Characterizing the Mixed-Severity Fire Regime of the Kootenay Valley, Kootenay National Park

by

Richard Kubian
Bachelor of Arts, University of Victoria, 1988

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Supervisory Committee

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Abstract

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Understanding historic fire regimes to develop benchmarks for emulating historic natural disturbance processes in the interest of conserving biodiversity has been actively pursued for approximately 30 years. Mixed-severity fire regimes are increasingly becoming a recognized component of historic fire regimes. Mixed-severity fire regimes are inherently difficult to classify and characterize given the complexity of the process and the multiple scales at which this complexity is expressed. I utilized a systematic study design to gather fire scar and stand dynamic information in order to describe and classify the historic fire regime. I established the presence of mixed disturbance regime dominated by a mixed-severity fire regime. The historic fire regime was mixed-severity over time dominated by individual high severity fire events occurring at a frequency of 60-130 years with some areas that experienced lower severity fire events occurring at a frequency of 20 - 40 years. Twenty-one per cent of the current landscape was dominated by high-severity fire, 42% by mixed-severity and 37% had an unknown fire history. I developed a fire regime classification scheme that provides a useful tool for considering fire severity in mixed-severity system with forest species that generate strong establishment cohorts. I was able to combine time-since-fire methods with a systematic study design and this combination provided an excellent tool to explore mixed-severity fire characteristics in a complicated mixed-disturbance forest. I found limited relationships between topographic controls and fire severity. I found a number of significant relationships that fit the broadly held perceptions of how fire severity would affect species relative densities and stand structure attributes. The existing stand-origin map and the Vegetation Resource Inventory stand age were largely accurate for high-severity 20th century fires but had decreasing accuracy in older forests and for mixed and unknown fire severity. The accuracy of the Vegetation Resource

Inventory leading species accuracy was quantified at 60%. My results have implications for fire and forest management in south-eastern British Columbia and in other forest systems that have historic mixed-severity fire regimes with tree species in strong establishment cohorts.

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Acknowledgments

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Dedication

For my family, and most especially Angela, without you none of this would have been possible, or worth doing.

To the memory of Alan Masters: one of the pioneers of fire history in Parks Canada.

Chapter 1- Introduction

1.1 Background

Fire is the primary determinant of vegetation dynamics in the forests and grasslands in the Southern Canadian Rocky Mountains and has fundamental implications for ecosystem processes (Tande 1979; Fryer and Johnson 1988; Masters 1990) (White and Pickett 1985). Fire shapes the structure, function and biodiversity of many of the ecosystems in western North America and native wildlife and plant species have adapted to fire over millennia (Bunnell 1995) (Agee 1993).

Changes to historic fire frequencies have been documented in Kootenay National Park (KNP) (Masters 1990; Hallett and Walker 2000; Cochrane 2007) and the Southern Canadian Rocky Mountains (White 1985; Fryer and Johnson 1988; Tymstra 1991; Rogeau 1996) over the last century. The historic fire regime of the Kootenay Valley in KNP included mixed-severity fires that may have maintained complex forest structure (Masters 1989; Cochrane 2007; Daniels, Soverel et al. 2008). Several lines of evidence indicate the presence of mixed-severity fire including observable structural attributes present in historic photos (Figure 1.1). Changes in the fire regime have important implications for example on available forage resources for ungulate populations (Van Egmond 1990).

The role of stand replacing fires in the fire regime of KNP has been studied (Masters 1990), but the role of mixed-severity fire has not. This project seeks to better understand the mixed-severity elements of the fire regime in the Kootenay Valley in KNP using fire history and stand reconstruction techniques. Building on existing information including stand origin mapping (Masters 1990) and a regional summary of fire history in the Kootenay and Columbia Valleys (Cochrane 2007) this study seeks to characterize the historic mixed-severity elements of the fire regime of the Kootenay Valley in KNP.

Figure 1.1 Oblique photo taken on the north end of the Kootenay Valley, Bridgland 1922 (Station 38 Image B22-202). The image was taken in as part by M.P. Bridgland's National Topographic Service mapping project and scanned as part of the Mountain Legacy Project (http://mountainlegacy.ca). The image shows an example of forest structure that was created by historic mixed-severity fires.

1.1.1 Background - Importance of Understanding Mixed-Severity Fire Regime

The maintenance of historic disturbance regimes within a natural range of variability has increasingly been recognized as an important aspect of managing ecological systems (Morgan, Aplet et al. 1994). The mimicking of historic disturbance regimes was initiated in the search for a mechanism to maintain biodiversity and sustain threatened and endangered species (Landres, Morgan et al. 1999) and many management agencies in North America have adopted policies aimed at mimicking natural disturbances to protect biodiversity values. Policy changes explicitly recognizing the protection of biodiversity occurred in both the Parks Canada Agency and British Columbia Ministry of Forests in the early 1990's.

The 1994 Parks Canada Agency policy mandates that naturally occurring processes will be managed with minimal interference (Parks Canada 1994). However active management may be allowed when the structure or function of an ecosystem has been seriously altered. Parks Canada recognizes that in many of its protected ecosystems the disturbance process of fire has been altered and that this is affecting the structure and function of ecosystems. Parks Canada's current fire management program includes an active restoration component that seeks to restore fire as a critical process in ecosystems where it has been removed. Ecological restoration in Parks Canada is guided by principles and guidelines (Parks Canada and the Canadian Parks Council 2008; Keenleyside, Dudley et al. 2012) that define broad direction to ensure restoration is efficient, engaging and effective. These guidelines define effective restoration as that which meets ecological integrity objectives and were the first national-level principles and guidelines for restoration of protected areas in the world.

The move to actively utilize a natural disturbance paradigm to guide forest management is evident in the policy change implemented as part of the British Columbia Ministry of Forests 1995 Forest Practices Code. Legislated by the Forest Practices Code and guided by the Biodiversity Guidebook (B.C. Ministry of Forests 1995) these changes explicitly recognized the importance of managing forests utilizing a natural disturbance paradigm. The Biodiversity Guidebook classifies the vegetation types of BC into natural disturbance types (NDT) and based on these types provides broad guidance for forest management. Forest companies continue to use NDT's to set indicators and targets aimed at sustainable forest management (Canadian Forest Products Ltd 2012). The NDT's form one of the keystone reference points linking forest management planning to biodiversity goals and as such play a significant role in determining the ecological implications of forest management in BC.

The Society for Ecological Restoration defines ecological restoration as *"the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed"* (Society for Ecological Restoration 2004). In the Kootenay Valley, changes to vegetation as a result of departure from the historic fire regime have degraded ecosystems but, not destroyed them. The process of ecological restoration (Higgs 2003) relies on two primary components: historic fidelity and ecological integrity. Historic fidelity refers to a loyalty or attention to pre-disturbance conditions. In this context "pre-disturbance" refers to the process or processes that altered the historic range of conditions. Ecological integrity is an all-encompassing term for the various features – resiliency, biodiversity, elasticity, stress response, etc. - that allow an ecosystem to adjust to environmental change (Higgs 2003) or that facilitate compositional and functional comparisons of the site being restored with natural habitats within the same region (DeLuca, Aplet et al. 2010). An understanding of the historic fire regime is required to provide historical fidelity context for the Parks Canada Agency's fire restoration program in Kootenay National Park.

The fire history of the mountainous area of the contiguous National Parks (Banff, Jasper, Kootenay and Yoho) has been relatively well studied over the past twenty years but several important questions remain unanswered. Several of these questions are related to the complex mixed-severity elements of the fire regime and the interplay of lethal fire causing tree mortality and non-lethal fire. In a literature review completed for the Province of British Columbia Wong et al. (2004) summarized known information and developed an assessment of the knowledge gaps associated with historic variability in BC One of the knowledge gaps noted was that mixed-severity fire regimes and the influence of topography are poorly described in BC. In this research project I will utilize an innovative combination of study methods to provide an improved understanding of the historic mixed-severity fire regime in the Kootenay Valley. The results will be used to set informed restoration objectives for the fire management program in KNP. This information will also improve the understanding of the historic mixed-severity disturbances in south-eastern BC which will have implications for improved forest and fire management. The methodology and results may also inform other agencies challenged with interpreting and managing mixed-severity fire regimes.

1.1.2 Background- Mixed-Severity Fire Regimes

Utilizing a natural disturbance paradigm to guide ecological management requires explicit understanding of key elements of the disturbance regimes that dominate an area. One of the key concepts required to summarize disturbance is that of a "disturbance regime" (Pickett and White 1985). A disturbance regime refers to the temporal and spatial pattern of the creation of open or altered patches (Pickett and White 1985). Specific to fire, Agee (1993) defines a fire regime as a generalized description of the role fire plays in an ecosystem. Fire regimes can be defined based on a variety of elements.

The concept of fire severity is based on impacts to vegetation as ranging from low severity through moderate severity to high severity. Severity is broadly related to tree mortality with low severity fire regimes generally defined by non-lethal fire resulting in little change to the mature vegetation cover. Conversely high-severity fire regimes are generally defined by lethal fire resulting in mortality and in turn change to mature vegetation. Moderate severity fire regimes represent a mix of severities. Agee (2005) recognizes the complexity of both the concept of fire severity classes and particularly of the moderate severity fire regime.

The concept of moderate severity fire regimes has evolved into that of a mixed-severity fire regime. In 2005 Agee defined a mixed-severity fire regime as one "*where the typical fire or combination of fires over time results in a complex mix of patches of different severity*". Although clearly defined there are several difficulties associated with assessing fire history in mixed-severity fire regimes. These difficulties are primarily driven by the fact that at no single point on the landscape is there a characteristic signature of a mixed-severity fire regime and that this signature is only visible at an appropriate scale (Agee 2005). While this variability makes it difficult to define mixed-severity fire regimes the structural diversity they create has significant ecological impact (Halofsky, Donato et al. 2011; Perry, Hessburg et al. 2011) making it important to accurately characterize them. The difficulties in characterizing fire history in mixed-severity fire regimes are confounded by ongoing debate regarding fire history methodologies.

1.1.3 Background - Fire History Methodologies

The disturbance process of fire has been considered important beginning with some of the earliest formal ecological studies (Clements 1916). Fire history, as an element of the disturbance process of fire, has been of interest since ecologists began to understand the significant role fire played in the ecosystem. It has only been in the last thirty years that the development of formal fire history methodologies has been undertaken (Agee 1993) moving the study of fire history from a "storytelling" approach to a more rigorous scientific effort. Typically the study of fire history has focused on determining the frequency of fire on a given landscape. Other elements of the historic fire regime that are often derived include: patch size, patch shape, seasonality and in some instances ignition source. It can be argued (Pickett and White 1985) that the era of formal study of fire history began with the seminal work of Heinselman (1973). Heinselman developed a life history approach utilizing dendrochronology – the study of tree rings. His techniques and attempts to determine and define fire frequency significantly moved the formal study of fire history forward.

Many modern fire history methodologies utilize a dendrochronological framework for exploring fire history through the analysis of fire-scarred trees and analysis of age class data as determined by increment cores. These methodologies often take root in the 1977 work of Arno and Sneck (Arno and Sneck 1977) who consolidated a methodology for determining fire history in the mountainous areas of the north-western U.S. As they point out in their introduction, they attempted to complete a review of the studies up until that date and compile the procedures and techniques into a methodology. Their work predated and set the stage for a period of active study of fire history in both the western U.S. (Agee, Finney et al. 1990; Baisan and Swetnam 1990; Agee 1991; Swetnam 1993; Brown and Swetnam 1994) and western Canada (White 1985; Johnson, Fryer et al. 1990; Masters 1990; Tymstra 1991; Rogeau 1996) in the late 1980's and early 1990's. Throughout the 1990's and into the early 2000's the study of fire history in North America continued to be advanced and received considerable attention (Grissino-Mayer and Swetnam 1995; Fule and Covington 1996; Camp, Oliver et al. 1997; Agee and Krusemark 2001; Morgan, Hardy et al. 2001; Rollins, Morgan et al. 2002; Howe and Baker 2003; Heyerdahl, Lertzman et al. 2007; Margolis, Swetnam et al. 2007; Iniguez, Swetnam et al. 2008)

Despite considerable effort and many advances, a universally accepted fire history methodology is still not available. This likely reflects the difficulty associated with studying a process as variable in time and space as fire. The debate about methodology and fire frequency measure is complicated by the different ecological systems that are being studied. Different systems provide different opportunities to collect fire evidence (fire scars, fire age class cohorts, repeat photographs) and in some cases may be driven by different types of fire (surface fire versus crown fire). Most dendrochronological measures of fire frequency are derived from two distinct methodological approaches: time-since-fire and point fire frequencies (Fall 1998).

The time-since-fire methodology had its roots in Heinselman (1973). Concerns about the lack of a consistent methodology in the early 1990's prompted Johnson and Gutsell (1994) to consider the evolving methodological approaches to sampling fire history. They criticized what they felt was the lack of a formal sampling design utilized in many of the past and contemporary fire history studies. They detailed a time-since-fire methodology that provided a well-documented approach to developing fire frequency estimates from a time-since-fire map. Time-since-fire maps often referred to as stand-origin maps are used primarily in high-severity fire systems where a researcher delineates stands created by individual fires from air photo interpretation. In this way the time-since-fire methodology derives areas of differing age classes for forest that was initiated by forest fire. Analysis of the age class distribution enables researchers to calculate a disturbance cycle (Johnson and Van Wagner 1985). The disturbance cycle, often referred to as the fire cycle, is the time required to disturb an area equivalent to the study area.

The point fire frequency methodology had its roots in Arno and Sneck (1977) where debate around methodology and interpretation was also present (Minnich, Barbour et al. 2000; Baker and Ehle 2001; Van Horne and Fule 2006). Point fire frequencies are utilized for low-severity fire regimes that enable the formation of many multiple fire scarred trees. Fire frequency is inferred from a network of fire scars and is referred to as a fire interval. Fire intervals are referenced as mean point fire intervals that refer to the average expected time between disturbances at a given point on the landscape (Heyerdahl 1997) or an area interval which describes the average time between disturbances occurring anywhere on the landscape (Grissino-Mayer 1995). Given the complex nature of mixed-severity fire regimes which are comprised of a mix of low and high severity fires the methodological concerns associated with these two approaches are exacerbated.

Several researchers have delved into the complexity of the historic mixed-severity fire regimes in western North America. Through the 1990's and into the early 2000's a number of studies explicitly recognized mixed-severity fire regimes utilizing methodologies based on a stand origin map (Barrett, Arno et al. 1991; Barrett 1994; Brown, Kaufmann et al. 1999; Kipfmueller and Baker 2000) or stand reconstructions (Arno, Smith et al. 1997) . Likely in response to criticisms regarding sampling methodology fire history studies in known mixed-severity fire regimes moved toward systematic sampling methodologies in the early 2000's (Ehle and Baker 2003; Fule, Crouse et al. 2003; Taylor and Skinner 2003; Wright and Agee 2004; Cochrane 2007). Several studies have sought to characterize fire severity by considering a mix of tree survivorship, fire scar evidence and age class cohort data (Sherriff and Veblen 2006; Hessburg, Salter et al. 2007; Sherriff and Veblen 2007; Beaty and Taylor 2008; Amoroso, Daniels et al. 2011; Heyerdahl, Lertzman et al. 2012; Marcoux 2013). All of these studies consider various elements of fire history information to classify fire severity but no standard classification scheme has been determined.

