old at the time of the fire.

Remnant patches in each age category were compared to a random sample of 10 plots in nearby forest of the same age in order to determine if stand tree density or basal area may have been a characteristic that caused the remnant patches to remain after the fire. For example, 9 remnant patches were determined to have burned when they were approximately 50 years old. These plots were compared to 10 plots randomly located across the landscape in forest that was approximately 50 years old in 1999. These 10 plots were established to represent the "average" 50-year-old forest. It was assumed that stands 50 years old in 1999 could be used to represent stands that were 50 years old prior to 1999.

Tree density (trees/ha) and basal area (m^2/ha) were calculated to compare remnant patches to the "average" forest. T-tests were used to test for significant differences between remnant plots and the "average" forest in each category.

3.2.4 Crown Fuels

The results of chapter two indicate that all of the remnant patches did burn in a previous fire and that the majority (24 out of 26) of the remnant patches in this study did burn in the most recent fire However, all of the trees within the remnants were not killed by the fire. If it is assumed that the most recent fire, the fire causing the stand initiation of the matrix forest , was a crown fire, then lower crown fuels in the patches might explain why tree mortality in the patches was less.

Van Wagner (1977) described how fire spreads through a fuel layer as the basic heat balance linking rate of spread, *R*, with the fuel bulk density, *d*, the heat of ignition, *h*, and the net horizontal heat flux, *E*, into the unburned fuel ahead of the fire:

$$R = E/dh \qquad [2]$$

Van Wagner (1977) described [2] as follows: *d* and *h* refer to the effective crown fuel (primarily live foliage) and to the whole crown space, not just the individual tree crown volumes. *E* is the required heat flux that must be supplied to the crown fuel at the specified values of *R*, *d*, and *h* and is designated E_0 when used in this critical sense. E_0 depends on *d*, while *h* is approximately a constant. Therefore when estimating fuels the main variable is d, fuel bulk density.

Other criteria are needed that specify limits on *R* and *d* because the crown spread process must fail if either *R* or *d* falls below a certain practical level. Two additional equations that limit horizontal heat flux and surface intensity can be found in Van Wagner (1977).

Three different classes of crown fire have been identified and each is classified according to the degree of dependence on the surface fire phase. An intermittent crown fire burns when the surface fire intensity reaches a critical point where the crowns begin to burn. A dependent crown fire is one in which the crown fire remains completely dependent on the surface fire to burn and the crown fire rate of spread is limited by the surface fire rate of spread. Dependent crown fires occur when both the critical surface intensity and critical spread rates are reached. In this case the crown phase supplies all of its own fuel but depends on the surface phase for a part of its ignition energy. The surface and crown phases of fire spread at the same rate in a dependent crown fire. The final type of crown fire is an independent crown fire. This is where the crown phase no longer depends on the surface phase and can run ahead on its own (Van Wagner 1977). Critical surface intensity and critical rate of spread are both exceeded and the heat flux is supplied entirely by the crown phase. This phase of crown fire propagation is speculated to occur as a result of wind combined with stand conditions with a continuous crown layer of low to moderate bulk density and an abnormally low foliar moisture content (Van Wagner 1977).

Bulk Density

Van Wagner (1977) described the crown fuel as a uniform layer of bulk density (kg/m^3) at some height above ground. Foliar bulk density was selected for examination in this study as Van Wagner (1977) used foliar bulk density as an estimator of crown fuels. To calculate foliar bulk density you must determine the foliage mass (kg) and know the depth of the tree canopy layer (m).

$$\text{Foliar bulk density} = \text{foliage mass/canopy volume} \quad [3]$$

$$\text{Canopy volume} = \text{depth of tree canopy} \times \text{area} \quad [4]$$

In order to compare the remnant patch crown fuels to those of the "average" forest of the same age, "fuel" plots were established. "Fuel" plots were established in stands that had a tree density and average age similar to those of the remnant patches at the time of the most recent fire. These plots were used to represent the crown fuels in the remnant patches at the time of the most recent fire. Three "fuel" plots were established in 50-year-old forest and 3 in 85-year-old forest. Four "fuel" plots were established in 150+-year-old forest.

Within each "fuel" plot the dbh of each tree was recorded. The depth of the tree canopy was determined by measuring the top height of three co-dominant trees and the height of the canopy above the ground. Foliar bulk density was calculated using equation [3]. Foliage mass was calculated using a foliage mass equation [5] developed by Blackwell (1989) for lodgepole pine in west central British Columbia:

$$\ln(\text{biomass of foliage}) = -4.664 + 2.216 \ln(D) \qquad [5]$$

where: D = the diameter at breast height (cm).

Surface Fuels

The focus of the above discussion is primarily based on crown fuels and crown fire propagation. This discussion would not be complete without addressing surface fuels. Surface fuels, as described in section 1.4.3, are where most wildland fires are ignited. Two of the three crown fire phases discussed above rely on surface fires (which burn surface fuels) for propagation, and thus their examination would appear to be very relevant.

Surface fuels were not examined in this study because it was not possible to know what the understory structure and surface coarse woody debris composition of the remnant patches was at the time of the fire. It was assumed that since most of the remnant patches had a surface fire at the time of the most recent fire, surface fuels (and understory) present in the patches in 1999 were not representative of the surface fuels present at the time of the most recent fire.

Surface fuels in "fuel" plots could not be used an estimator of surface fuels at the time of the most recent fire because the "fuel" plots were not examined for previous fire history. In order to estimate surface fuels it would be necessary to find plots the same age and density as the remnants at the time of the fire, which had no previous fire history. This was not feasible with the amount of resources available for this project. Additionally, 9 of the 26 remnant patches sampled had burned in a previous fire, prior to the most recent fire, as well as during the most recent fire (Table 3). It would not be possible to estimate the amount of surface fuels remaining after each fire.

3.2.5 Statistical analysis

Before any data can be used in parametric statistical analysis, it must meet certain assumptions (Zar 1984). In particular, data sets must: (1) be random; (2) be normally distributed; and (2) have homogeneous variances (Sokal and Rohlf 1995). Plot locations for this study were selected as described in section 1.6. To meet the criterion of normally distributed data points, distribution histograms, probability plots and skewness (one tail of curve is drawn out more than the other) and kurtosis (proportion of data found in the centre and in the tails in relation to those in the shoulders) were examined.

Where generated, model residuals were examined for homogeneity of variances. *F*-tests were used to test whether samples were homoscedastic prior to testing differences between means (Sokal and Rohlf 1995).

In some instances data transformation had to be performed to meet the assumptions. In particular the tree density data in all 50-year-old plots (stand reconstructed, "average" and "fuel") and 85-years-old plots were logarithmically transformed. Slope data was also logarithmically transformed to meet assumptions.

All statistical analyses were completed with SYSTAT ver. 9.0.1 (SPSS Inc. 1999a, 1999b) or a student version of Minitab rel. 9.5 (MINITAB 1995). Graphs were produced with Sigmaplot 2000.

3.3 RESULTS AND DISCUSSION

3.3.1 Topographic Features

ANOVA of elevation and slope indicated that there was no significant difference in elevation (α=0.05, P= 0.980) or slope (α=0.05, P=0.127) between remnant patches and the matrix forest in the study area.

Aspect accounted for no differences between remnant patches and matrix forest (α=0.05, X^2=7.369, CV= 9.488) (Table 7).

Table 7. Aspect contingency table. Expected frequency values are in parentheses.

Aspect	No Aspect	North	East	South	West	Total
Remnant Plots	6 (9)	7 (4)	2 (3)	3 (3)	8 (7)	26
Matrix Plots	12 (9)	1 (4)	5 (4)	3 (3)	6 (7)	27
Sum	18	8	7	6	14	53

Kushla and Ripple (1997) examined the role of terrain in a fire mosaic of a temperate coniferous forest. They found that ridgeline proximity was more effective in explaining live canopy ratio (LCR), the ratio of living canopy cover surviving the wildfire, to that before the burn, than elevation or proximity to streams. Those areas with greatest LCR had northern, or northeastern aspects and lower slopes, whereas those areas that burned intensely had western or southwestern aspects and steeper slopes (Kushla and Ripple 1997).

The study area in Kushla and Ripple (1997) included portions of the Western Cascades (elevations 500-1500 m) and the High Cascades (elevations over 1500 m), where the topography is rugged. The combination of slope and aspect is possibly one reason this study's findings differed from Kushla and Ripple (1997). Slope steepness affects solar radiation intensity, fine fuel moisture, as well as fire behavior. Slopes within remnant patches examined in this study were not very pronounced and averaged 5% (Table 2).

3.3.2 Soil Moisture

Chi square contingency analysis found no significant difference (α=0.05, X^2=2.352, CV=7.815) between the soil moisture regime of the remnant patches and the soil moisture regime of the matrix forest. Relative soil moisture regimes in study plots ranged between 1 and 4. These translate to actual soil moisture regimes of between extremely dry and moderately dry.

Table 8. Relative soil moisture regime contingency table with expected values in parentheses.

SMR	1	2	3	4	Total
Remnant Plots	1 (0)	14 (16)	6 (5)	5 (4)	26
Matrix Plots	0 (1)	19 (17)	5 (6)	3 (4)	27
Sum	1	33	11	8	53

Quirk and Sykes (1971) found that unburned patches of 200-year-old spruce occurred in slight depressions having higher soil moisture than the adjacent 34-year-old stand that had originated in fires. Spence et al. (1999) suggested that the location of fire skips, in the western boreal forest of Canada, is not random and that the largest skips generally occupy wetter microsites.

Differences between findings in this study and the literature are likely due to the climate of the area. The SBPSxc is classified as such because it is a very dry (x) subzone. For example, in the ESSFwk, a wet cool subzone, relative soil moisture regimes between 1 and 4 translate to actual soil moisture regimes of moderately dry (1) to moist (4). Wetter microsites in the SBPSxc are generally small and localized. They occur primarily at the fringe of wetlands and along stream channels (Steen and Coupe 1997). It is possible that even the wetter areas in the SBPSxc are dry enough to sustain fire.

3.3.3 Tree Size Class Reconstruction

Analysis of each of the age categories determined there to be significant differences (α=0.05) between the density and basal area of the remnant patches and those of the "average" forest at the time of the last fire (Tables 9 and 10).

Table 9. Means and standard deviations (in parentheses) for tree density (stems/ha) at the time of the last fire in remnant patches and the "average" forest in each age class and p values from t-tests.

Age of remnant when burned	Remnant patches	"Average" forest	p
50 years (tree density)	419 (222)*	5217 (1776)*	0.0000
85 years (tree density)	547 (251)*	2975 (689)*	0.0000
150+ years (tree density)	515 (200)	1434 (462)	0.0002

*indicates data that were $\log_{10}$ transformed for analysis, back transformed values are displayed in the table.

Table 10. Means and standard deviations (in parentheses) for basal area (m^2/ha) at the time of the last fire in remnant patches and the "average" forest in each age class and p values from t-tests.

Age of remnant when burned	Remnant patches	"Average" forest	p
50 years (basal area)	2.33 (3.04)	11.53 (1.78)	0.0000
85 years (basal area)	2.30 (1.31)	10.44 (1.24)	0.0000
150+ years (basal area)	5.59 (3.22)	13.27 (4.27)	0.0023

The differences in overstory stand attributes of remnant patches may be derived from the fire events that created the patches. Lower tree density in remnant patches may reflect stem mortality that occurred during the fire (Delong and Kessler 2000).

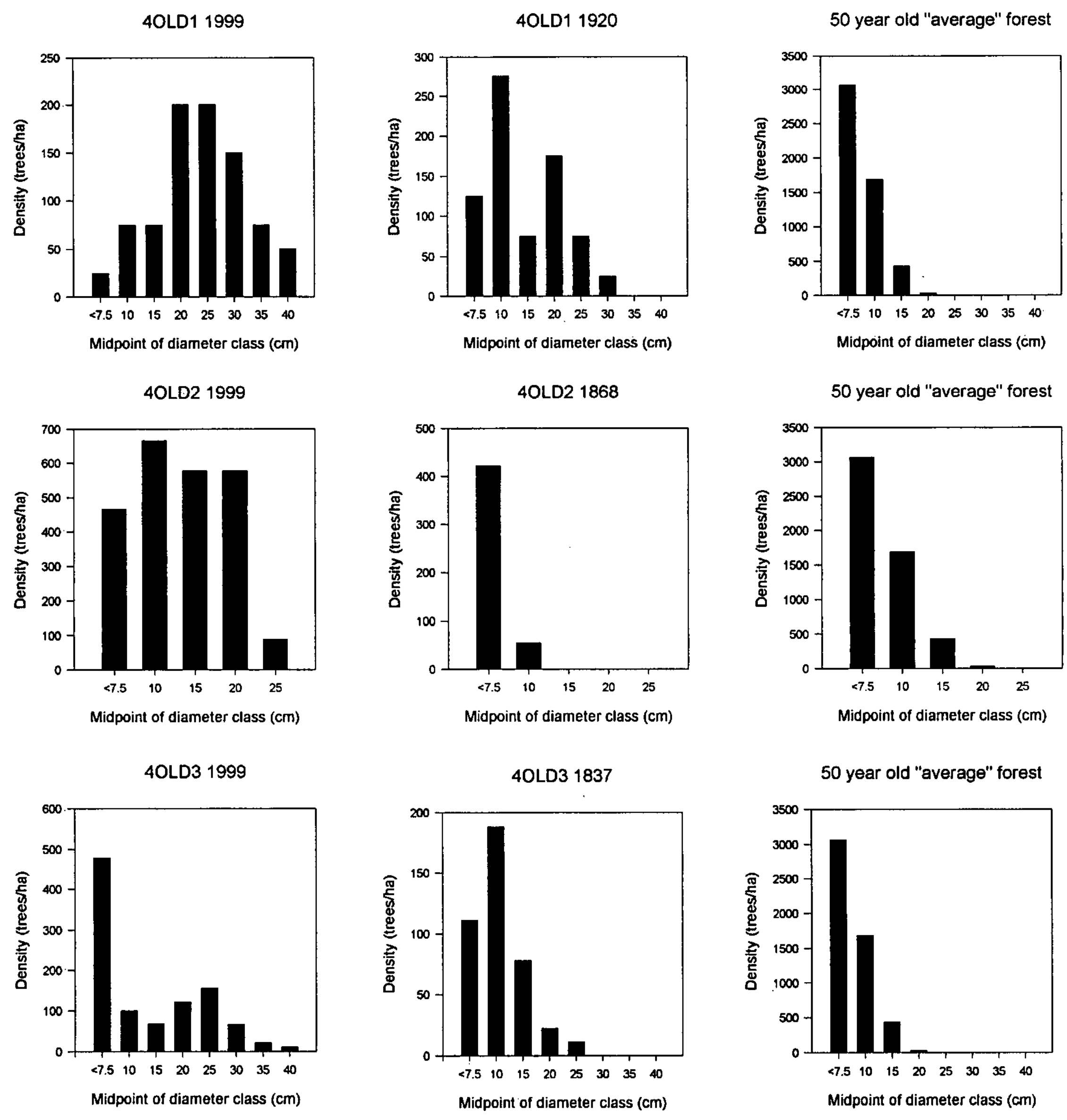
Retrospective studies, such as this one, have difficulties determining the pre-fire conditions of the remnant patches.

Figures 5a-i provide a visual comparison of tree size class distributions in each plot as estimated for the year of the most recent fire and as measured in 1999. The fire year estimate does not include small trees that may have been present, but died afterwards as a result of various agents (Arno et al. 1995). The fire year tree number estimates are minimums because there were probably more trees present at the time of the fire that were subsequently killed by the fire. What is displayed in the graphs is the size class distributions of trees remaining after the fire. Each graph is labeled in the following manner:

Fire number-OLD- Plot number Year

where: fire number is the fire in which the plot was established; OLD was the label given to remnant plots; and the last number represents the plot number, whether the plot was the first (1), second (2) or third (3) patch sampled within the fire; and the year is the year in which the graphed stand structure was present. Size class distributions labeled 1999 were the distributions existing in 1999 when the actual measurements were made; distributions in other years (fire years) were estimated from reconstructions. Size class distributions for the year of the most recent fire are placed next to the "average" determined for a forest of a similar age to that of the forest in the remnant plot when the last recent fire occurred.

Figure 5a. Tree size class distribution in remnant patches in Fire 4 in 1999 and the year of the most recent fire recorded in the patch.