Developing a classification scheme to link fire history evidence including age class cohorts to fire severity is a challenging endeavour. In fire dependent ecosystems age class cohorts of forests are linked to fire disturbance (Agee 1993). There are two tree populations related to a disturbance event: an establishment cohort represents trees that establish after an event while remnant trees are those that survive an event. Establishment cohorts have also been called recruitment cohorts (Sherriff and Veblen 2006; Brown, Wienk et al. 2008) or regeneration cohorts (Ehle and Baker 2003). Remnant trees have also been called survivors (Ehle and Baker 2003) or residuals (Heyerdahl, Lertzman et al. 2012) . Some studies have also considered the inverse of the remnant trees which are the trees killed by a fire, as evidenced from snags or down and dead tree boles, referred to as the mortality pulse (Ehle and Baker 2003; Sherriff and Veblen 2006). The size and distribution of these age class cohorts is one line of evidence that can be used to interpret the severity of historic fire events.

The criteria used for most current fire severity classifications relate age cohort breakpoints to low, mixed and high severity (Agee 1990; Agee 1993). High severity fire events are those that result in the mortality of trees and are often referred to as stand replacing fires. Low severity fire events are those that do not result in mortality of trees and are often referred to as stand maintaining fires. Pure high-severity fire regimes have single age class establishment cohorts and no remnant trees. Fire scar evidence is generally found only at the boundaries of these events or in remnant islands of unburned forest. Pure low-severity fire regimes have multiple age class cohorts and abundant fire scar evidence as there are many survivors from any fire event. Mixed-severity fire regimes are those that display a range of characteristics from both high and low severity fires. They show evidence of both high and low severity fire events through age class cohorts, including establishment cohorts and remnant trees, as well as fire scar evidence. Mixed-severity fire regimes are most difficult to classify as they display a range of cohort and fire evidence (Agee 2005). Indeed even high and low severity fire regimes are difficult to characterize with respect to age class cohorts: the survivability of individual trees can be driven by many factors.

At the heart of the challenge in defining the historic severity of fire is the range of spatial and temporal heterogeneity inherent in all fire regimes (Turner and Romme 1994; Agee 1998) and the multiple scales at which this heterogeneity occurs (Falk, Heyerdahl et al. 2011). Three kinds of heterogeneity exist in fire regimes (Lertzman, Fall et al. 1998): temporal heterogeneity expressed over a range of scales related to drivers such as climate and land use change, spatial heterogeneity expressed over a range of scales related to study area size and homogeneity and finally spatial heterogeneity created by within fire variation of fire behaviour that drives the survivorship of patches within the fire and of individual trees. Classifying historic severity at the stand scale must recognize these different patterns of heterogeneity. This is particularly important for a classification scheme designed to define fire severity utilizing age cohort data as the survivorship of individual trees is at the heart of the issue.

Within-fire variability in fire severity occurs because of heterogeneity in fire behaviour which drives tree mortality and survivorship. Fire behaviour variability is driven by a wide range of factors such as diurnal changes in temperature and humidity, seasonality and rapidly changing factors such as wind speed and direction (Ryan 2002). Individual fire events display mixed-severity characteristics (Collins and Stephens 2010). The fire behaviour that results in this mixed-severity signal occurs at different scales resulting in the survivorship of unaffected forest patches, partially burned forest patches and of individual trees (Stuart-Smith and Hendry 1998). A classification scheme that considers age cohorts must allow for individual tree survival while differentiating from islands of unaffected or partially burned forest. In addition classification of fire severity at the plot scale must account for temporal heterogeneity by being able to differentiate between the severity of a single fire at a site and fire severity over time. A site may show indications of a high severity fire in its age cohort data such as a strong establishment cohort pulse linked to a known fire event but still show evidence of mixed-severity over time such as multiple fire scars or establishment cohort evidence from earlier or later fires. Determining how to utilize the age class cohort information to establish breakpoints to define fire severity is critical to accurate classification.

The classification of age cohort data is complicated by a decreasing record as trees are subjected to death and in turn decay. This decreasing record problem is common to fire scar analysis and has been considered in that area of study (Fall 1998). Tree death and decay, weather disturbance related or not, results in limitations of temporal depth to the record one is able to consider (Swetnam 2011). The problem makes it difficult to determine fire severity for older fire events as age information, both establishment cohorts and remnant trees, is decreasing over time. Many ecosystems age cohorts are affected by other disturbances such as forests insects and disease (Agee 1993; Antos and Parish 2002). This can complicate the analysis of age cohorts related to fire regimes as there may be multiple disturbances creating cohorts. The presence, scale and impact of other disturbances need to be carefully considered when analyzing cohorts

In their review of the state of estimating historical variability from natural disturbances in BC Wong et.al. (2003) included an overview of quantitative methods for estimating attributes of natural disturbances. They catalogued methods and provide a key to assist the land manager in determining the appropriate approach for determining attributes of natural disturbances. They pool the various methodologies and analysis procedures based on the type of information that a researcher is able to accurately gather. Based on their literature review and expert opinion they have broadly defined a preferred methodology for the study of disturbance where the evidence is based on a record of intervals between consecutive disturbances. They note that a typical use of this methodology would be in low to mixed-severity disturbance regimes. They recommend utilizing a regular grid or random selection to sample for disturbance history across a landscape. This broad approach provides the baseline from which the systematic grid methodology of this study has evolved.

It is important to recognize that research to describe historic fire regimes has not been limited to dendrochronological techniques. Attempts to utilize photo interpretation to analyze fire history have been undertaken (Arno and Gruell 1983; Rhemtulla, Hall et al. 2002; Zier and Baker 2006) and provide a valid and useful tool for linking fire frequency to vegetation structure. The utilization of paleoecological methodologies to determine fire history elements such as fire frequency has been evolving over the past decade and has resulted in several important studies (Lertzman, Gavin et al. 2002; Hallett, Lepofsky et al. 2003; Hallett, Mathewes et al. 2003; Hallett and Hills 2006; Gavin, Hallett et al. 2007; Arabas, Black et al. 2008). Swetnam noted that when considering historic disturbance regimes the highest degree of confidence is developed when researchers consider multiple lines of evidence (Swetnam, Allen et al. 1999).

1.1.4 Background - Fire History Study in and adjacent to Kootenay National Park

Fire history in and immediately adjacent to Kootenay National Park has been analyzed using three different methodological approaches. Masters (1990) utilized a dendrochronological time-since fire methodology to determine a fire cycle for the 1400 km^2 study area of Kootenay National Park. His key findings were that fire frequency for the study area had changed over three different time periods. He estimated the fire cycle for the park was 2700 years for 1988-1928, 130 years for 1928-1788 and 60 years between 1778-1508. He determined that the longer fire cycles after 1788 and 1928 may have been due respectively to cool climate associated with the Little Ice Age and a recent period of high precipitation. He did not find any affect on fire cycle due to fire suppression. He was unable to spatially partition the area due in part to the inadequate size of his study area. He found no relationship between elevation, aspect and fire frequency. He noted that his findings were accurate for forests with stand replacing fire regimes and that sites with understory fire may require further study (Masters 1989).

Research by Hallett and others (Hallett and Walker 2000; Hallett, Mathewes et al. 2003; Hallett and Hills 2006) utilized high-resolution charcoal analysis of lake sediments and stand-age information to reconstruct a 1000-year fire history around Dog Lake located in the Kootenay Valley in KNP. He found that macroscopic charcoal accumulation rates represented a complex spatial aggregation of local to extra-local fires around the lake. Peaks in charcoal accumulation indicated frequent stand-destroying fires during the 'Mediaeval Warm Period' (~ AD 1000-1300) and other significant fires at c. 1360, 1500, 1610 and 1800.

Cochrane (Cochrane 2007) completed a dendrochronological fire history study that utilized a stratified random sampling approach to determine the fire history of mixed conifer stands within the Dry-Cool Montane Spruce sub-zone of British Columbia. His study area (α 9600 $km^{2)}$ stretched from the Columbia Valley north into the Kootenay Valley terminating in KNP. He concluded that fire was more frequent in this stand type than previously thought and that fire had played a significant role in establishing the complex structure that characterizes these stands. He noted that heterogeneity of these stands was a result of variable fire behaviour and characterized these stands as created by a mixed-severity fire regime. He noted that fire frequency had been altered and that this may be having effects on ecological resilience as fire is only occurring when conditions are extreme.

There have been several related studies in nearby areas in the southern Canadian Rocky Mountains. Tande (Tande 1979) completed a dendrochronological based fire history study in the montane area of Jasper National Park utilizing using a sampling design that pre-dated the time-since-fire methodology. He extensively sampled a 43 km^2 study area near the Jasper townsite by first establishing stand boundaries from air photos and systematically sampling stands he identified to determine fire origin and fire frequency. In addition he collected fire scars between plots to supplement fire frequency information. He concluded that fire periodicity and extent have declined since 1913 accompanied by reduced structural hetrogenity. White (White 1985) completed a dendrochronological based fire history study in Banff National Park. White developed a time-since-fire map for his 4000 km^2 study area. He did not develop a fire cycle for his entire study area but does report a decrease in area burned and number of fires from 1880-1980. He concluded that this was primarily due to a reduction in human caused fires.

Tymstra (Tymstra 1991) studied the fire history of Yoho National Park also using a dendrochronological based methodology with an adjusted time-since-fire design. Tymstra developed a time-since-fire map utilizing fire scar and increment core based age class information. From this time-since-fire map he determined a fire cycle of 132 years for the 1300 km^2 study area. He determined that there was a spatial break with longer fire cycles in the eastern areas of the park adjacent to the continental divide and shorter fire cycles in the western area of the park. He developed a two fire return interval index to differentiate between stand replacing high intensity fires and low to moderate intensity fires that did not result in stand replacement. He found the fire regime in YNP to be dominated by large, high intensity fires.

Johnson and Larsen (1991) completed a dendrochronological time-since-fire study in the Kananaskis Valley, Alberta. They reported a change in fire frequency ~ 1730 that they related to changes in climate. They calculated a fire cycle of 50 years for their study area prior to 1730 and from 1730 –1980 they calculated a fire cycle of 90 years. Rogeau (Rogeau 1996) completed a dendrochronological fire history study for the contiguous area of Banff National Park and Mount Assiniboine Provincial Park, BC. She utilized a time-since-fire methodology and analyzed fire frequency over her entire study area as well as by a number of areal sub-classes. She reported minimum fire cycles of 170 years for Banff National Park and 220 years for Mount Assiniboine Provincial Park. She determined that heterogeneity in fire occurrence in mountainous terrain violated the assumptions of the time-since-fire methodology. She recommended caution when interpreting fire cycle results due to differential fire frequencies over space.

Van Wagner et. al. (2006) analyzed the collective data from seven contiguous national and provincial parks (Jasper National Park, Banff National Park, Yoho National Park, Kootenay National Park, Mount Assiniboine Provincial Park, Spray Valley Provincial Park and Peter Lougheed Provincial Park) to determine historic fire cycles. They utilized four statistical methods to determine fire cycles and spatially segregated their analysis utilizing the continental divide to compare east side versus west side results. They concluded that the different statistical approaches yielded similar results. They found that the east side parks had a fire cycle of 60-70 years prior to 1760 that changed to a fire cycle of 175 years until 1940 when the rate of burning declines significantly. For the west side parks they found a fire cycle of 90-100 years prior to 1840 and then an erratic pattern with decreasing rates of burning.

In addition to the work completed immediately adjacent to Kootenay National Park several other recent studies have been completed in the Kootenay Region that have implications for the study area. DaSilva (2009) completed a fire scar based study in the Joseph and Gold Creek drainages near Cranbrook, BC. He documented a mixed-severity fire regime with evident effects of fire exclusion in the last century as well as strong relationships between slope aspect and fire frequency. Nesbitt (2010) completed a tree cohort and fire scar based study in the mixed conifer forests in the Nelson area of the West Kootenays. He documented evidence of fire exclusion and site to site differences in fire history suggesting topography and land use caused variability in fire histories at individual sites. Greene (2011) completed a fire scar and tree cohort study near Creston BC. He identified a mixed-severity fire regime and evidence that fire occurrence varied with elevation, slope steepness and slope aspect. Marcoux (2013) completed a follow up study to Da Silva in the Joseph and Gold Creek drainages utilizing a cohort and fire scar study methodology. She documented a mixed-severity fire regime that varied by elevation and did not fit current disturbance type classifications used in British Columbia. This body of work provides a strong line of evidence that the NDT classification system may not adequately represent mixed-severity fire regimes in British Columbia.

1.2 Study Area

The study area is located on the valley floor and walls of the Kootenay River Valley in Kootenay National Park (Figure 1.2). The Kootenay River Valley is in the Western and Main Ranges of the Rocky Mountains. It is bound to the northeast by the Vermillion Range, to the southeast by the Mitchell Range to the northwest by the Brisco Range and to the southwest by the Stanford Range. The Kootenay River flows southeast along the valley floor through the entire study area. The Kootenay River is joined by its tributary the Vermillion River, which flows in from the northeast, near Kootenay Crossing. Two larger drainages flow into the Kootenay from the east at Daer Creek and Pitts Creek.