50 year old "average" forest is compared to each of these remnant patches because 4OLD1, 4OLD2 and 4OLD3 were approximately 50 years old at the time of the most recent fires in 1920, 1868 and 1837 respectively.

Figure 5b. Tree size class distribution in remnant patches in Fire 6 in 1999 and the year of the most recent fire recorded in the patch.

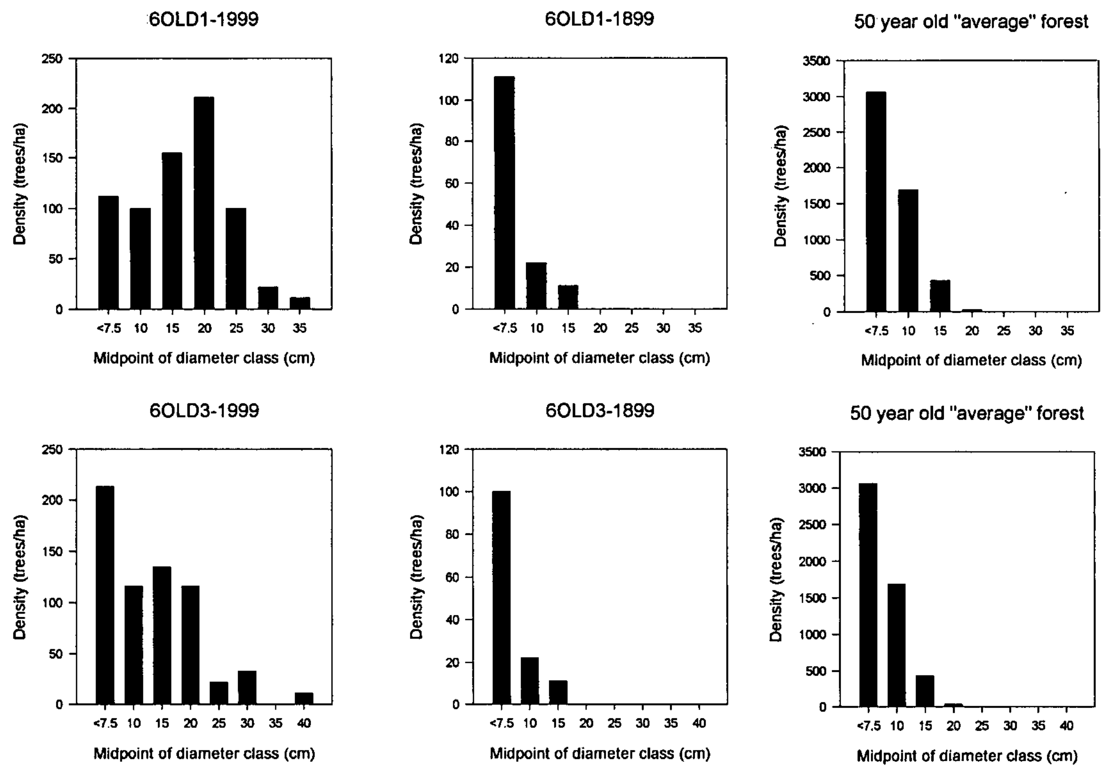


Figure 5c. Tree size class distribution in remnant patches in Fire 10 in 1999 and the year of the most recent fire recorded in the patch.

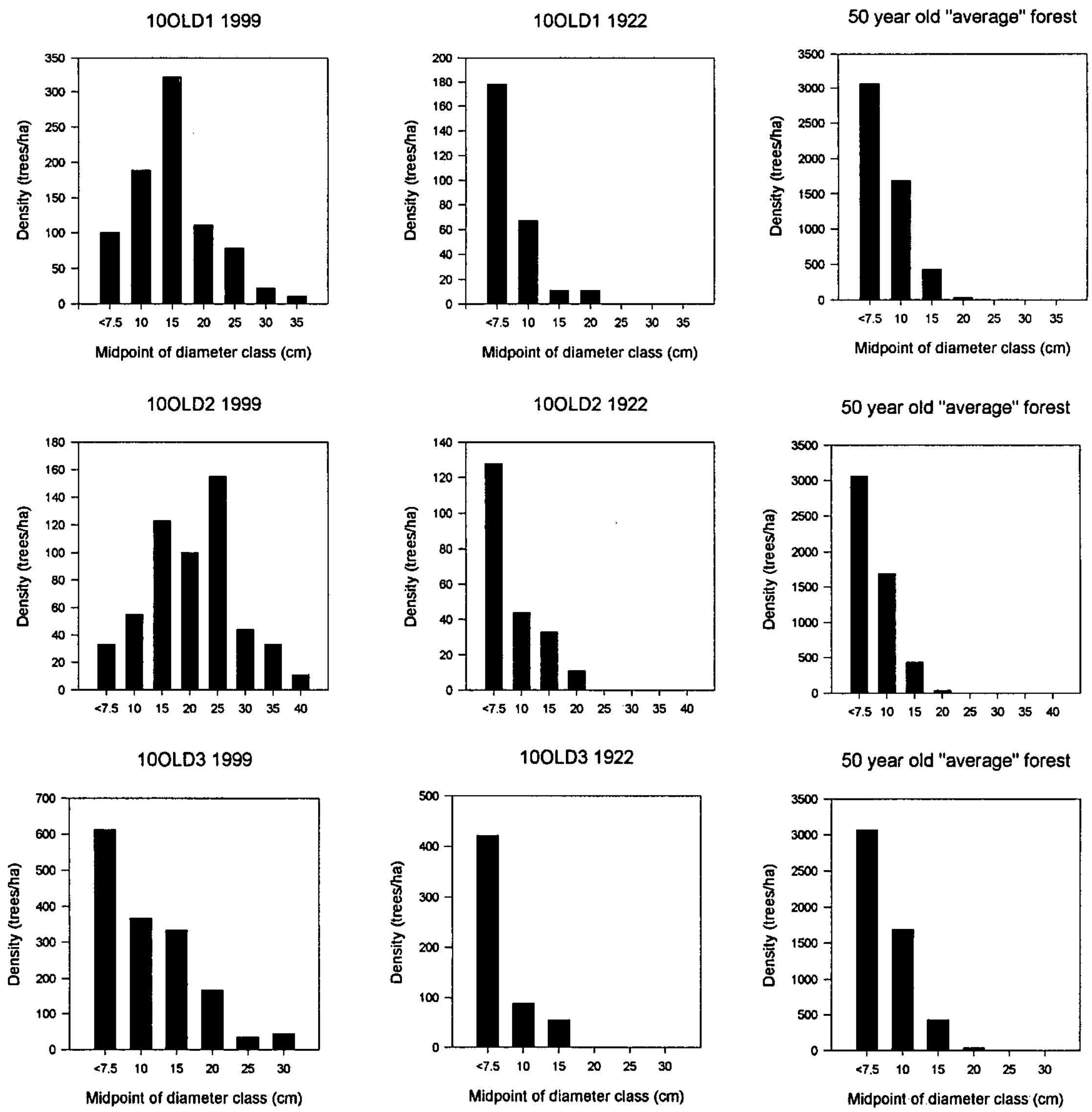


Figure 5d. Tree size class distribution in remnant patches in Fire 11 in 1999 and the year of the most recent fire recorded in the patch.