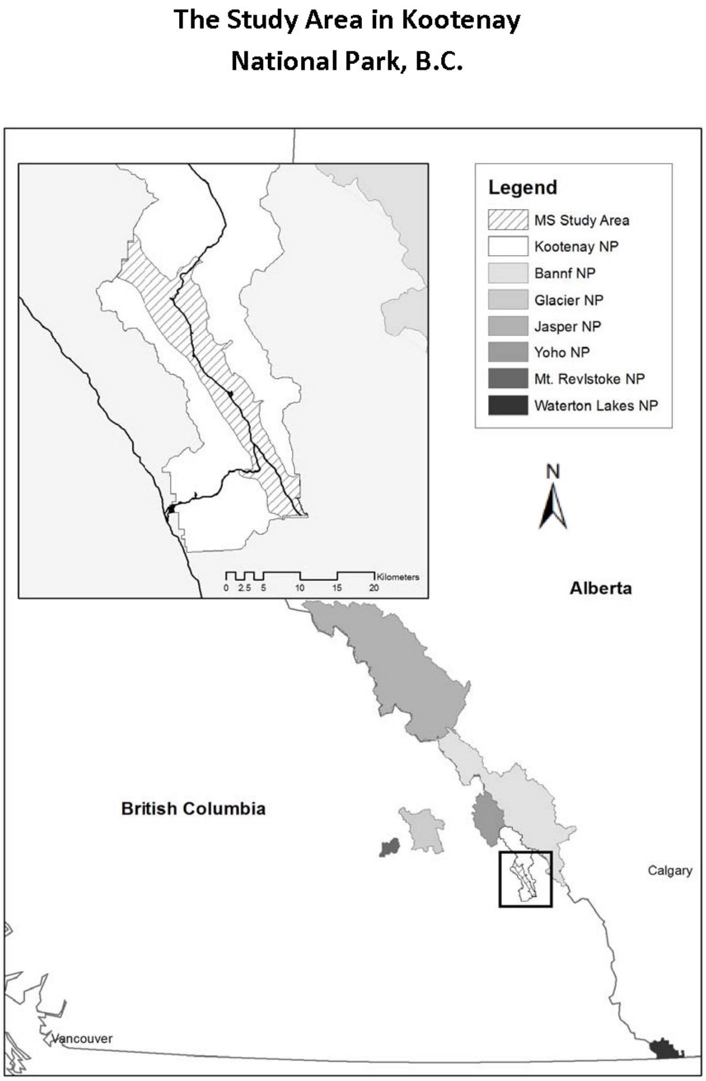


Figure 1.2 The study area in Kootenay National Park (KNP) related to adjacent national parks in British Columbia and Alberta. Inset is the MS BEC zone study area in the south end of KNP.

The study area encompassed a 35,400 ha area of forests along the valley floor of the Kootenay River valley in the southern end of the 1406 km^2 Kootenay National Park. The Kootenay River Valley is a broad U-shaped valley with a northwest to southeast strike. It is relatively homogenous in landform with prominent valley walls, benchland and bottomland features (Achuff, Holland et al. 1984). The study area soil parent materials are primarily calcareous and include glacial, fluvial, glaciofluvial and colluvial genetic materials (Achuff, Holland et al. 1984). Soil textures range from coarse to fine and organic material accumulation is limited to wet depressions. The study area contains primarily rapidly to moderately well drained soils dominated by Eutric Brunisols (Achuff, Holland et al. 1984). Wetland areas account for a small but important component of the soil community. The climate of the Kootenay Valley is considered to be Cordilleran with well defined maximum precipitation in winter months , poorly defined minima in late winter/early spring and a weak secondary maximum in summer (Hare 1974; Janz 1977). The climate is highly variable season to season and day to day driven by climatic controls that include latitude, position in the North American Continent, intervening mountain barriers and local topography (Janz 1977). The study area experiences mean annual temperature of 2.3 ± 3.4ºC (seasonal temperature ranges of -11.0ºC in winter and 15.2ºC in summer), and receives mean annual precipitation of 511.2mm per year (340.7mm as rain, 170.5cm as snow), Kootenay National Park, Kootenay Crossing 50º 53’ 00.000” N, 116 03’ 000” W, 1,174.0 m.a.s.l. (Environment Canada 2010).

The study area was delineated by establishing the boundaries of the Montane Spruce zone (MS) according to the BC Biogeoclimatic Ecosystem Classification (BEC) System (Pojar, Klinka et al. 1987). The MS BEC zone is closely related to the Montane Ecoregion as classified by the Parks Canada Ecological Land Classification system (Achuff, Holland et al. 1984). The elevation range of MS BEC zone is from 1200-1650m on south aspects to 1100-1550m on north aspects; the Montane Ecoregion is classified up to 1700 m on north aspects and 1900 m on south aspects. The MS BEC zone is dominated by climax white spruce (*Picea glauca (*Moench) Voss) and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt*.)*, with minor amounts of Douglas-fir (*Pseudotsuga* *menziesii* (Mirb.) Franco var. *Glauca* (Beissn.). Seral stands of lodgepole pine (*Pinus contorta* Loud. Var. *Latifolia* Engelm.) are common. The Montane Ecoregion is characterized by vegetation dominated by Douglas-fir, white spruce and trembling aspen (*Populus tremuloides* Michx.). In the Kootenay Valley the Montane Ecoregion extends from the valley floor and is noted to have had widespread wildfires resulting in seral lodgepole pine forests over much of the area (Achuff, Holland et al. 1984). The study area contains western larch (*Larix occidentalis* Nutt.) at the northern extent of its current range with scattered individuals throughout the valley (Achuff, Holland et al. 1984). Other tree species found in the study area include western hemlock (*Tsuga heterophylla* (Raf.) Sarg.).

1.2.1 Land Use History

The Kootenay Valley falls in the traditional territory of the Ktunaxa and Shuswap First Nations (Ktunaxa Nation Council Society 2005). Two of the seven bands that form the nation are currently centered in the area with the ?akisqnuk band in Windermere and the kyaknu╪i?it band in Invermere (Ktunaxa Nation Council Society 2005). First Nations peoples used the Kootenay Valley primarily as a travel route and a seasonal hunting and gathering area (Choquette 1987). European exploration and habitation of the Columbia Valley was first recorded in 1807 with the explorer David Thompson travelling down Howse Pass and taking up residence in the nearby Columbia Valley at David Thompson house (Belyea 1994). His explorations were part of the expanding fur trade which was the initial driver for European interest in much of Western Canada. Further exploration followed with the first recorded European travelling through Kootenay National Park being Sir George Simpson, Governor of the Hudson Bay Company, in 1841(Galbraith 1976). The Palliser Expedition continued to explore the area visiting occasionally from 1858-1860 (Spry 1995). Homesteading and permanent settlement in the Columbia Valley was occurring by the 1880’s (Harris 1997). In 1914 a road was completed to connect the Bow Valley to the east with the burgeoning human settlement in the Columbia Valley and the developing interests at Radium Hot Springs (Parks Canada Agency 2013). Kootenay National Park was established in 1920 with the boundaries being amended in

1922 to roughly its current size (Parks Canada Agency 2013). In 1923 the Banff-Windermere Highway was opened (Parks Canada Agency 2013)

The above land use history likely had implications for the fire regime. First Nation use almost certainly had some impact on the historic fire regime as both of these peoples were known to use fire as a resource management tool (Barrett 1980). Fire use by First Nations occurred in many nearby cultures (Norton 1979; Barrett and Arno 1982; Lewis 1982; Turner 1991; Gottesfeld 1994). The reasons for First Nation fire use varied but included graze management for horses and game, enhancing food crops, improving travel routes and camping locations (Barrett 1980; Pyne 1982; Boyd 1999). Settlement period land use likely had limited impact on the fire regime as there was limited homesteading in the study area and the area was not utilized for resource extraction such as mining.

The establishment of the Park in 1920 would have initiated the first formal land management which would have practiced active fire suppression. Beginning in the 1930's fire suppression was a significant concern and the active suppression and reporting of wildfires suppression was occurring (White 1989). A search of the fire records data base that tracks fire records from the 1920's through until the present indicated no known wildfire greater than 60 hectares has occurred in the valley since 1926. Fire suppression policy in the National Parks evolved in the 1980's to include the understanding of the need to reintroduce fire as a keystone ecological process (White 1989). In Kootenay National Park this resulted in the evolution of a prescribed fire program that began in the early 2000's with several prescribed fires under 50 hectares in size. The program evolved to include the 1400 ha Mitchell Ridge prescribed burn completed in 2009. The Park currently operates under a Fire Management Plan that includes the utilization of prescribed fire and the provision for unplanned wildfire to contribute to ecological goals (Parks Canada Agency 2011).

1. 3 Research Objectives

In this study I seek to better understand the fire regime specific to the MS BEC zone in the Kootenay Valley. This information is required to provide improved guidance for active fire management in the park and may prove useful to other resource management agencies utilizing natural disturbance paradigms to guide management. Elements of mixed-severity fire have increasingly been documented as part of fire history study in recent regional research (Heyerdahl, Brubaker et al. 2001; Da Silva 2009; Nesbitt 2010; Amoroso, Daniels et al. 2011; Greene 2011; Marcoux 2013). Evidence suggests (Masters 1989; Cochrane 2007; Daniels, Cochrane et al. 2007; Daniels, Soverel et al. 2008) that an element of mixed-severity fire exists in the Kootenay Valley that has not previously been characterized. I sought to understand the extent and drivers of mixed-severity fire in the MS BEC zone of the Kootenay Valley.

Specifically I sought to address three research questions, each followed by a prediction:
Q.1.Does the fire regime of the Kootenay Valley have a mixed-severity signature detectable by linking age cohort information to fire event evidence?
A mixed-severity fire signature will be observable in the age cohort data linked to fire event evidence.

Q.2. Does the spatial pattern of high-severity and mixed-severity fire in the study area differ by topographic attributes?
Fire severity will vary by slope angle, slope aspect or elevation. High severity fire will be more common on cooler slope aspects at higher elevations.

Q.3. Does the accuracy of the stand-origin map vary with fire severity or stand age?
The stand origin map will be more accurate in younger stands generated by high severity fire.

To address these questions I developed a study method to systematically sample the MS BEC zone of the Kootenay Valley in order to collect age cohort and fire event evidence.

Chapter 2 - Methods

2.1 Introduction

To explore the mixed-severity fire regime in the MS BEC zone of the Kootenay Valley forest age structure data and fire history information inferred from fire scars was used to answer three research questions:

> Q.1.Does the fire regime of the Kootenay Valley have a mixed-severity signature detectable by linking age cohort information to fire event evidence?
>
> Q.2. Does high-severity and mixed-severity fire in the study area differ by bottom up controls?
>
> Q.3. Does the accuracy of the stand origin map vary with fire severity or stand age?

My research involved systematically collecting fire history and age cohort data to apply in a fire severity classification scheme. Utilizing this scheme I attempt to establish relationships between fire severity and bottom up controls. Finally I analyze the accuracy of the existing stand-origin map.

2.2 Research Design

To examine the fire history in 43 plots in KNP I used a systematic research design to collect fire scar and age cohort data following established sampling methodologies (Fule, Crouse et al. 2003; Schoennagel, Turner et al. 2006; Sherriff and Veblen 2006; Brown, Wienk et al. 2008; Heyerdahl, Lertzman et al. 2012). To select each plot, I used a geographic information system (GIS:ESRI, ARCGIS 2012) to overlay a 2 km by 2 km grid on the 3km by 10km area of the MS BEC zone in the Kootenay River Valley. The grid was visually adjusted to minimize plot disruption by watercourses or other non-forested features and 51 intersection points within the MS BEC zone were selected. Plot locations (UTM coordinates) were then generated for field sampling from the GIS. In the field, plot centres were located using a GPS unit and assessed to verify that adequate forest cover existed along 100-m transects orientated along the four cardinal bearings from plot centre. If more than 60% of any one transect intercepted non-forested vegetation or was deemed inaccessible due to travel limitations such as an impassable water course plot centres were adjusted. Seven plots were adjusted by moving the plot centre at a 90° angle away from the non-forested vegetation or disrupting feature by an adequate distance to enable a full 100 metre transect. In total 43 plots were sampled; eight plots were deemed inaccessible and could not be sampled.

2.3 Field Sampling

At each plot sampling was undertaken to assess fire history and stand dynamics related to disturbance. Two stand-dynamic sampling methodologies were used. The stand-dynamic methodology used during a pilot study from July through September 2008 ($n = 4$ plots) was modified during the primary field season from May through September 2009 ($n = 39$ plots). In 2008 at each plot centre I documented stand composition and age structure using a fixed-area 20 x 20 metre plot (Daniels, Soverel et al. 2008). All trees with a diameter at breast height (DBH $\geq$10 cm) were sampled for species, DBH and status as living or dead. Because stand densities varied, sample sizes were uneven among sites. During the primary field season in 2009, I documented stand age utilizing an n-tree density-adapted sampling design (Lessard, Drummer et al. 2002). Based on a review of the data compiled during the pilot field season I switched to the more time effective N-tree sampling design. It was felt this sampling design provided an approach that would adequately capture the primary age class (overstory) structure that I required to relate age cohorts to fire severity. Using the N-tree design I sampled the 20 trees (DBH $\geq$ 10 cm) closest to plot centre to a maximum distance of 30 m (Heyerdahl, Miller et al. 2006). The distance to the furthest tree was measured, from which tree density was estimated. During both field seasons each sampled tree was cored as close to the tree base as possible and a maximum of three attempts was made to include the pith. The height of core collection was recorded and cored trees were permanently marked with a tree tag.

In 2008 and 2009, fixed-area plots of 1.44 ha were systematically searched for fire scarred trees. Four 100 x 40 m transects anchored at plot centre were established on cardinal bearings to define the fire scar search area. Inside this plot I located and assessed all observed fire-scarred trees. Fire scars were differentiated from other mechanical scarring using field-based criteria such as charcoal and basal scarring (Arno and Sneck 1977; Dieterich and Swetnam 1984). Up to five fire-scarred trees were selected in each plot to maximize fire history information. Preference was given to trees with more than one scar, living trees and scarred Douglas-fir and western larch as these thick-barked species are known to be fire resistant and strong recorders of fire scars. Samples were gathered either by cutting full or partial cross sections (Arno and Sneck 1977; Cochrane and Daniels 2008). Attempts were made to minimize impact by selecting fire-scar samples with minimum ecological impact (no active nest sites visible). For each tree from which a scar was collected, the species, DBH, and scar sample height were recorded.

Baseline metrics describing physical attributes at each plot were collected in both seasons including: slope aspect, slope angle, BEC site series and moisture regime. Site slope aspect was converted into a linear solar exposure index representing warm (0 = southwest) to cool (180 = northeast). Moisture regime was established using a classification scheme developed from the BEC system (Comeau et al. 1984; Braumandl, Curran et al. 2002). This scheme utilizes the relative abundance of plant indicator species to determine the site series. The site series are considered over on an edatopic grid to classify a site into one of eight moisture regime classes ranging from 0 (xeric) to 7 (sub-hydric). To facilitate analysis I classified these 8 classes into one of three moisture groups xeric (Moisture Regime Class 0-2), mesic (Moisture Regime Class 3-4) and hygric (Moisture Regime Class 5-7).

2.4 Geographic Information System Data

I used GIS and data utilized by Kootenay National Park to derive several biophysical attributes for each plot. I determined the elevation (meters above seas level. m.a.s.l.) for each plot centre location based on a 30 x 30 meter Radarsat Digital Elevation Model (DEM). While I had determined plot-level slope angles and aspects in the field, fire behaviour can be influenced by aspect at a broader scale (Countryman 1978). In order to consider slope angle and slope aspect at a broader-scale I developed a metric for landscape topography. I down sampled the 30 m x 30 m DEM to create an interpolated 90-meter DEM grid. Utilizing the interpolated 90-meter DEM grid I established a landscape-scale slope aspect and slope angle for each plot centre. As described above I converted the landscape aspect into a linear solar exposure index representing warm (0 = southwest) to cool (180 = northeast). In order to test for relationships between existing ecological data and fire history I utilized the GIS to determine the ecosite from the ELC system (Achuff, Holland et al. 1984) and the leading species and stand age from the Vegetation Resource Inventory (VRI: (BC Ministry of Sustainable Resource Management 2002)) for each of the plot centers. To facilitate analysis for the ELC I grouped the multiple ecosites to the ecosection scale. Finally, I extracted the stand-origin calendar year for each plot as determined by Masters (1990).

2.5 Dendrochronological Analysis

Fire scars were processed and crossdated by the author while cores were processed and crossdated by staff at the Tree-Ring Lab at UBC (Jones 2010). Fire-scar and core samples were prepared following well-established procedures (Stokes and Smiley 1996). Fire-scar disks were air dried and unstable samples were mounted on wooden supports. In order to view rings through a microscope fire-scar disks were sanded using progressively finer sandpaper to 400 grit. Fire-scar samples from live trees were visually crossdated (Stokes and Smiley 1996) to existing tree-ring chronologies (Daniels, Cochrane et al. 2007). Fire-scar disks from dead trees were measured to the nearest 0.001 mm using a Velmex bench interfaced with Measure J2X V3.2.1 measuring software (VoorTech Consulting, Holderness, NH). The resulting tree-ring series were statistically crossdated using the programs COFECHA (Holmes 1983; Grissino-Mayer 2001a) to assign a calendar year to the outermost ring of each sample. Each fire scar was delineated to annual resolution and the calendar year was recorded (Dieterich and Swetnam 1984). All crossdated samples were subjected to a final review to determine which scars could be attributed to fire. To ensure that my fire scar record was accurate relative to the modern fire suppression period the Kootenay National Park fire record database was searched to determine if any reported fires occurred in or adjacent to my plots. I revisited the morphology of all scars and compared the scar years to other scar years in the plot and tree age information to conservatively differentiate scars caused by fire versus other disturbance agents. Only scars caused by fire were used in subsequent fire history analyses.

Similar to the fire-scar disks, cores were air dried, mounted on wooden supports and sanded using progressively finer sandpaper to 600 grit. Two main sources of error can affect tree age estimates: missing rings and the number of years it took each tree to grow to the coring height. These error sources were addressed using crossdating, estimating missing rings at pith, and height corrections. Cores from live trees were visually crossdated and cores from dead trees statistically crossdated using the methods described above. To verify crossdating for the cores, we used the Math Graph function of TSAP-Win (Rinn 2003) to visually compare the ring-width series of the individual samples against the ring-width series of the appropriate species-specific chronologies. For all cores, we assessed whether or not the core included pith, arced rings near the pith or neither arced rings nor pith. For cores that included ring arcs, we estimated the number of missed rings to the pith using geometric measures of the rings (Duncan 1989). To estimate the number of years it took each tree to grow to the height at which it was sampled, we applied height corrections derived from saplings collected in Kootenay National Park (Daniels, L.D. 2007, unpublished raw data).

2.6 Disturbance History

To graphically represent disturbance histories at the plot level I created histograms for each plot. These histograms detail the stand age data, showing the number of trees that established each decade. Samples were differentiated into two classes, one with a combined age correction (rings from the pith or height to the core) of ≤20 years (91% of age samples) and a second class with a combined correction (pith and height) of 21-40 years (8%). Samples with a correction greater than 40 years were discarded (1%). Fire events consisting of calendar years determined from fire scars and the stand-origin date assigned by Masters (1990) were also depicted. These histograms were used to visually link fire events to age cohorts and identify age cohorts that were not linked to fires.

A preliminary review of my histograms indicated that several of my plots showed strong establishment cohorts following fire, several showed a weaker relationship between fire events and establishment cohorts and some showed no relationship between fire events and establishment cohorts. To characterize fire severity across my study area and to analyze potential relationships between fire severity and other forest attributes I developed a fire-severity classification scheme. The criteria for my scheme included fire scar (Heyerdahl, Lertzman et al. 2012), establishment cohort and remnant tree data relative to documented fire events (Sherriff and Veblen 2006; Amoroso, Daniels et al. 2011). The newly developed scheme was specific to the forest types in my study area and was designed to assess fire severity through time. As such I considered multiple lines of evidence of the severity of fire at a site over time and not just the severity of the last fire to affect a site. In my study area stand level disturbance related to mountain pine beetle (*Dendroctonus ponderosae*) has been documented in the 20th century. Known outbreaks occurred in the 1940's (Shrimpton 1994) and through the 1980's until present (Canadian Forest Service 1980-2006). The presence of these disturbances has been shown to affect stand age dynamics (Dykstra and Braumandl 2006; Dordel, Feller et al. 2008; Axelson, Alfaro et al. 2009) which indicates that the potential exists for historic age class cohorts to have been driven by landscape scale forest insect outbreaks. Working with age class cohorts in my study area required cautious interpretation with respect to assigning establishment cohorts to fire disturbance.

I developed a classification fire-severity classification scheme (Figure 2.1) using three criteria to classify my plots into one of three fire-severity groups: high fire severity, mixed fire severity and unknown fire history. I chose to not establish a low-severity fire group since my data revealed few trees with multiple fire scars and a low abundance of tree species such as ponderosa pine and western larch that are commonly associated with frequent low-severity fire.

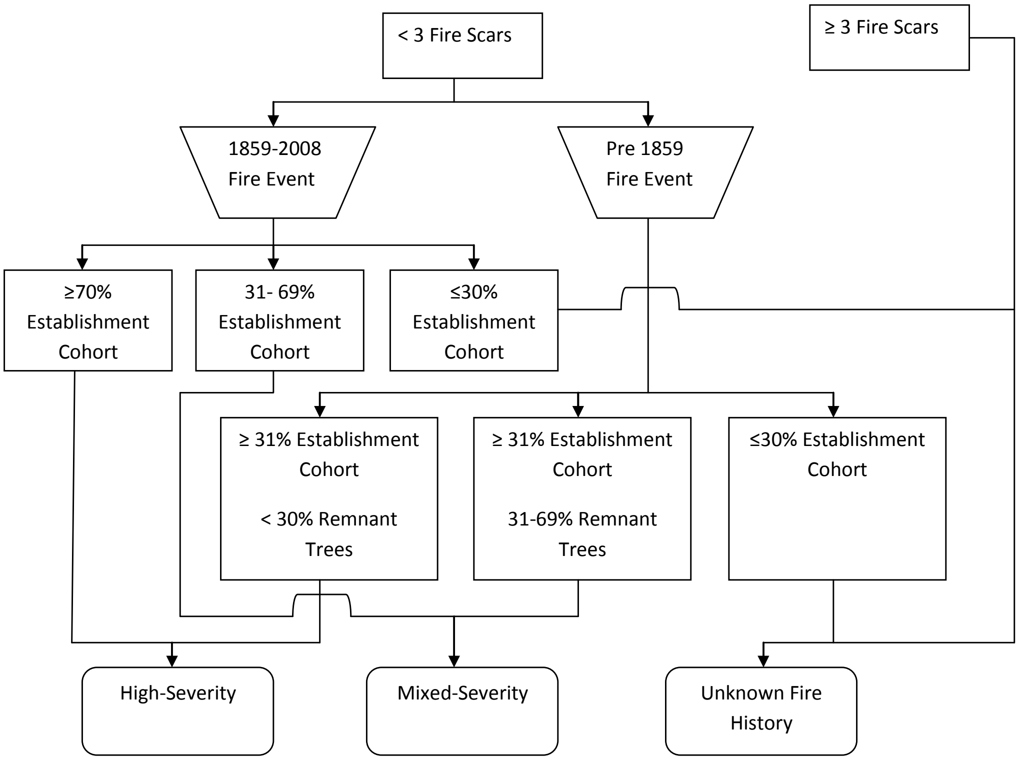


Figure 2.1 Fire-severity classification criteria outlined in a decision tree.

The first criterion I utilized in my classification scheme was fire scar years. The presence of multiple fire scar years indicates tree survivorship following low-severity fires. I chose a conservative break point of ≥3 fire scar years as evidence that a plot had been affected by mixed-severity fires in the past. For this assessment I considered the fire scar years I determined for each plot. These data included multiple scars on single trees or a composite of fire scars at a plot dated to different years on multiple trees.

The second criterion focussed on the establishment of even aged cohorts post fire as evidence of fire severity. I defined breakpoints to link fire severity to establishment cohorts for relatively recent fire events. I chose to consider this criteria for fire events that burned <150 years prior to sampling as this time frame limited the probability that in-stand disturbance had significantly affected the stand age dynamics. Either a fire scar year or a stand-origin year represented a known fire event. I utilized Masters (1990) stand-origin data as a fire event as it had to be linked to an establishment cohort.

The forests in the study area contain lodgepole pine which regenerates from serotinous cones (Achuff, Holland et al. 1984) and forms even-aged post-fire cohorts immediately following fire (Lotan and Perry 1983). I chose to utilize a 20-year window after disturbance as a conservative approach to ensure establishment cohorts were tightly linked to fire events. This criterion is well supported as post-fire establishment cohorts of both lodgepole pine and white spruce form in <20 years following moderate-to-high severity fires in the eastern foothills of the Rocky Mountains (Amoroso, Daniels et al. 2011). In addition, preliminary review of my age class data indicated ≥91% of my age data had combined corrections <20 years indicating an adequate degree of accuracy in my data to utilize this criteria. To classify plot level fire history in ponderosa pine-dominated forests with mixed-severity fire regimes researchers considered age cohorts that included a pulse of 20 to 70% of trees in a stand to represent a mixed-severity fire (Sherriff and Veblen 2006; Hessburg, Salter et al. 2007). Given the prevalence of lodgepole pine throughout my study area and the presence of other disturbance types that drove establishment cohorts I chose to take a conservative approach. I considered cohorts that included ≥70% of trees in to represent a high-severity fire similar to several other studies (Sherriff and Veblen 2006; Hessburg, Salter et al. 2007; Amoroso, Daniels et al. 2011). I considered establishment cohorts of 30-69% to represent mixed-severity. In stands where <30% of trees in a plot established after a fire or if age cohorts were present but not related to a known fire event the cohorts were classified as unknown fire history.

The final criterion I utilized was the presence of remnant trees that survived fires that burned >150 years prior to sampling. Several studies have considered remnant trees to be an important indicator of fire severity, as they represent the survivorship of trees from a pre-existing stand (Sherriff and Veblen 2006; Heyerdahl, Lertzman et al. 2012). For my classification scheme I identified remnant trees in plots with fire events >150 years ago and calculated the percentage of remnant trees that survived individual fires. I took this step to compensate for the decreasing record problem in which evidence of post-fire cohorts that established long ago decreases through time due to tree death and stand development processes. Using remnant trees compensates for the loss of evidence through time by emphasizing survivorship. Fires that burned > 150 years ago were considered to be high-severity if ≤ 30 of the trees were remnants and ≥ 31% established in a post-fire cohort. I considered the fire event to be mixed-severity if 31-69% of the trees were remnants and ≥31% established in a post-fire cohort. Fire events with ≤ 30% establishment cohort were classified as unknown severity.

2.7 Fire Frequency

Quantifying fire frequency is one of the core elements of most fire history studies. Fire frequency derived from fire-scar dates is often calculated for individual trees, plots and the study area depending on the research questions and ecosystem studied. The calculation of fire frequencies requires 2 or more fire scars to generate means as the intervals represent the period between fires. The decreasing record through time needs to be considered when conducting fire-frequency analysis. Challenges associated with limited sample sizes and decreasing fire record are overcome by developing composite fire records that amalgamate individual tree records at various scales (Dieterich 1980). For forests dominated by thin-barked species such as lodgepole pine, which are not strong recorders of multiple fires (Agee 1993), opportunities to develop fire frequency metrics can be limited. Given I was working in a system dominated by thin barked species I limited my fire frequency analysis to the plot and study area.

At the plot scale I amalgamated the fire scars from individual trees to generate composited-plot-level fire intervals (CPFI). I report CPFI as the mean and range of all fire scars for those plots with 1 or more fire intervals. For the study area I amalgamated all recorded fire scars to generate composited study area fire intervals (CSFI). I utilized FHX2 software (Grissino-Mayer 2001b) to develop the CSFI as well as to compare periods of contrasting land management. To consider fire frequency changes related to different land management practices I partitioned my historic fire scar record in two equal 80 year sections to ensure equal representation and direct comparability. The period from 1847 – 1927 was defined as the “settlement period” and was bound by the arrival of European activity in the Park (Galbraith 1976), and the start of modern fire suppression (White 1989). The period 1766 – 1846 was defined as the “pre-settlement” period. I did not develop metrics for the modern fire suppression period 1928 – 2008 as there has been no unplanned wildfire in the study area greater than 60 hectares in size since 1926. For CSFI and each historic time period I report the time period of record, number of fires, and the range and mean for fire return intervals in the study area. In addition I report on these metrics for those fire events that scarred at least 25% of the samples to provide fire frequency metrics for larger fires.

2.8 Fire Severity Drivers

Forest fire is influenced by a mix of top-down controls such as regional climate and bottom-up controls such as topography, forest composition and fuel loads (Falk, Heyerdahl et al. 2011). Given the scale of my study area and my interest in understanding the drivers for specific management purposes, I chose to focus on the bottom-up controls. Specifically, I focused my analysis on assessing whether topographic drivers varied among the fire severity groups. I analyzed the following continuous variables to describe relationships to fire severity groups using analysis of variance (ANOVA:(SPSS Inc Released 2009)): elevation, slope angle, slope aspect, solar exposure index, landscape slope angle, landscape slope, landscape solar exposure index. In addition I utilized ANOVA to assess whether Masters (1990) stand age varied among the fire severity groups.

Forest fire is also influenced by and influences species composition and stand size structure. The relationship of individual tree species to fire severity is understood at the physiological scale but not at the community scale (Agee 1993). Several studies have established relationships between forest composition and fire regime parameters (Beaty and Taylor 2001; Heyerdahl, Brubaker et al. 2001; Beaty and Taylor 2008; Marcoux 2013). To explore relationships among fire severity with forest composition and structure I utilized ANOVA to test for differences among fire severity groups and the following stand attributes: tree density, average DBH, maximum DBH, DBH range, age class continuity index, age class range and relative abundance of the three primary tree species white spruce, lodgepole pine and Douglas-fir. I used an age class continuity index to consider the relationship between my stand age class distribution and fire severity

(Marcoux 2013). This index provides a metric for the continuity of tree establishment. It is compiled by taking the total number of ten year bins in the age class range and dividing it by the number of occupied ten year bins. I utilized contingency table analysis to assess variation among fire severity groups for the following: ELC Ecosections and BEC moisture regimes and site series.