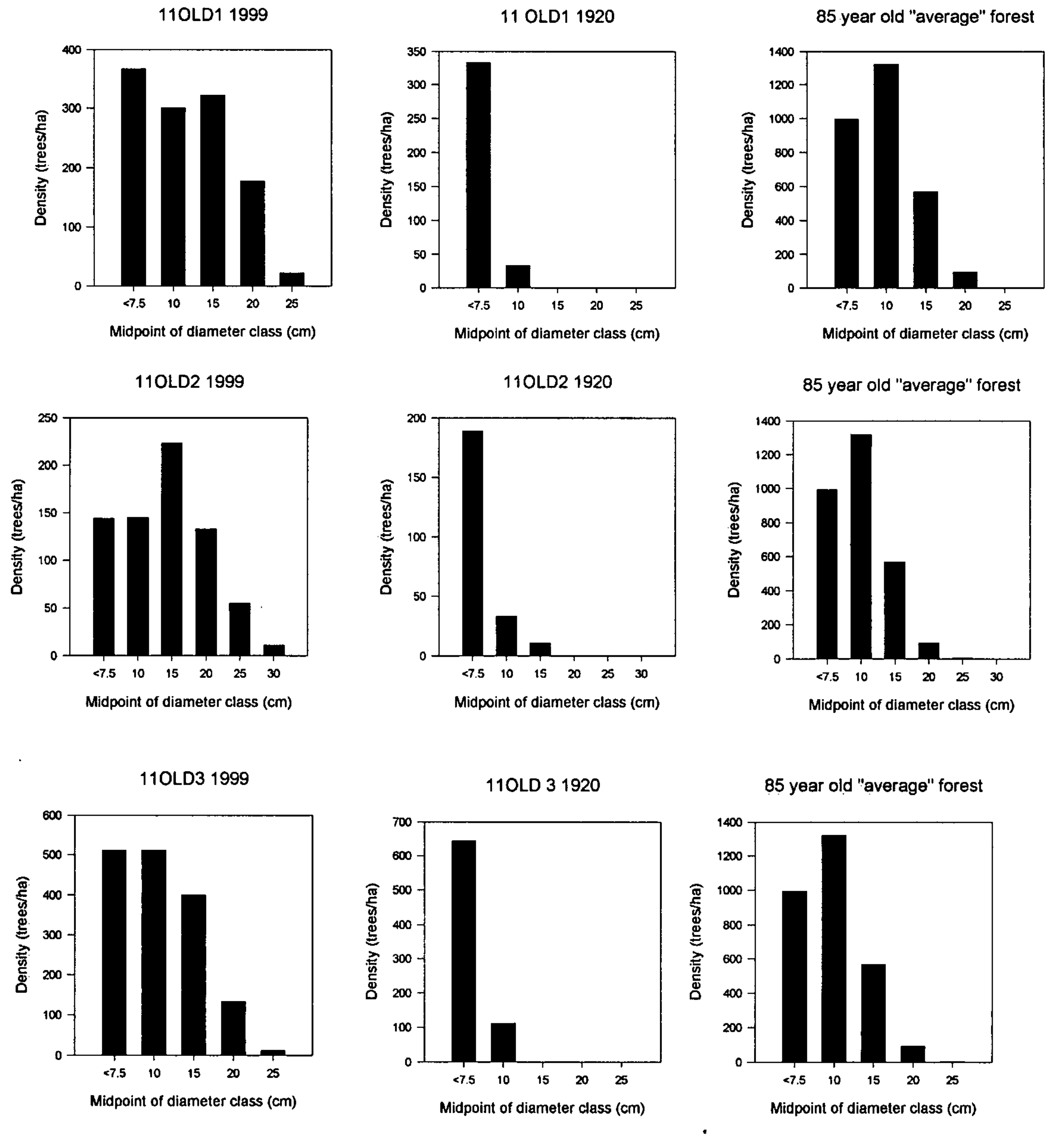


Figure 5e. Tree size class distribution in remnant patches in Fire 13 in 1999 and the year of the most recent fire recorded in the patch.

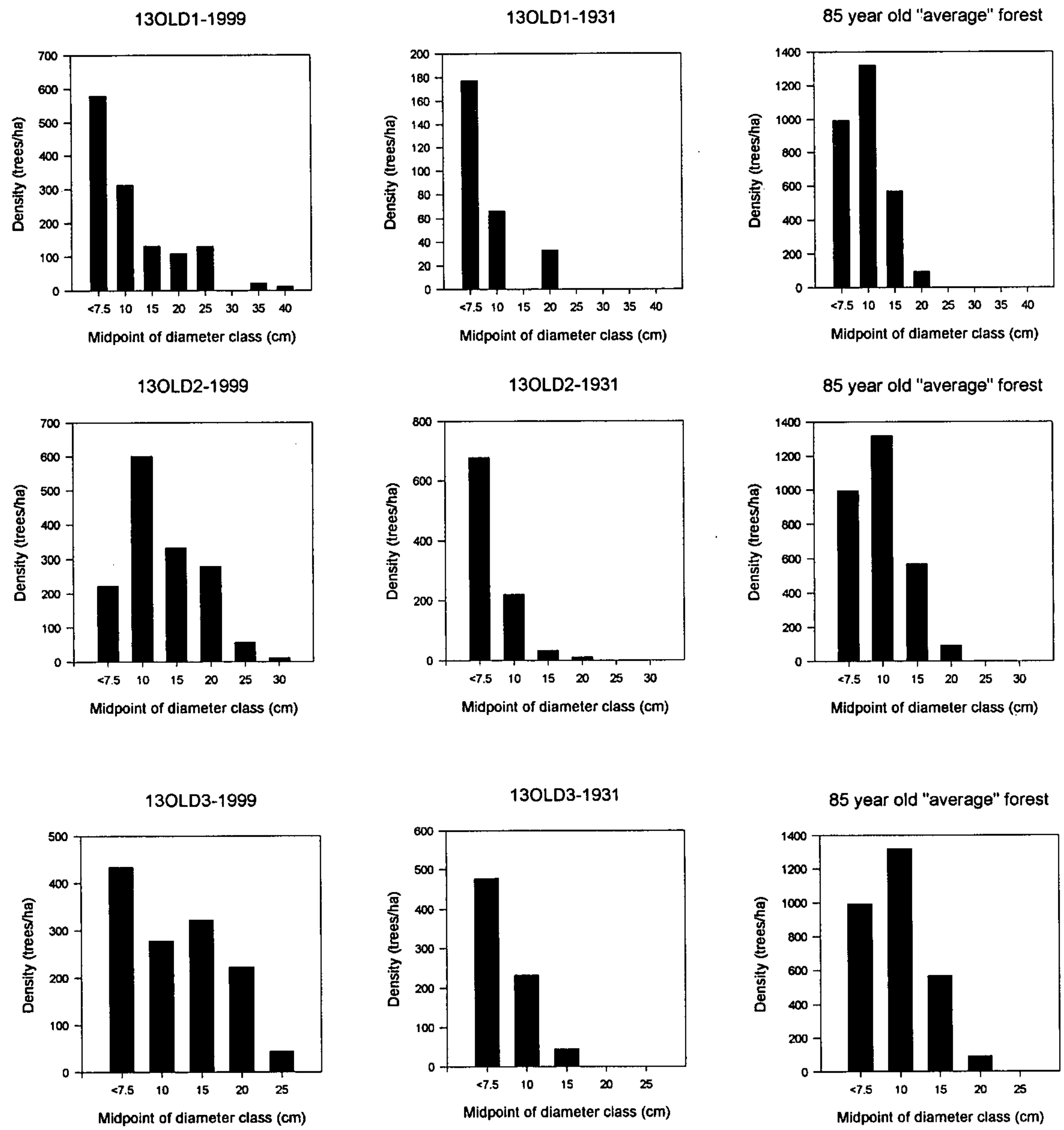


Figure 5f. Tree size class distribution in remnant patches in Fire 20 in 1999 and the year of the most recent fire recorded in the patch.