2.9 Stand-origin and VRI Map Accuracy

The stand-origin map (Masters 1990) and Vegetation Resource Inventory (VRI) are two data sources frequently used by Kootenay National Park to consider a wide range of issues such as wildlife habitat related to stand age and leading species. To better understand the accuracy of the existing stand-origin map and VRI data for my study area in the Kootenay Valley I compared these data to a number of forest age and fire history attributes I collected.

Stand-origin maps are a common result of traditional fire history reconstructions used to estimate fire frequency. I analyzed my data to determine the extent of the discrepancies between the stand-origin map and my age class data and to understand if these discrepancies were related to fire severity or the age of the forest. I utilized my age data at the plot scale to determine: the estimated year of establishment of the oldest tree, the calendar year corresponding to the median tree age, and the calendar year of the oldest tree in the largest cohort. If there were two equal cohorts I used the earlier cohort. For each plot I calculated the difference between Masters (1990) stand-origin date and each of the observed forest age attributes. I plotted the differences in box plots to describe the accuracy of the stand-origin map relative to my stand-dynamics data and fire severity groups. I used my error values to develop 20 year classes (error class 1 ± 0-19 years: class 2 ± 20-39 years: and class 3 ± 40 years or more) to facilitate analysis. I utilized Contingency Tables to consider the relationship between my fire severity groups and the error classes. I utilized ANOVA to determine the relationship between stand-origin year and the error classes.

The VRI classification of KNP was completed in the last ten years. The data layer replaced the vegetation classification from the Ecological Land Classification as the primary data layer used to consider ecological issues. As a new data layer to KNP, its limitations are not yet well understood. To assess the accuracy of the VRI stand age I calculated the difference between the VRI generated stand ages and my stand-dynamic attributes (oldest tree, median age, and age of largest cohort) following the error class approach utilized for the stand-origin map analysis. I converted VRI stand ages to stand-origin years to complete the analysis. Utilizing confusion matrices (Lillesand, Kiefer et al. 2003) I examined the accuracy of the VRI leading species relative to the leading species from my field data.

Chapter 3 - Results

3.1 Introduction

In order to determine forest structure, to reconstruct fire history and to explore the links between fire severity and plot attributes I sampled 43 plots (Figure 3.1) in a systematic grid covering the Montane Spruce BEc zone in the Kootenay River Valley in Kootenay National Park. This chapter details the results of these investigations.

3.2 Plot Attributes

Field plots were located across the range of elevation, slope angle and slope aspect of the study area (Table A-1). Elevations of plots ranged from 1101to 1467 metres above sea level (m.a.s.l.) (1225 S.D. ± 65.75: mean ± SD). Site and landscape slope aspects covered the full range from 0 to 360º. Site slope angles ranged from 0 to 40º (7 ± 9.2). Landscape slope angles ranged from 0.5 to 19.8º (6 ± 5.3). Moisture regimes varied from 1 to 6 and site series varied from 1-7. Twelve different ecosites were recorded representing 4 ecosections.

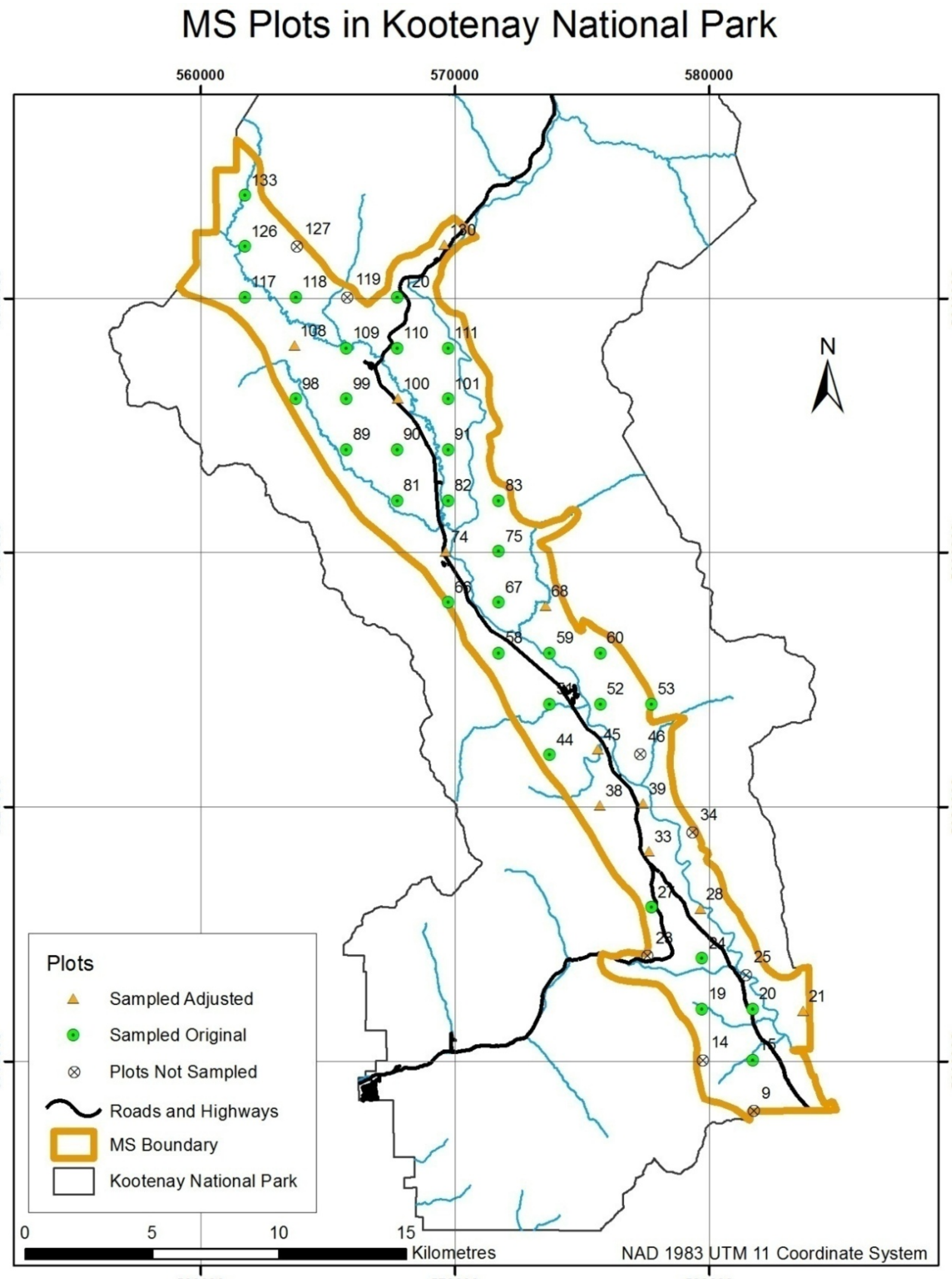


Figure 3.1 Systematic grid of 51 plots covering the MS BEC Zone of the Kootenay Valley. Forty-three sampled plots and field adjustments to plot locations are shown.

3.3 Species Composition and Tree Ages

Tree densities (DBH > 5 cm) ranged from 132 to 2548 trees per ha (723 ± 501 trees per ha; Table 3.1). White spruce dominated 24 of 43 plots (56%); lodgepole pine dominated 15 plots (35%) and Douglas-fir dominated the remaining 4 plots (9%). Subalpine fir was a minor component in nine plots and western larch and western hemlock were each present in one plot. Relative abundance across the study area for the three dominant species was: white spruce 46%, lodgepole pine 39% and Douglas-fir 13%.

I sampled 982 trees of which 746 (76%) were living and 236 (24%) were dead snags. I excluded 62 (6%) of the samples due to low sample quality or difficulties in crossdating. Of the 920 trees that were successfully dated 731 (79%) were living and 189 (21%) were dead snags. Ninety-five percent of cores included either the pith or ring arcs, and 5% did not include any arcs. Most cores (86%) were missing an estimated five or fewer rings (range 0–87). Based on height corrections, most trees (87%) took an estimated 10 or fewer years to grow to coring height (range 0–38). When the two corrections were combined, 91% of the trees had total required adjustments ≤ 20 years and 73% were adjusted by ≤ 10 years. The results of this dendrochronological analysis support the use of 20 year age classes to consider age cohort assignment as 91% of the samples had total adjustments ≤ 20 years. These summary data were utilized to determine relationships with fire severity groups.

Table 3.1 Plot species and stand structure attributes: tree density, leading species (SW = white spruce, SE = englemann spruce, LP = lodgepole pine, FD = Douglas-fir, SaF = subalpine fir, WL = western larch, and WH = western hemlock), Vegetation Resource Inventory (VRI) leading species, age range and age class continuity index.

Plot Number	Tree Density (trees/ha)	Leading Species	Relative Abundance by Species (%)				VRI Leading Species	Age Range (years)	Age Class Continuity (index)
			SW	PL	FD	Other Species			
15	408	SW	85	0	15		SE	126	53
19	1047	SW	60	0	30	SaF 10	FD	203	33
20	892	SW	80	20	0		FD	126	35
21	287	PL	0	50	50		FD	167	60
24	1074	SW	65	20	15		PL	27	100
27	1508	PL	0	70	30		PL	29	80
28	203	PL	0	95	5		PL	21	100
33	1875	PL	37	63	0		PL	19	100
38	650	SW	86	0	10	WL 3	SE	101	55
39	1625	PL	31	69	0		PL	87	60
44	297	SW	60	5	0	SaF 20 WH 15	SE	139	67

45	650	SW	72	28	0		SE	148	75
51	663	SW	90	5	0	SaF 5	SE	168	29
52	302	PL	35	60	5		FD	94	82
53	458	SW	50	35	15		FD	126	36
58	355	SW	55	0	40	SaF 5	SE	123	80
59	630	SW	95	0	0	SaF 5	SE	114	50
60	367	PL	30	45	25		SE	64	100
66	551	SW	100	0	0		SE	81	73
67	546	SW	85	15	0		SE	100	77
68	482	SW	80	20	0		FD	169	45
74	1264	PL	30	70	0		SE	39	100
75	804	SW	55	25	20		FD	133	67
81	454	PL	30	70	0		PL	110	75
82	589	PL	20	80	0		PL	89	64
83	185	PL	10	70	20		PL	39	100
89	721	SW	45	35	0	SaF 20	PL	82	82
90	202	PL	30	50	10	SaF 10	PL	65	90
91	392	SW	50	50	0		PL	58	100
98	654	SW	55	45	0		SE	26	100
99	2293	SW	70	30	0		PL	13	100

100	302	SW	80	20	0		PL	59	78
101	396	PL	0	70	25	SaF 5	PL	267	31
108	804	SW	40	35	25		PL	182	38
109	132	SW	100	0	0		SE	158	72
110	449	FD	29	33	38		FD	43	86
111	1106	SW	65	10	25		FD	82	45
117	1764	PL	20	80	0		PL	40	86
118	1132	PL	5	80	15		PL	24	100
120	225	FD	5	30	65		FD	23	100
126	896	SW	45	30	20	SaF 5	SE	105	46
130	412	FD	20	30	50		FD	58	63
133	1047	FD	0	0	100		SE	75	60

3.4 Disturbance History

My results clearly indicate the presence of a mixed-severity fire regime in the MS BEC zone of the Kootenay Valley. Based on fire scars, age cohorts and remnant trees (Table A-2), the fire history of 9 plots was classified as high-severity, 18 plots included evidence of mixed-severity fires and at 16 plots fire history could not be determined (Table 3.2: Figure 3.2).

Table 3.2 Plots delineated into fire severity groups.

Fire Severity Groups	**Plots**	**Count**
High Fire Severity	20,24,27,28,33,38,98,118,120	9
Mixed Fire Severity	15,19,21,39,59,75,82,89,90,99,100,101,108,109,111, 117,126,133	18
Unknown Fire History	44,45,51,52,53,58,60,66,67,68,74,81,83,91,110,130	16