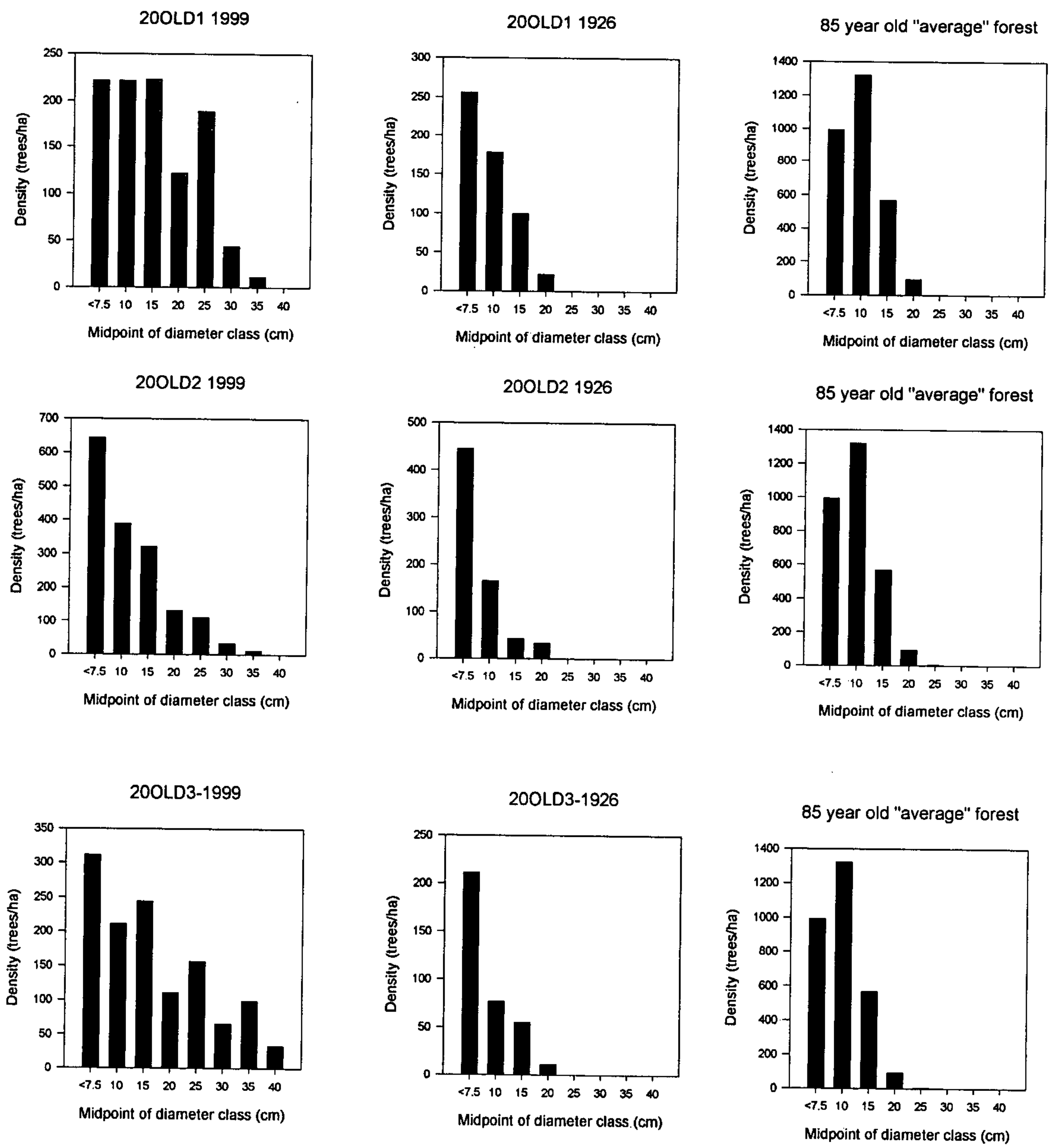


Figure 5g Tree size class distribution in remnant patches in Fire 21 in 1999 and the year of the most recent fire recorded in the patch.

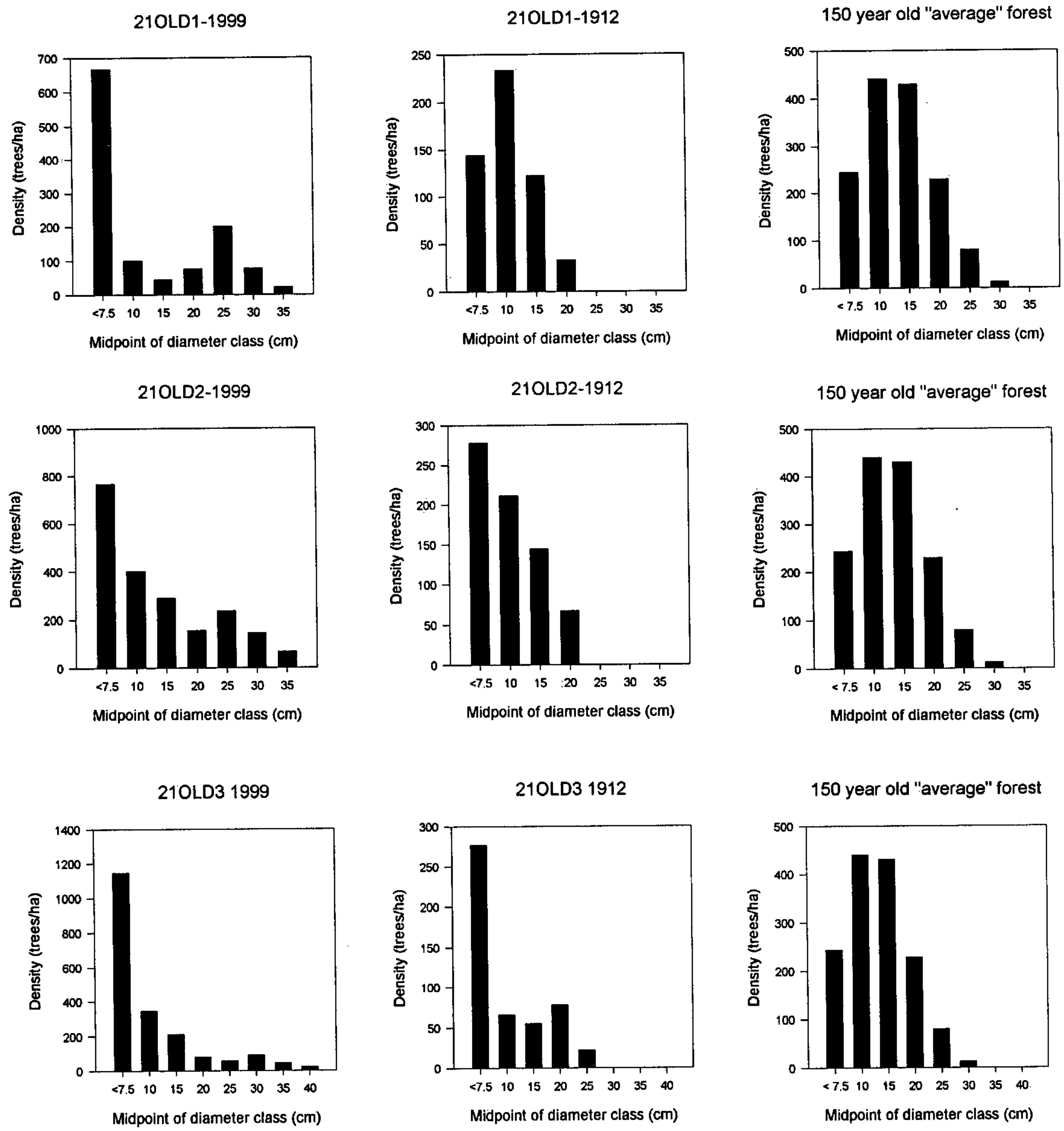


Figure 5h. Tree size class distribution in remnant patches in Fire 26 in 1999 and the year of the most recent fire recorded in the patch.

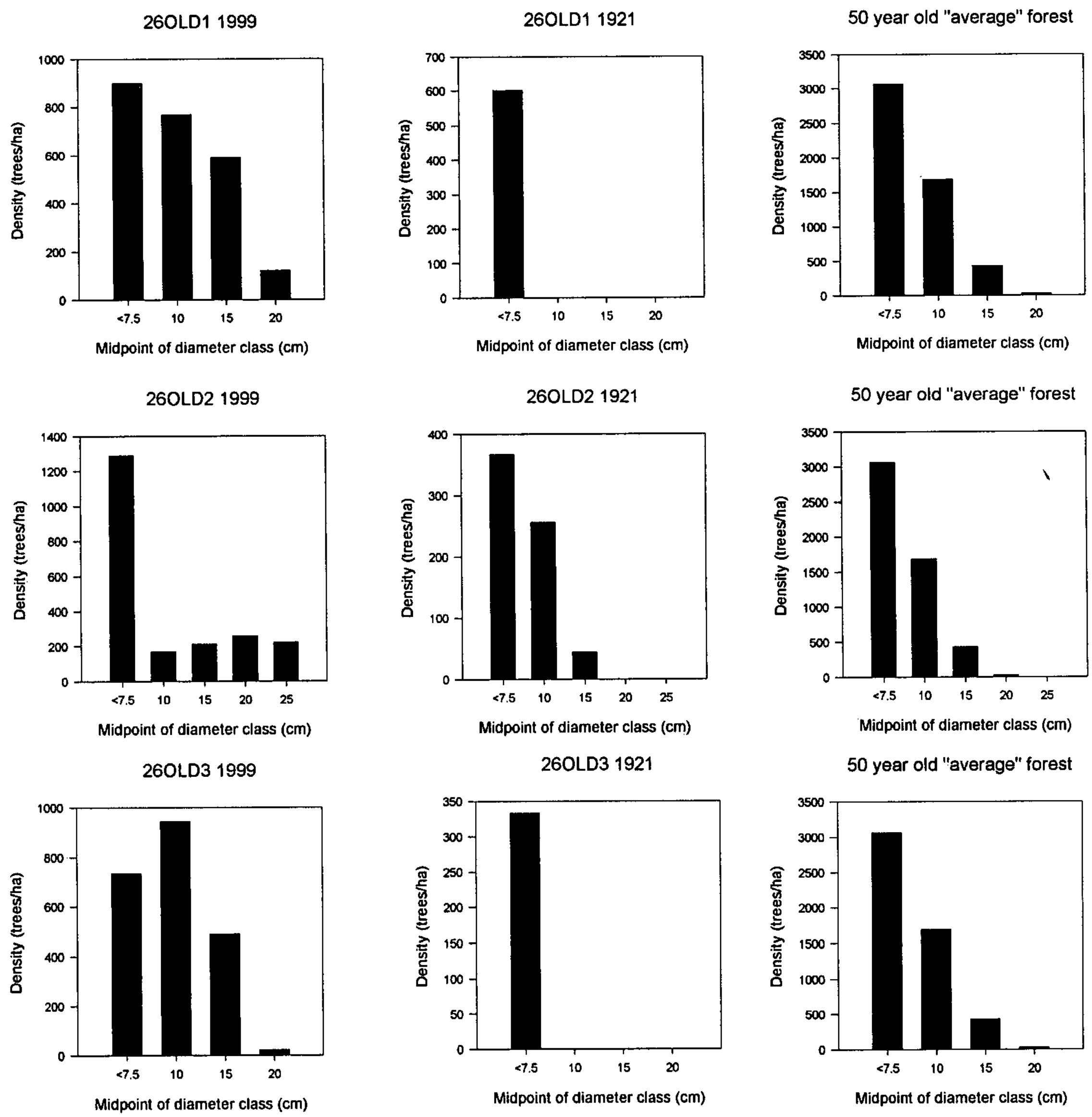
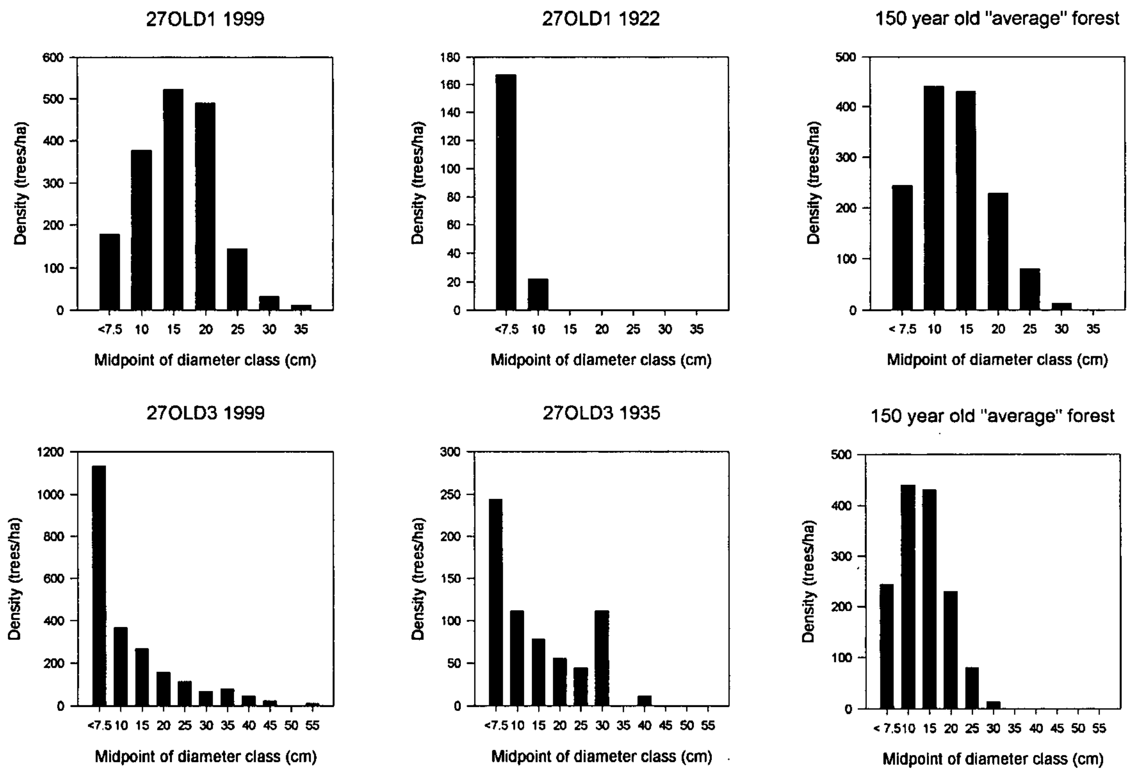


Figure 5i. Tree size class distribution in remnant patches in Fire 27 in 1999 and the year of the most recent fire recorded in the patch.



Diameter distributions are closely regulated by plant community interactions (Knowles and Grant 1983). Many features of community structure relate to plant size and disturbance history. Parker (1988) noted that size is a better indicator of resource allocation and dominance than age, and that diameter structures provide a useful framework for examining forest dynamics. Visual examination of the remnant stand structures (Figures 5a-i) were consistent with literature (e.g. Harcombe and Marks 1978, Knowles and Grant 1983, Lorimer 1985). The majority of the remnants (50-years-old and 85-years-old at the time of fire) had reconstructed stand diameter structures consistent with that of an uneven-aged forest often approximated by the "reverse-J" curve (Lorimer 1985) (Figures 5a (4OLD2-1868, 4OLD3-1837), 5b (6OLD1-1899, 6OLD3-1899), 5c (10OLD1-1922, 10OLD2-1922, 10OLD3-1922), 5d (11OLD1-1920, 11OLD2-1920, 11OLD3-1920), 5e (13OLD1-1931, 13OLD2-1931, 13OLD3-1931), 5f (20OLD1-1926, 20OLD2-1926, 20OLD3-1926), 5h (26OLD1-1921, 26OLD2-1921, 26OLD3-1921), and 5i (27OLD1-1922)) with many individuals in the smaller diameter classes and very few to none in the mid and larger diameter classes. Lodgepole pine is known for its reputation as a former of even-aged stands following disturbance (Knowles and Grant 1983). Remnants that burned when 150+ years old had similar structures, but without such a steep slope because of more fire-surviving trees remaining in larger diameter classes (i.e. Figure 5g (21OLD2-1912)).

Remnants 4OLD1-1920 and 27OLD3-1935 have reconstructed stand structures possibly suggesting two bursts of regeneration. 4OLD1-1920 has a large number of stems in the 10 and 20 centimetre diameter classes. This pattern may have formed because of a previous fire. However, Figure 4a does not indicate that there were 2 fires in 4O1. It is possible that a previous fire did occur in the patch but that it did not scar the trees. Similarly, insects or disease may have caused some thinning at a previous date that may account for the second pulse of regeneration. 27OLD3-1935's structure can be explained by the presence of an earlier fire in the remnant patch (Figure 4i).

The remnant patches measured in 1999 generally had one of two structures. The most common remnant patch distribution could be approximated by the normal distribution where most of the trees occurred in the middle diameter classes with fewer trees in the smaller and larger diameter classes (i.e. Figures 5a (4OLD1-1999), 5b (6OLD1-1999), and 5c (10OLD2-1999)). This could be explained as a result of the majority of trees growing at some average rate, with smaller numbers of slower – and faster-growing trees forming the tails of the distribution (Lorimer 1985). Some remnants in 1999 had a large number of trees in the smallest diameter class followed by a normal distribution of trees in other diameter classes (i.e. Figures 5a (4OLD3-1999), 5g (21OLD1-1999). This could be explained by gaps that have opened in the canopy allowing for the regeneration of the understory. These gaps may have been caused by the presence of a second fire in the remnant patch, such as in 4OLD3-1999 and 21OLD1-1999. The second structure that developed in remnant patches following fire is one in which there are approximately an even number of trees in each diameter class (i.e. Figures 5a (4OLD2-1999), 5d (11OLD1-1999), and 5h (26OLD3-1999). This stand structure developed as the trees that survived the fire increased in diameter and moved to larger diameter classes. At some point, presumably when adequate resources (i.e light) became available, an understory of trees became established that represented the small diameter class present in 1999.