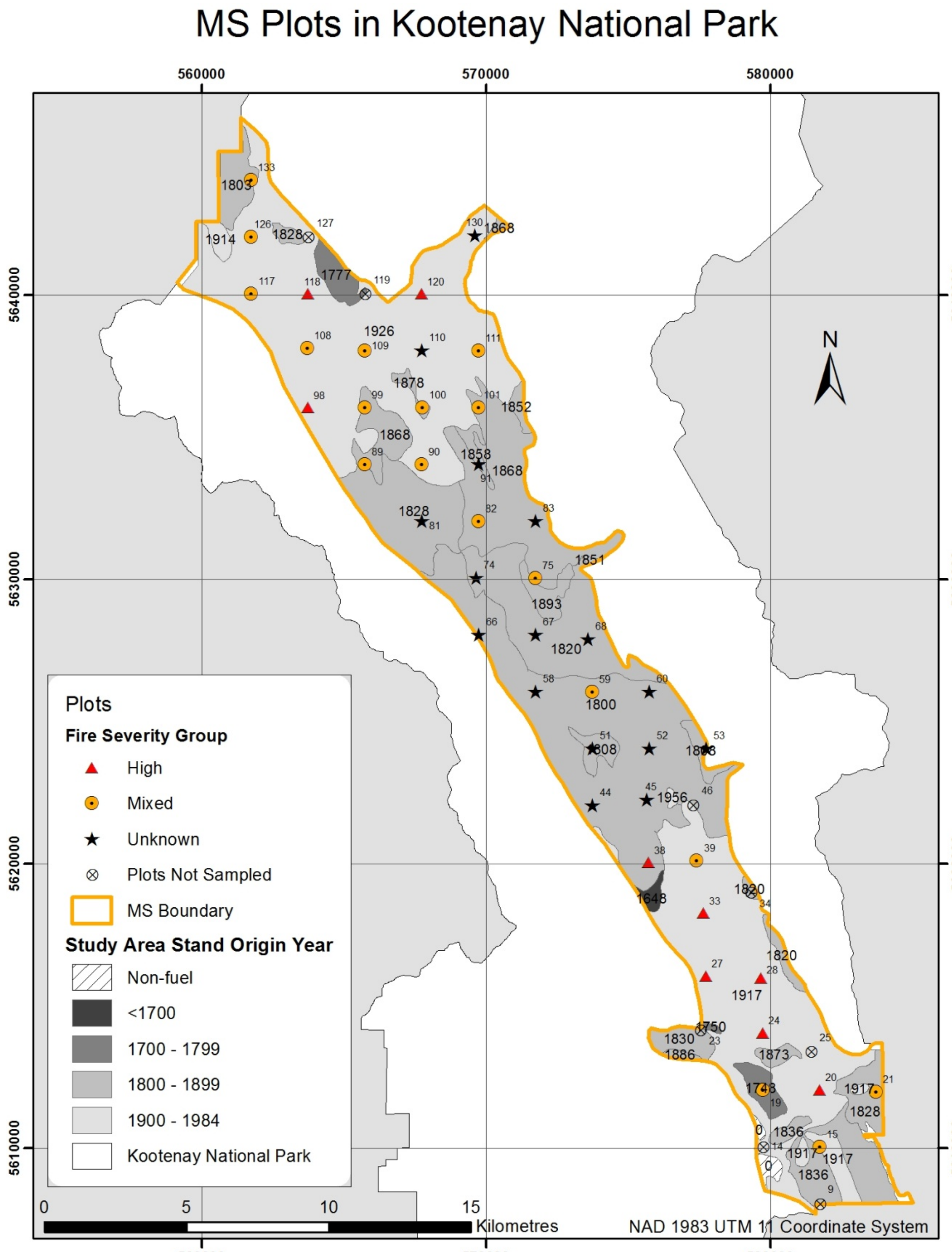
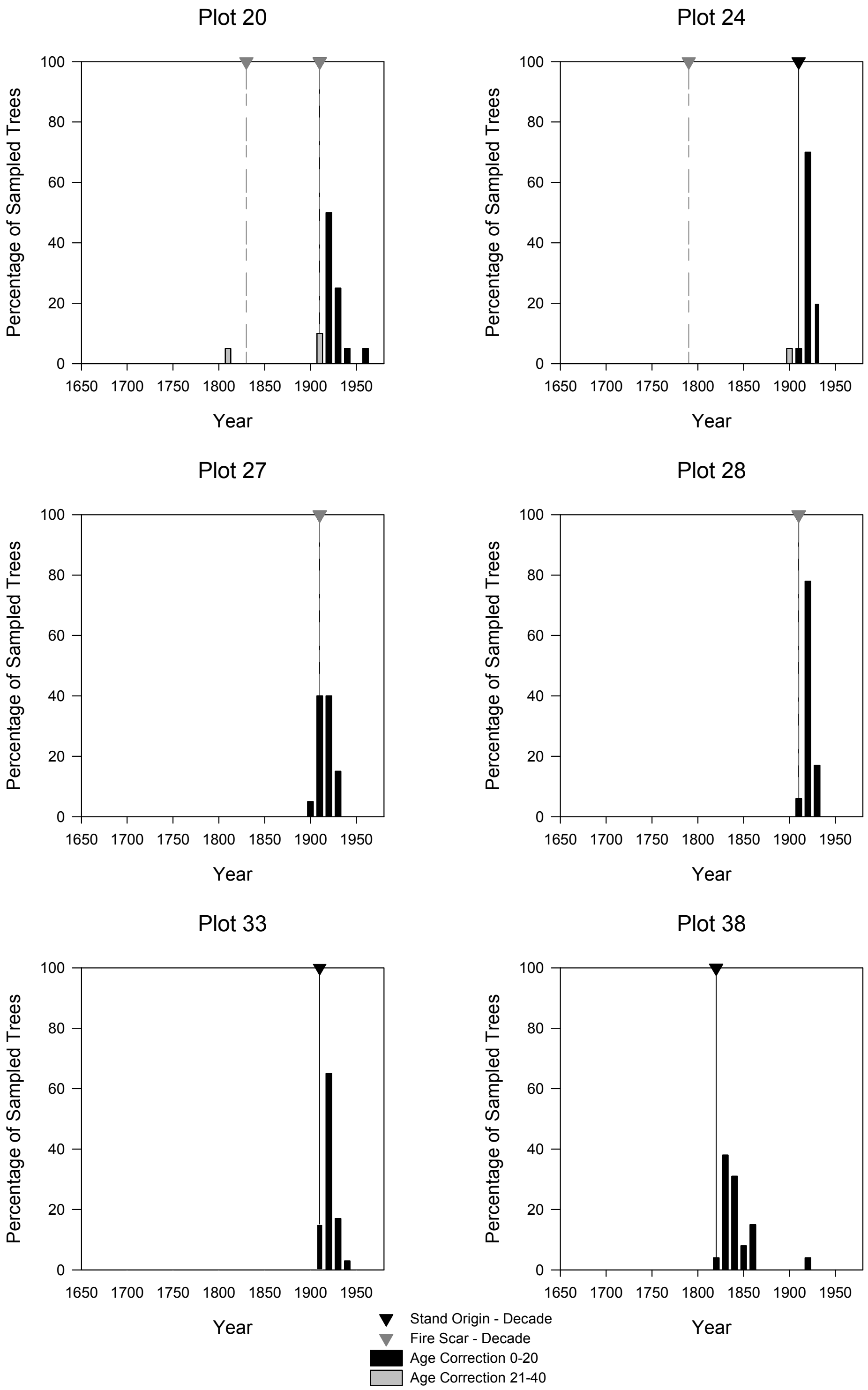


Figure 3.2 Forty-three fire history plots delineated by fire severity group overlaid on stand-origin-map polygons (Masters 1990).

To explore the influences of the criteria I chose to develop my classification scheme I will briefly describe the influence of each of the criterion in determining how plots were classified into the fire severity groups. Histograms depicting fire events relative to age cohorts created for the 43 plots are useful to visualize age cohort relationships to fire events and to understand the relationship of non-fire age cohorts. These histograms are displayed for each of the fire-severity categories.

The fire history of plots 20, 24, 27, 28, 33, 38, 98, 118 and 120 were classified as high-severity (Figure 3.3). To be classified high-severity a site had to have <3 fire-scar years and any fire that burned after 1859 had to initiate a cohort that included ≥70% of the sampled trees or any fire that burned before 1859 had to initiate a cohort that included ≥ 30% of the sampled trees and ≤ 30% trees were remnants that survived the fire. Of the 9 high-severity plots, 4 plots (Plots 33, 38, 98, 120) had no fire scars, 4 plots (Plots 24, 27, 28, 118) had 1 fire-scar year and one plot (Plot 20) had 2 fire-scar years. At Plots 27, 28, and 118, the fire-scar year were concurrent with the establishment cohort that indicated high severity fire. Plot 24 had a fire scar that was unrelated to the establishment cohort. Plot 20 had 2 fire-scar years, one of which 1 was related to the establishment cohort. Of the 9 high- severity plots, Plots 20, 24, 27, 28, 33, 98, 118 had a cohort that included ≥ 80% of trees that established after fires in 1917 or 1926. At Plot 120, the cohort included 70 -79% of trees that established after the 1926 fire. All of these sites remnant trees accounted for ≤ 15% of the trees in the plot. Only the fire history of Plot 38 was classified as high severity based the presence of remnant trees that survived a fire prior to 1859.


Plot 20
Plot 24
Plot 27
Plot 28
Plot 33
Plot 38
Percentage of Sampled Trees
0
20
40
60
80
100
Year
1650
1700
1750
1800
1850
1900
1950
Stand Origin - Decade
Fire Scar - Decade
Age Correction 0-20
Age Correction 21-40

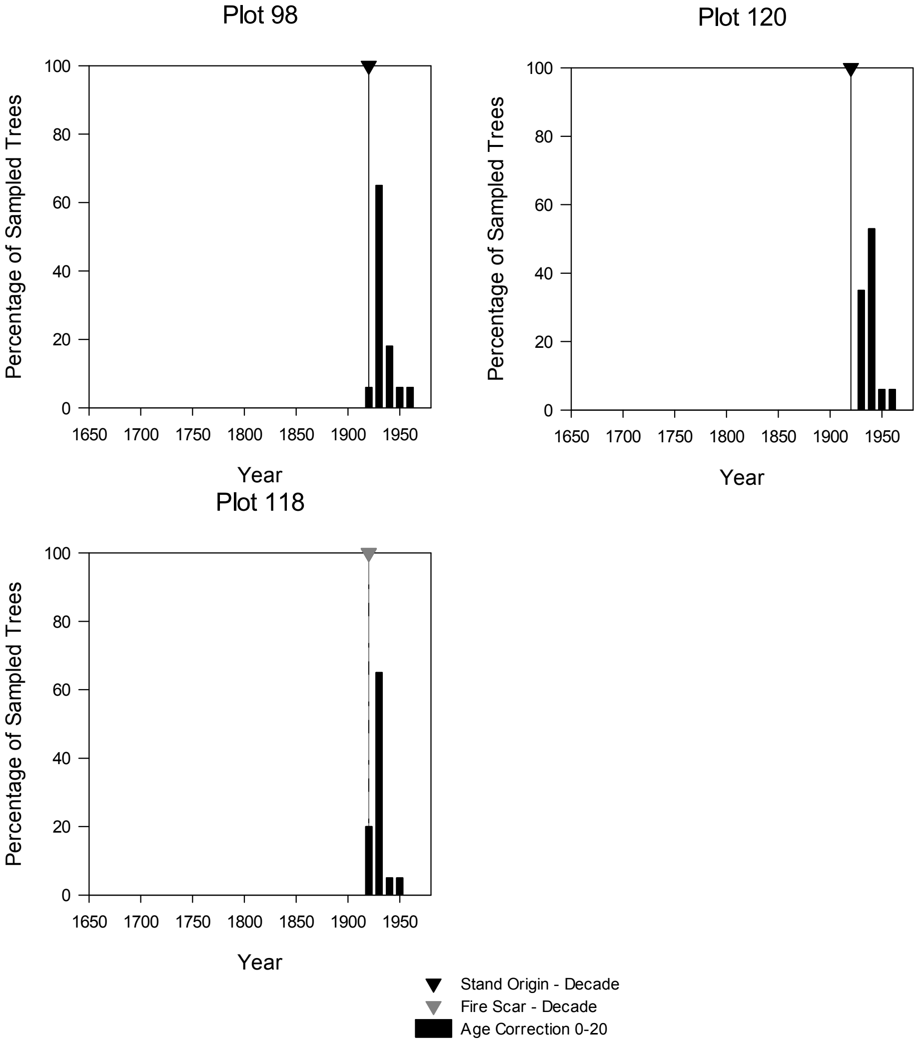
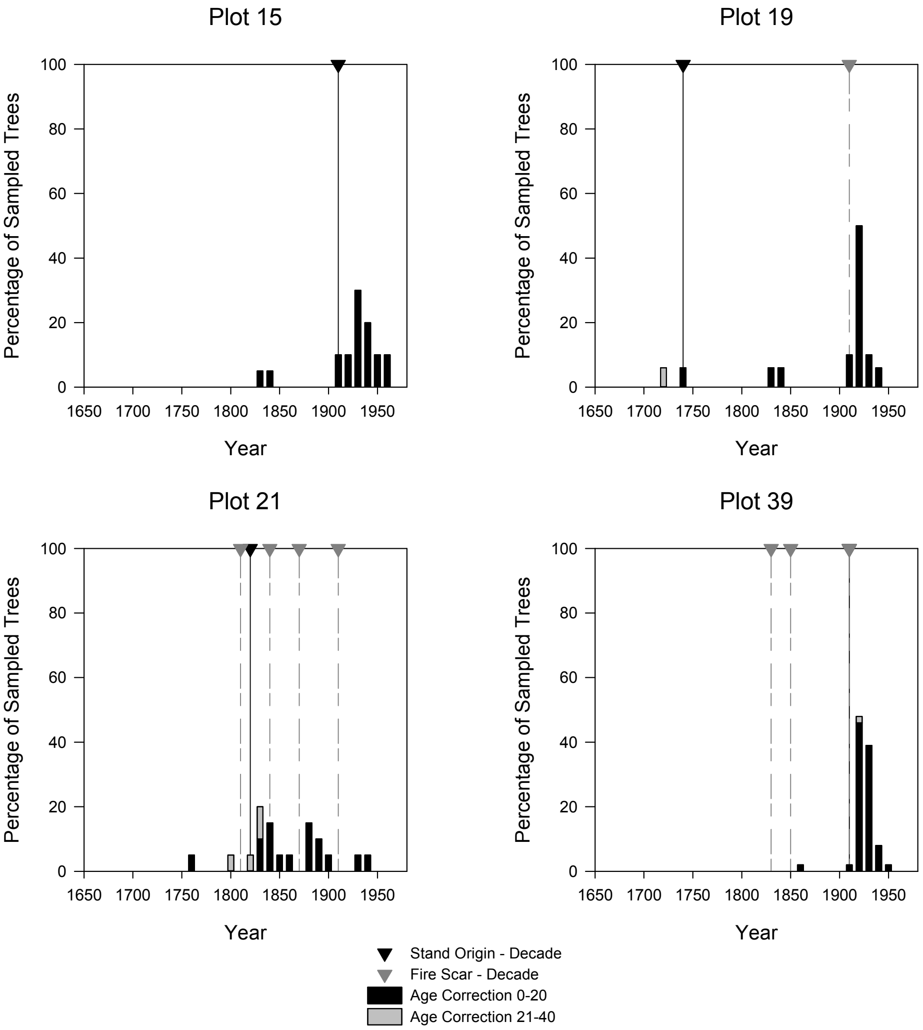
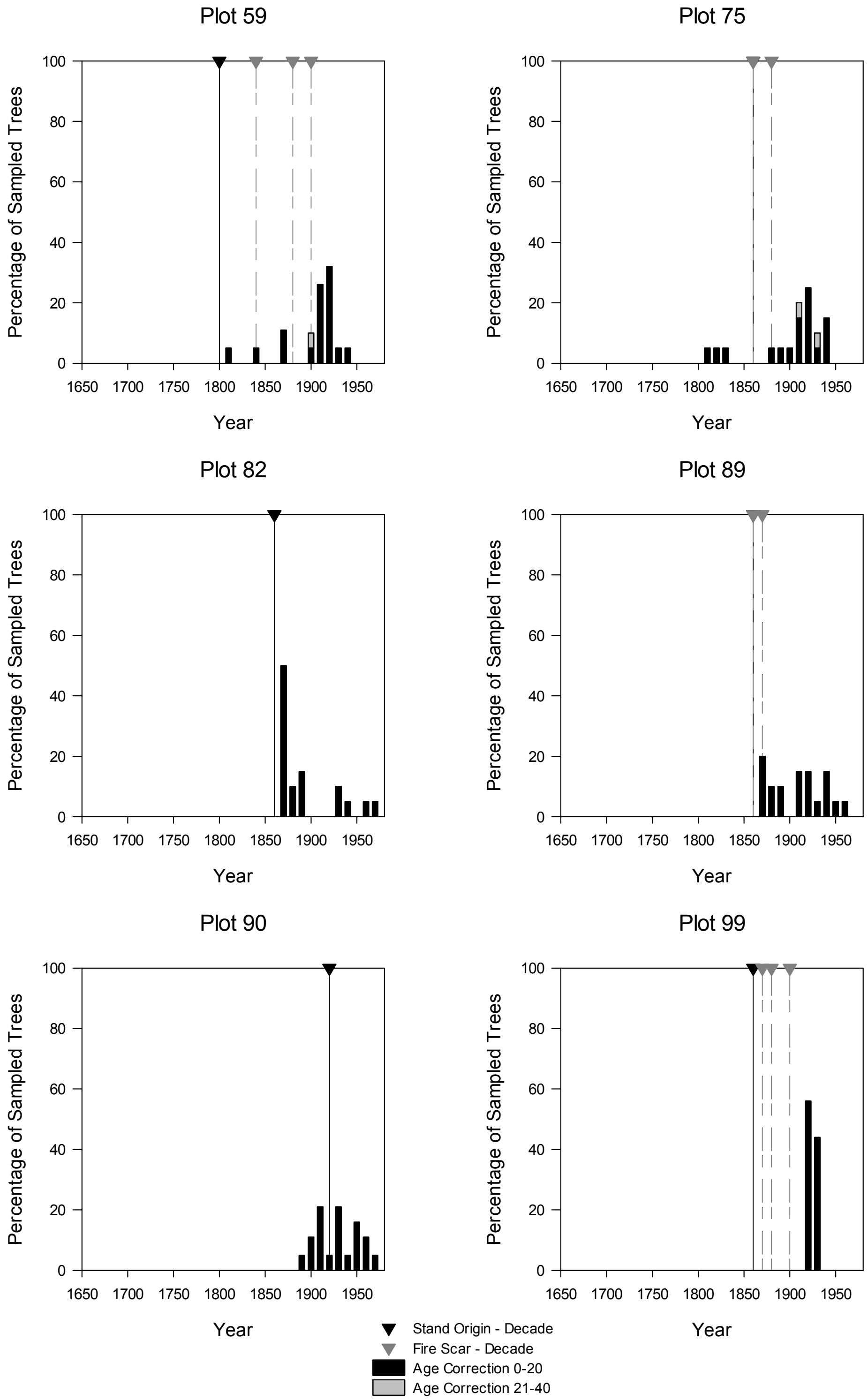
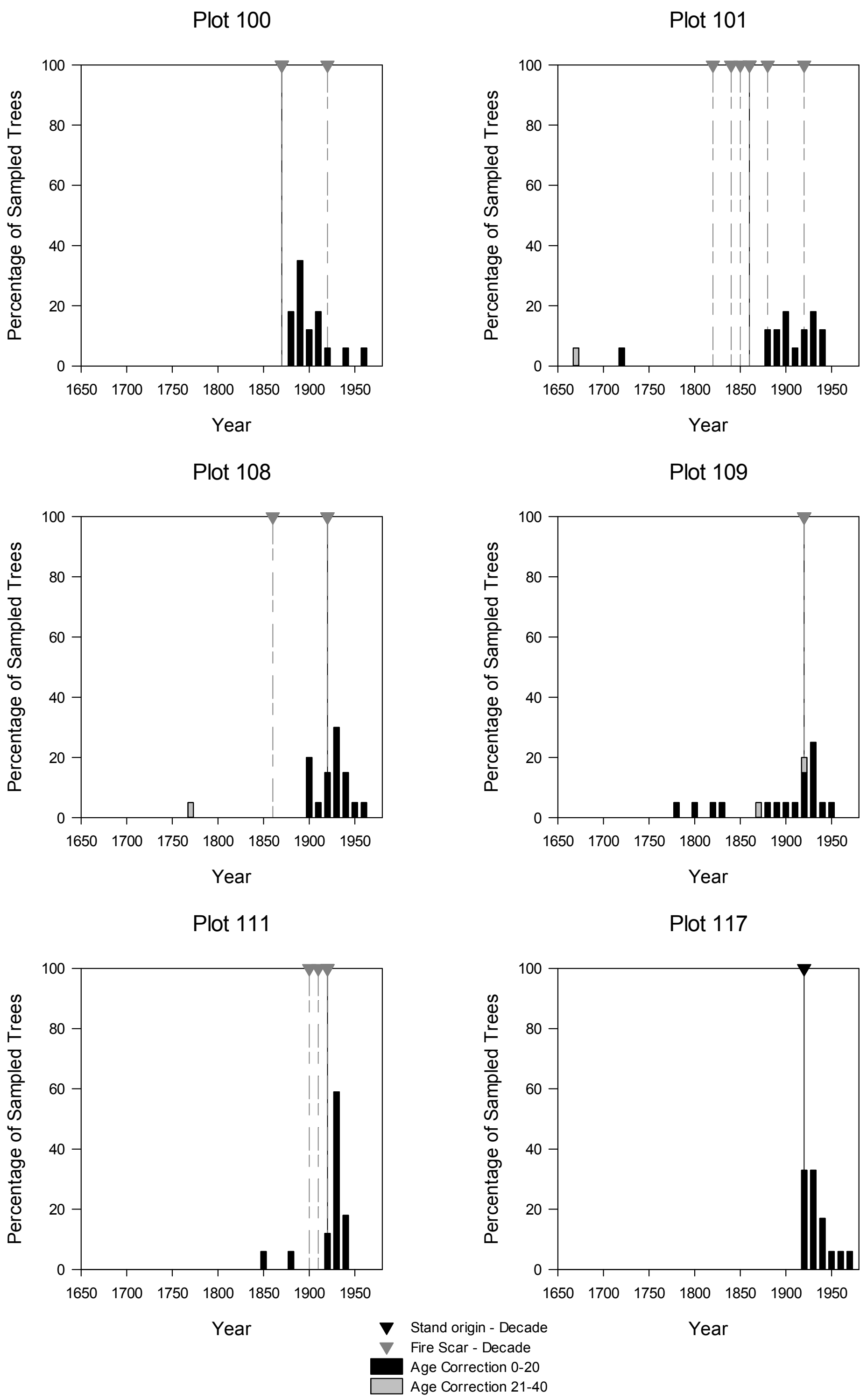