Multiple disturbances in remnant patches may explain the complex size class distributions present in some remnants in 1999. 10OLD2-1999, 11OLD1-1999,

11OLD3-1999, 13OLD1-1999, 13OLD3-1999, 20OLD3-1999, 21OLD1-1999, 21OLD3-1999, and 27OLD3-1999 all have diameter distributions that are possibly the result of multiple fires, insect attack and/or disease within the remnant patches. Focus on diameter relations without information on aging precludes a detailed consideration of the historical development of these patches (Parker 1988).

3.3.4 Crown Fuels

"Fuel" plots were established to represent the crown fuels in remnant patches at the time of the most recent fire. Before a comparison of bulk density was conducted, "fuel" plots were tested to see how well they represented the remnant plots tree density at the time of the last fire. It was considered important that "fuel" plots have a similar tree density to the remnant patches that they were representing because tree density may have been a factor that caused the remnant patches not to be killed in the most recent fire.

Table 11. Means and standard deviations (in parentheses) for tree density (trees/ha) in remnant patches at the time of the last fire, "fuel" plots, and "average" forest at the time of the last fire established in each age class.

Tree age category	Remnant patches	"Fuel" plots	"Average" forest
50 years (tree density)	440(222)*	1840(622)*[a]	5217(1766)*[b]
85 years (tree density)	547(251)*	1167(309)*[a]	2975(689)[b]
150+ years (tree density)	515(200)	1463(277)[a]	1434(462)

* indicates data that were log_{10} transformed for analysis. Back transformed values appear in table; [a] indicates "fuel" plots that were significantly different from remnants within the age category; [b] indicates "average" forest plots that were significantly different from "fuel" plots within the age category.

"Fuel" plots established to represent 50-year-old, 85-year-old and 150+-year-old remnant patches had significantly different densities than the remnant plots.

Due to the inability to represent the remnant patches directly (with respect to tree density), 50-year-old, 85-year-old and 150+-year-old "fuel" plots were compared to the “average” forest plots in each respective age category. The purpose of this was to determine what the relationship of the “fuel” plots (with respect to tree density) in each age category was compared to the remnant patches and “average” forest.

The following tree density relationships were established for each age category:

50-year-old: Remnant plots < “fuel” plots < “average” forest

85-year-old: Remnant plots < “fuel” plots < “average” forest

150+year-old: Remnant plots < “fuel” plots = “average” forest.

Foliar Bulk Density

Foliar bulk density comparisons were made between the “fuel” plots and the “average” forest in each age category. The results are displayed in Table 12.

Table 12. Means and standard deviations (in parentheses) for foliar bulk density (kg/m^3) in “fuel” plots and “average” forest established in each age class.

Tree age category	"Fuel" plots	"Average" forest	p
50 years (bulk density)	.03(.01)	.08(.05)	0.01
85 years (bulk density)	.03(.01)	.04(.01)	0.10
150+ years (bulk density)	.04(.01)	.05(.02)	0.53

In the 50-year-old age category there was a significant difference between the “fuel” plots foliar bulk density and the “average” forest foliar bulk density. This is possibly due to the large difference in tree densities between the 50-year-old “average” forest and 50-year-old “fuel” plots (Table 11). Similarity in foliar bulk density in the 85-year-old and 150+ -year-old categories could be explained by the similarity in tree densities between the “fuel” plots and the “average” forest (Table 11).

In order to determine if lower tree density affects foliar bulk density, I calculated foliar bulk density using the tree densities of my remnant patches at the time of the most recent fire. These calculations used the average depth of tree canopy measured in "fuel" plots in each age category. Results are displayed in Table 13.

Table 13. Means and standard deviations (in parentheses) for foliar bulk density (kg/m^3) in "fuel" plots and hypothetical plots with remnant tree densities at the time of the most recent fire.

Tree age category	"Fuel" plots	Remnant density	p
50 years (bulk density)	.03(.01)	.010(.020)	0.007
85 years (bulk density)	.03(.01)	.004(.003)	0.014
150+ years (bulk density)	.04(.01)	.014(.008)	0.003

It was determined that plots with tree densities similar to the remnant patches at the time of the most recent fire had significantly lower foliar bulk densities than the "fuel" plots examined. Even when the depth of the tree canopy was varied, the estimated foliar bulk densities of remnant patches was still significantly lower than the "fuel" plots. This suggests that at lower tree densities, significantly lower foliar bulk densities may contribute to why some areas do not experience fires that kill all of the trees.

3.3.5 Fire Behavior

Other factors that affect fire behavior may have played a role in leaving the remnant patches. Wind dynamics during the fire, such as wind speed and direction, could contribute to the formation of remnant patches (Foster 1983). A reduction in wind speed may cause a crown fire to become a surface fire thereby leaving remnant patches. A change in wind direction could cause the fire to leave patches by changing the direction of the fire front.

Timing of the fire relative to diurnal temperature can also contribute to fire pattern (Delong and Kessler 2000). A crown fire burning during the day may become a surface fire as temperatures decrease and the relative humidity increases with nightfall.

Similarly, if it started to rain during the course of the burn, patches experiencing heavy rain may not be burned. Precipitation produces an immediate rise in fine-fuel moisture, which changes ignition probability (Foster 1983). Flannigan and Harrington (1988) demonstrated that the total area burnt by a given fire in the boreal forest is correlated strongly with the number of consecutive days without rain that have preceded the start of the fire. By influencing the flammability of the forest landscape, this dry period combines with the meteorological conditions occurring during the fire to determine the extent and the precise boundaries of the areas. Thus, the potential influence of natural firebreaks or of terrain type could be completely eliminated, or conversely greatly amplified depending on factors such as wind speed and direction, or relative humidity of the air (Dansereau and Bergeron 1993).

Van Wagner (1977) considered that crown fire propagation is dependent on three crown properties: (1) height above ground; (2) foliar bulk density; and (3) foliar moisture content. Height of fuels above the ground and surface fuels were not possible to determine in the remnant patches at the time of the most recent fire. It is possible that there were not enough surface fuels present in remnant patches at the time of the most recent fire to provide enough heat for crown fire propagation.

3.4 CONCLUSION

It is not completely certain why trees in the study patches escaped being killed during the fire which established the surrounding forest. Factors such as local weather at the time of the fire or surface fuels, neither of which could be assessed, might have been important factors. However, of the factors I was able to study, low tree density and basal area may have been important. Other factors, such as topographic features, soil moisture, and crown fuels, do not appear to have been important.

4.0 FUTURE CONSIDERATIONS

4.1 MANAGEMENT IMPLICATIONS

Studies such as this one are important to land managers as they allow managers to determine: (1) whether or not certain forest stands within their jurisdiction should never be prescribed burned, or (2) whether they should always be protected from fire (protected areas), or (3) whether or not certain stands should never be logged (species conservation in timber harvesting areas), or (4) whether patches of reserved old forest can be rotated around a landscape.

With regard to the above points, this study in the SBPS determined that: (1) remnant patches within the matrix have burned in the past and do not need to be completely excluded from prescribed burning plans. However, not all trees within the remnants were killed, meaning stand replacing prescribed fires should not be applied in remnants; and (2) remnant patches could be selectively logged as a means of imitating fire disturbance. Remnant patches in this study had lower tree densities than the "average" forest. Selectively logging leave patches within a harvested area could be used to emulate remnant patches in the SBPSxc.

Other relevant findings for management in the SBPSxc include:

(1) remnant patches in the three age categories examined have significantly lower tree densities and basal areas when compared to the matrix forest. The findings of this study indicate that in 50-year old stands, remnant patches had an average density of approximately 400 trees/ha, while remnants in 85-year-old and 150+-year old stands had densities of approximately 525 trees/ha. These numbers could be

used as guidelines for managers trying to mimic remnant patch tree density.

(2) topographic features - slope, aspect and elevation - do not differ between remnant patches and matrix forest, indicating that remnants can be simulated on the landscape in a variety of topographic positions and aspects; and

(3) relative soil moisture regime does not appear to affect the location of remnant patches. Thus, not only wetter sites should be considered to emulate remnant patches in the SBPSxc.