Figure 3.3 High-severity plot histograms. Detailing age class cohorts in ten year bins, fire scar(s) and stand-origin decades.

The fire history of plots 15, 19, 21, 39, 59, 75, 82, 89, 90, 99, 100, 101, 108, 109, 111, 117, 126 and 133 were classified as mixed-severity (Figure 3.4). To be classified mixed-severity a site could have >3 fire scars and/or a post 1859 fire event linked to an establishment cohort ≥30-69% and/or a pre 1859 fire event with an establishment cohort ≥30 and 30-69% of the plots trees were remnants that survived the fire. Of the 18 mixed-severity plots 8 (Plots 21, 39, 59, 99, 101, 111, 126, 133) had ≥3 fire scar criteria and 10 had <3 scars. Plots 21, 59, 101 would have been assigned to mixed-severity regardless of fire scars, plots 59 and 101 based on establishment cohort criteria post 1859, and plot 21 based on pre 1859 remnant trees. Four (Plots 39, 99, 111, 126) had strong establishment cohorts from the 1917 and 1926 fires (3 >80% and 1 70-79%) and one (Plot 133) was moved from the unknown fire history classification. All of the 10 (Plots 15, 19, 75, 82, 89, 90, 108, 109, 111, 117) that were assigned mixed-severity based on non-fire scar criteria were assigned based on post 1859 establishment criteria. Five (Plots 15, 75, 89, 90, 110) having establishment cohorts ≥30 – 49% and 5 (Plots 19, 82, 108, 109, 117) having establishment cohorts ≥50 – 69%. It is important to note that mixed-severity sites include sites with lower severity characteristics but these were not separated as a stand-alone category.




Plot 59
Plot 75
Plot 82
Plot 89
Plot 90
Plot 99
Percentage of Sampled Trees
0
20
40
60
80
100
1650
1700
1750
1800
1850
1900
1950
Year
▼ Stand Origin - Decade
▼ Fire Scar - Decade
■ Age Correction 0-20
▨ Age Correction 21-40


Plot 100
Plot 101
Plot 108
Plot 109
Plot 111
Plot 117
Percentage of Sampled Trees
0
20
40
60
80
100
Year
1650
1700
1750
1800
1850
1900
1950
Stand origin - Decade
Fire Scar - Decade
Age Correction 0-20
Age Correction 21-40

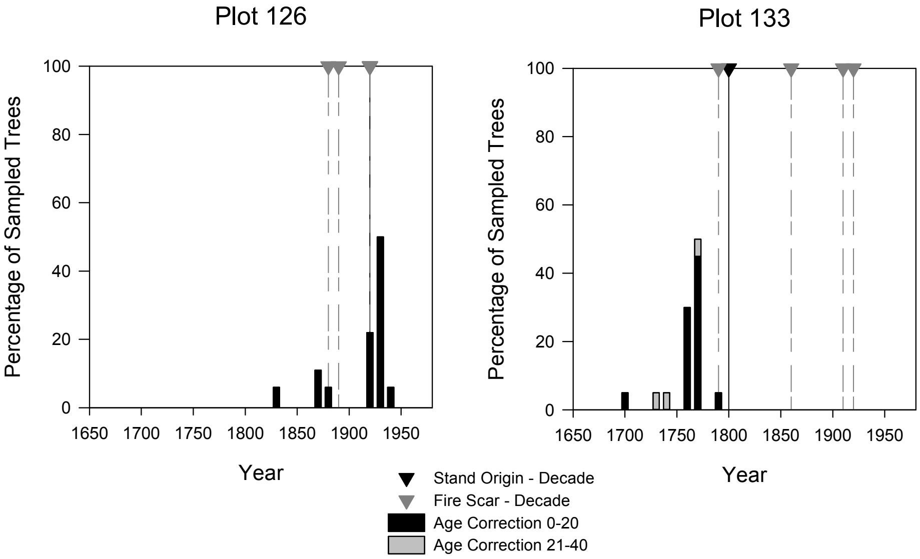
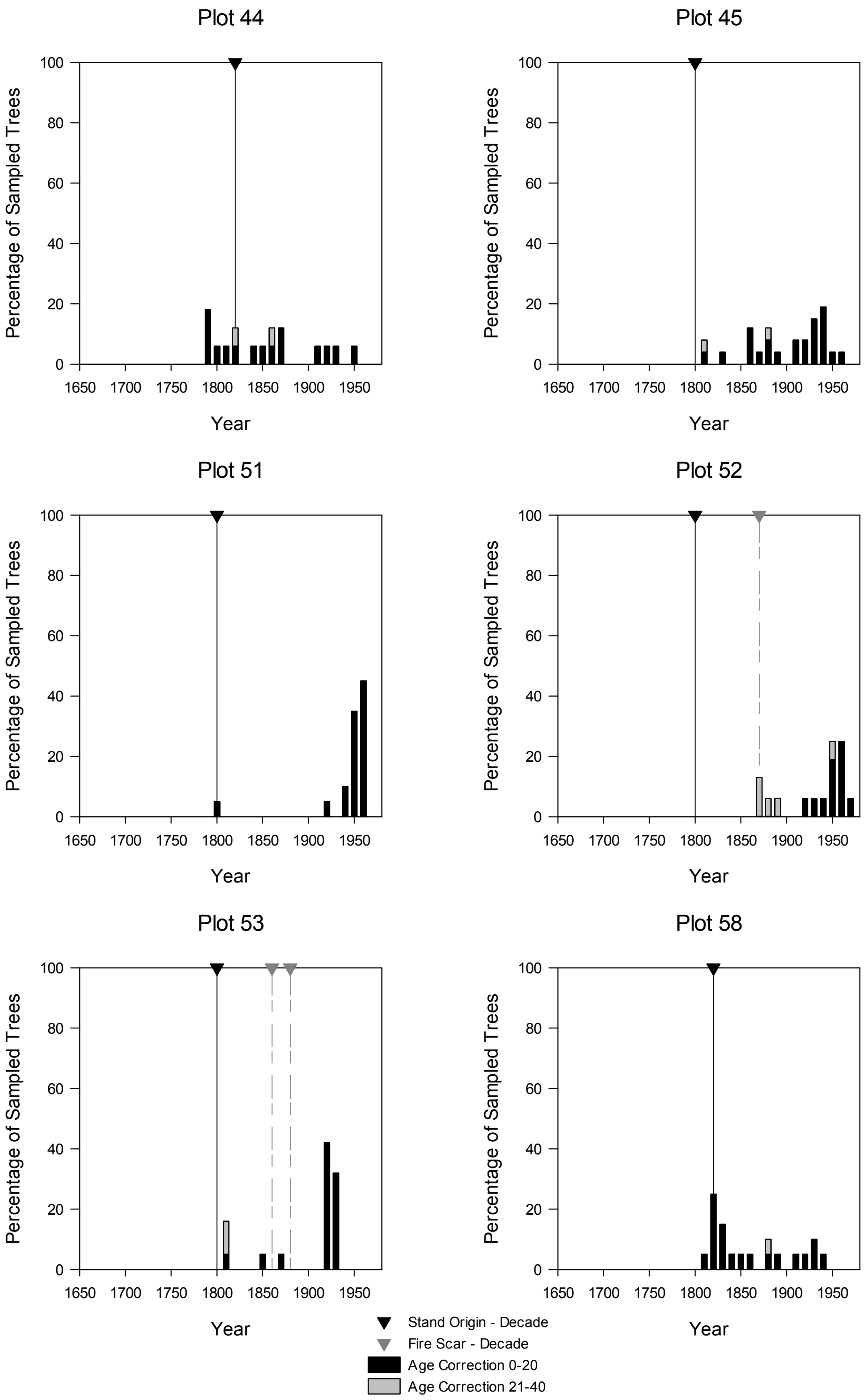
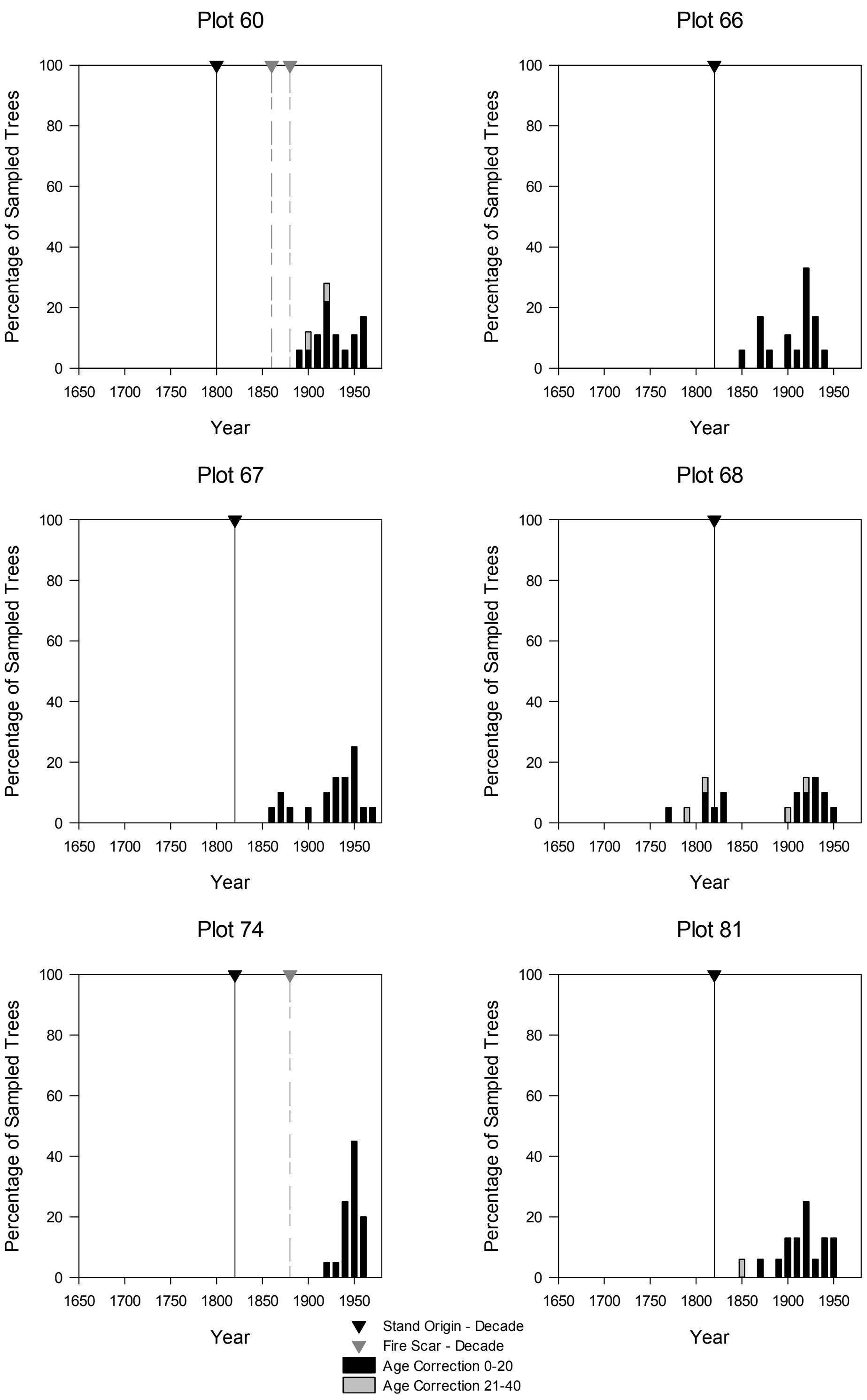


Figure 3.4 Mixed-severity plot histograms. Detailing age class cohorts in ten year bins, fire scar(s) and stand-origin decades.