4.2 FUTURE STUDIES

The results of this study are specific to the SBPSxc, a drier climatic region of British Columbia. In order to get a more thorough understanding of fire in the SBPS it would be helpful to study remnants in a wetter sub-region or to examine the fire history of stands specifically located in wetter areas, such as drainages, to determine if they have escaped burning in the last 200-300 years.

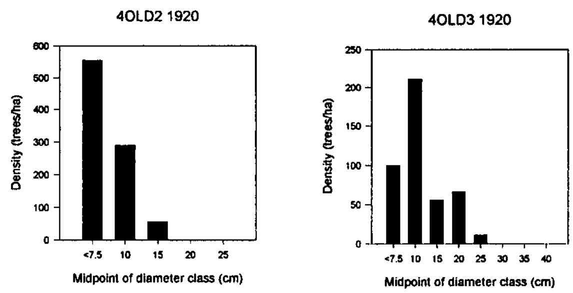
Currently there are plans to conduct a similar study in a wetter climatic region. This will aid in quantifying the characteristics of remnant patches on a broader scale.

This research did not evaluate remnant patch size or abundance. Research will be required to determine the number of patches of various sizes that reflect the landscape pattern. Additionally, differences in characteristics between larger and smaller patches should be determined in order for remnant patches to be included in management plans that focus on maintaining the natural variability of the landscape.

Based on the discussion of crown fuel and fire behavior differences between remnant patches and the matrix, many knowledge gaps can be identified. To learn more about crown fires, the International Crown Fire Modelling Experiment (ICFME) in Ft. Providence, NWT was established. It is an extensive experimental burning program (including many high-intensity crown fires) in major fuel types, and is accompanied by the monitoring of numerous wildfires. Some of the research activities being conducted by the ICFME that would benefit a study on remnant forest patches include: (1) extensive inventory of ground, surface, and aerial fuel loads on each plot prior to and immediately following each experimental fire in order to determine overall fuel consumption levels, and moisture content determination for all important fuels (by strata) just prior to ignition; and (2) detailed monitoring of on-site weather conditions. The above data are difficult, if not impossible, to obtain through a retrospective study. More information on the ICFME can be obtained from their website at: www.nofc.cfs.nrcan.gc.ca/fire/frn/nwt/.

Results of chapter 2 indicate that two remnant forest patches (Fire 4 Patches 2 and 3) in this study did not burn in the most recent fire, but rather in a previous fire. Because of the small sample size (n = 2) it was not considered statistically feasible to compare these remnant patches to the other 24 sampled. Examination of the pith dates on fire scared samples in these two patches (Fire 4 Patch 2 and Fire 4 Patch 3 in Table 5), indicates that they were not samples from exceptionally older trees. Almost all of the remnant fire scar samples collected have pith dates prior to, or within the same time periods (1750-1850). Similarly, a review of the estimated stand structures (Figures 5a-i) does not reveal any obvious differences between 4OLD2 -1920 (Fire 4 Patch 2 in 1920, the time of the most recent fire) and 4OLD3-1920 (Fire 4 Patch 3 in 1920, the time of the most recent fire) (Figure 6) and the rest of the remnant plots at the time of the most recent fire. If the sample size were larger, it would be interesting to compare the patches that did not burn in the most recent fire to those that did.

Figure 6. Stand structure of remnant patches in Fire 4 in the year of the most recent fire (1920). These two patches did not burn in 1920, but in a previous fire.



Landres et al. (1999) provided an excellent progression for research on natural variability in ecological systems.

(1) Site interpretation derived from the history of several individual sites, using techniques such as dendrochronology and stand analysis , allows understanding the specific forces influencing current conditions.
(2) The landscape history is compiled based on the individual site histories.
(3) The landscape-scale disturbance regime is interpreted from the site-specific understanding of factors controlling disturbance processes, a general understanding of disturbance mechanisms, and simulation models that may be used to extend these inferences to areas where site-specific data are lacking.
(4) The landscape management plan is developed based on an understanding of the landscape-scale disturbance regime, current landscape conditions, and the desired future conditions (or social objectives) for the landscape

This thesis is part of step (1) in understanding remnant patches.

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APPENDICES

Appendix 1

Stand characteristics of remnant patch plots.

Plot	Density (trees/ha)	Basal Area (m^2/ha)	Tree Height (m)	Height to Crown (m)
4O1	800	10.56	19.5	7.5
4O2	477	0.90	14.5	3.5
4O3	410	4.31	19.5	6.5
6O1	144	0.35	18.3	2.5
6O3	133	0.48	17.3	3.5
10O1	267	1.14	10.5	3.1
10O2	216	1.38	14.3	5.9
10O3	567	2.45	12.4	4.5
11O1	366	0.46	11.9	2.9
11O2	233	0.52	9.5	2.5
11O3	755	1.67	12.3	2.9
13O1	276	1.61	14.1	3.5
13O2	944	3.32	14.5	2.5
13O3	754	3.19	13.5	4.5
20O1	556	3.94	17.9	2.1
20O2	688	3.60	17.3	2.3
20O3	354	2.36	17.3	3.8
21O1	532	5.25	19.1	0.7
21O2	700	7.18	24	0
21O3	498	6.42	23.3	0
26O1	600	0.57	15.5	3.5
26O2	667	3.37	17.5	3.3
26O3	333	0.15	10.7	1.9
27O1	189	0.32	16.3	4.3
27O3	654	8.81	18.7	2.5

Appendix 2

Stand characteristics of average forest plots.

Plot*	Density (trees/ha)	Basal Area (m^2/ha)	Foliage Mass (kg/m^2)	Bulk Density (kg/m^3)	Tree Height (m)	Height to Crown (m)
50-1	6100	10.55	0.2	0.022	10.4	1.35
50-2	5600	12.29	0.24	0.081	12	9
50-3	6300	10.92	0.21	0.071	12	9
50-4	2250	9.37	0.19	0.021	14.2	5.2
50-5	4525	14.43	0.29	0.033	14.2	5.2
50-6	3350	8.96	0.18	0.016	13.8	2.4
50-7	5050	11.66	0.23	0.02	13.8	2.4
50-8	5750	11.87	0.23	0.033	12.4	5.4
50-9	4475	11.17	0.22	0.032	12.4	5.4
50-10	8775	14.09	0.27	0.031	10.6	2
85-1	3850	11.19	0.23	0.023	16.4	6.4
85-2	3250	11.72	0.24	0.024	16.4	6.4
85-3	3625	12.26	0.25	0.028	12.8	3.8
85-4	1675	11.32	0.24	0.027	12.8	3.8
85-5	2650	10.5	0.22	0.019	18	6.8
85-6	2950	10.66	0.22	0.019	18	6.8
85-7	2425	9.4	0.2	0.015	14	1
85-8	2375	9.02	0.19	0.014	14	1
85-9	3325	9.95	0.2	0.018	11.4	0.4
85-10	3625	8.38	0.16	0.015	11.4	0.4
150-1	1475	16.39	0.38	0.029	19.2	6.2
150-2	1975	14.57	0.32	0.022	16.8	2.4
150-3	775	6.9	0.16	0.017	10	1
150-4	1150	11.63	0.27	0.019	16.4	2.6
150-5	1060	6.85	0.15	0.017	13.6	4.8
150-6	1900	11.86	0.26	0.029	13.6	4.8
150-7	1660	8.79	0.19	0.027	14.4	7.4
150-8	2125	8.52	0.18	0.025	14.4	7.4
150-9	1025	7.5	0.17	0.015	13.6	2.6
150-10	1200	9.42	0.21	0.019	13.6	2.5

*Plot labels are as follows: Age of forest-replicate.

Appendix 3

Stand characteristics of "fuel" plots.

Plot*	Density (trees/ha)	Foliage mass (kg/m^2)	Bulk Density (kg/m^3)	Tree Height (m)	Height to Crown (m)
50-F1	2466	0.4339	0.043	11	0.8
50-F2	1222	0.3542	0.035	11	0.8
50-F3	1833	0.3083	0.03	11	0.8
85-F1	1250	0.5174	0.043	13	1
85-F2	825	0.3034	0.025	13	1
85-F3	1425	0.393	0.033	13	1
150-F1	1625	0.6412	0.0364	18.6	1
150-F2	1050	0.4486	0.0252	18.8	1
150-F4	1550	0.7971	0.0539	18.8	4
150-F5	1625	0.8074	0.0546	18.8	4

*Plot labels are as follow: Age of plot-replicate. F represents fuel plot.