The fire history of plots 44, 45, 51, 52, 53, 58, 60, 66, 67, 68, 74, 81, 83, 91, 110 and 130 were classified as unknown fire history (Figure 3.5). To be classified unknown fire history a site had to have < 3 fire scars and no fire event linked to an establishment cohort ≥30. Plots 52, 74, 110, 130 had 1 fire scar and plots 53, 60, 91 had 2 fire scars. Plot 44 had no establishment cohort >30% while the other 15 plots had establishment cohorts. Fourteen of these plots were driven by post-1859 cohorts with plot 58 driven by pre-1859 remnant trees. Seven of the 14 plots (60, 67, 68, 74, 81, 91, 110) had establishment cohorts ≥30 – 49% and 7 (Plots 45, 51, 52, 53, 66, 83, 130) had establishment cohorts ≥50. Plots 51 and 53 had strong establishment cohorts >70%. Plots 45, 51, 52, 66, 67, 74 had establishment cohorts post 1926. This is significant in that 1926 is considered the start of the modern fire record period. The establishment cohorts in this group are certainly not the result of fire and provide strong evidence of non-fire disturbance establishment cohorts.


Plot 44
Plot 45
Plot 51
Plot 52
Plot 53
Plot 58
Percentage of Sampled Trees
0
20
40
60
80
100
Year
1650
1700
1750
1800
1850
1900
1950
▼ Stand Origin - Decade
▼ Fire Scar - Decade
■ Age Correction 0-20
▨ Age Correction 21-40


Plot 60
Plot 66
Plot 67
Plot 68
Plot 74
Plot 81
Percentage of Sampled Trees
0
20
40
60
80
100
Year
1650
1700
1750
1800
1850
1900
1950
Stand Origin - Decade
Fire Scar - Decade
Age Correction 0-20
Age Correction 21-40

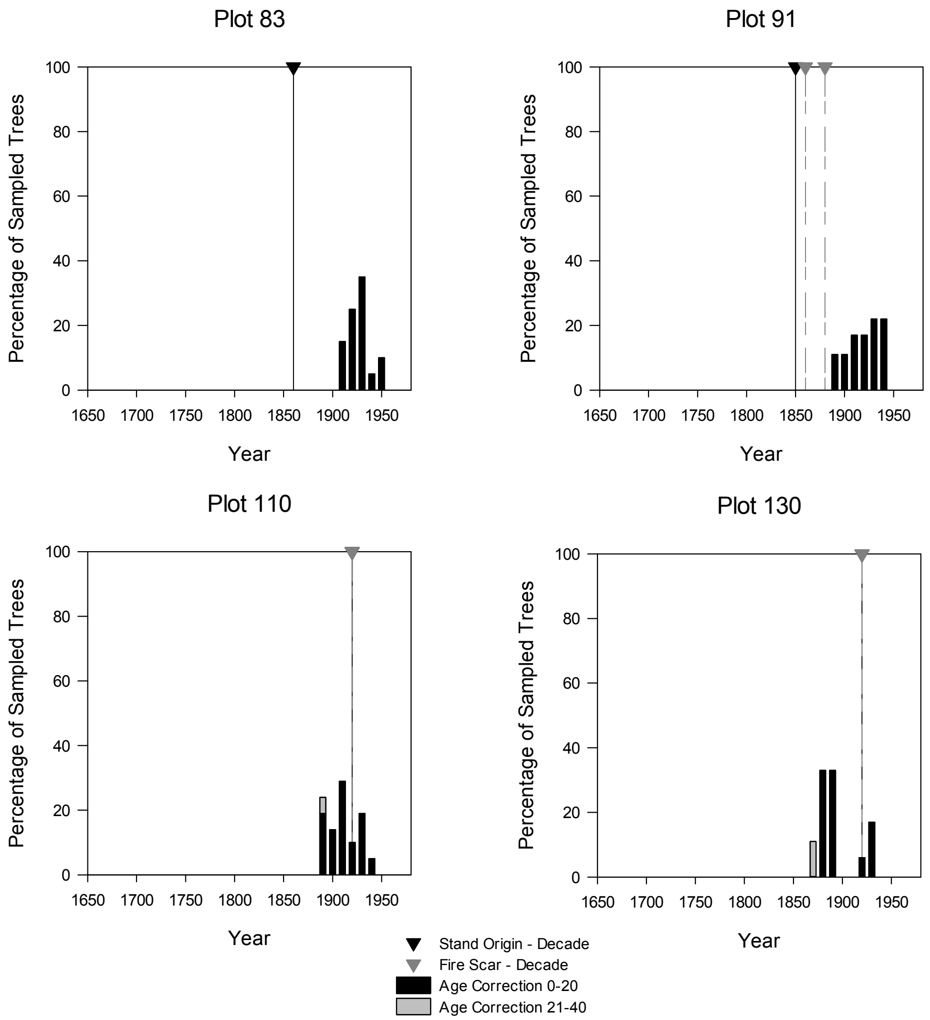


Figure 3.5 Unknown fire history plot histograms. Detailing age class cohorts in ten year bins, fire scar(s) and stand-origin decades.

3.5 Fire Frequency

Cambial scars were common on a range of tree species in the Kootenay River Valley. Scarred trees were present in 38 of the 43 (88%) plots. Of the 171 scarred disks that were sampled from 163 trees, I successfully crossdated 153 scar samples from 146 trees. The scar lobes of six samples (4%) were deemed insufficient to process upon review at the lab and 12 (7%) could not be crossdated. Of the 146 crossdated trees, 86 (59%) were dead and 60 (41%) were alive at the time of sampling. The species breakdown of these trees included 127 lodgepole pine (87%), 12 Douglas-fir (8%), 2 white spruce (1%), and 2 western larch (1%); species could not be determined for 3 samples (2%).

Cambial scares attributable to fire were not that common in the Kootenay River Valley occurring in only 60% of the plots. Those that did occur were rarely multi-scarred and occurred primarily in standing dead lodgepole pine. Utilizing a conservative approach to ensure scars were related to fire, I confirmed that 83 (57%) of the trees included scars that were attributed to fire and 63 (43%) of the trees had scars that could not be attributed to fire. The 83 fire-scarred trees were from 26 of the 43 plots. Of the 83 fire-scarred trees, 52 (63%) were dead and 31 (37%) were alive at the time of sampling. The species breakdown of the fire-scarred trees included 67 lodgepole pine (81%), 11 Douglas-fir (13%), 2 western larch (2%), and 1 white spruce (2%); species was not determined for 2 samples (2%). In total, 123 fire scars were recorded on the 83 trees. Individual trees had 1 to 5 fire scars with 51 (61%) of the trees having a single fire scar, 27 (33%) having two fire scars and 5 (6%) having three or more fire scars. Of the 32 trees with multiple scars, 27 (84%) were lodgepole pine, 4 (13%) were Douglas-fir and 1 (3%) were white spruce.

Fire scars provide strong evidence of frequent fire occurrence across the study area and varying fire frequency for individual plots. Within the Kootenay River Valley, 30 fire years were recorded over the period 1679 to 2009 (Table 3.3: | Figure B-1). Recorded fire years were: 1796, 1798, 1817, 1822, 1831, 1834, 1846, 1848, 1852, 1853, 1863, 1864, 1869, 1871, 1872, 1873, 1875, 1878, 1881, 1883, 1884, 1889, 1896, 1900, 1904, 1905, 1913, 1917, 1918 and 1926. Of the 26 plots that recorded fire 11 (42%) recorded a single fire year, 7 (27%) recorded two fire years and 8 (31%) recorded 3 or more fire years. Eleven fire years occurred on more than one tree. Seven fire years occurred at multiple plots: 1848 (2), 1869 (7), 1883 (3), 1889 (3), 1896 (2), 1917 (6) and 1926 (11). The 1917 and 1926 fire events were within the period of recorded history for the Park and occurred at the south and north ends of the study area respectively. CPFI calculated for the 15 plots with 2 or more fire scars ranged from 4-86 years.

Table 3.3 Fire event summary by plot: number of fire scar trees, fire scar years, composite plot fire interval reported as a mean and range and non-fire scars present.

Plot	**Number of Fire Scar Trees**	**Fire Scar Years**	**Composite Plot Mean Fire Return Interval (Range)**	**Non-Fire Scars Present**
15	0	None	N/A	N
19	3	$1917_{(3)}$	N/A	N
20	2	$1917_{(2)}$,$1831_{(1)}$	86	N
21	4	$1917_{(4)}$,$1878_{(3)}$,$1846_{(1)}$,$1817_{(1)}$	33 (29-39)	N
24	1	$1798_{(1)}$	N/A	N
27	2	$1917_{(2)}$	N/A	Y
28	5	$1917_{(5)}$	N/A	Y
33	0	None	N/A	Y
38	0	None	N/A	N
39	2	$1917_{(2)}$, $1853_{(1)}$, $1834_{(1)}$	42 (19-64)	Y
44	0	None	N/A	Y
45	0	None	N/A	Y
51	0	None	N/A	Y
52	1	$1873_{(1)}$	N/A	Y
53	3	$1883_{(2)}$,$1869_{(2)}$	14	N
58	0	None	N/A	N
59	3	$1905_{(1),}1883_{(2)}$, $1848_{(1)}$	29 (22-35)	Y
60	3	$1883_{(1)}$, $1869_{(2)}$	14	Y
66	0	None	N/A	N
67	0	None	N/A	N
68	0	None	N/A	Y
74	1	$1881_{(1)}$	N/A	Y
75	5	$1889_{(4)}$,$1869_{(4)}$	20	Y.

81	0	None	N/A	Y.
82	0	None	N/A	Y.
83	0	None	N/A	Y.
89	5	$1875_{(4)}$, $1869_{(1)}$	6	Y.
90	0	None	N/A	Y.
91	1	$1889_{(1)}$, $1869_{(1)}$	20	Y.
98	0	None	N/A	Y.
99	6	$1926_{(6)}$, $1900_{(1)}$, $1896_{(1)}$	15 (4-26)	Y.
100	2	$1926_{(1)}$, $1872_{(1)}$	54	Y.
101	4	$1926_{(3)}$,$1889_{(4)}$,$1869_{(1)}$,$1864_{(2)}$,$1852_{(1),}$$1848_{(1)}$,$1822_{(1)}$	17 (4-37)	N
108	2	$1926_{(2)}$, $1863_{(1)}$	63	Y.
109	1	$1926_{(1)}$	N/A	Y.
110	4	$1926_{(4)}$	N/A	N
111	5	$1926_{(5)}$,$1913_{(1)}$,$1904_{(2)}$	11 (9-13)	Y.
117	0	None	N/A	Y.
118	6	$1926_{(6)}$	N/A	N
120	0	None	N/A	Y.
126	5	$1926_{(5)}$, $1896_{(4)}$, $1884_{(1)}$	21 (12-30)	Y.
130	3	$1926_{(3)}$	N/A	Y.
133	5	$1926_{(3)}$,$1918_{(1)}$,$1869_{(2)}$,$1796_{(1)}$	43 (8-73)	N

$_{(X)}$ = Number of fire scar trees associated with each Fire Year.

While most of these plots had few multiple fire scars 3 plots had $\geq$4 fire scar which is approaching a point that may be considered representative of a low severity fire regime. I will review each of these 3 plots briefly. Plot 21 had a MFRI of 33.33 years and 4 fire scar years (1817, 1846, 1878, 1917) recorded on 4 trees. Stand-dynamics data showed that the oldest tree on the site dated to 1768, there was a 123 year age range and an age class continuity index of 60 with the largest cohort (35%) initiated in 1830. The plot had a mixed species composition of Douglas-fir (50%) and lodgepole pine (50%). Plot 101 had a MFRI of 17.33 years and 7 fire scar years (1822, 1848, 1852, 1864, 1869, 1889,1926) recorded on 4 trees. One of the recorder trees on this site was a long lived Douglas-fir that recorded 5 of the 7 fires at this site. Stand-dynamics data showed that the oldest tree on the site dated to 1675, there was a 267 year age range and an age class continuity index of 31 with the largest cohort (41%) initiated in 1929. The plots species composition was dominated by lodgepole pine (70%) with a strong Douglas-fir (25%) cohort. Plot 133 had a MFRI of 43.33 years and 4 fire scar years (1796, 1889, 1918, 1926) recorded on 5 fire scarred trees. Stand-dynamics data showed that the oldest tree on the site dated to 1702, there was a 60 year age range and an age class continuity index of 60 with the largest cohort (80%) initiated in 1761. The plots species composition was Douglas-fir (100%). The fire history at these plots indicates relatively frequent low severity fire.

CSFI calculated for the composited study area (Table 3.4) quantifies frequent fire across the study area and frequent large fires affecting ≥25% of the trees within the study area. CSFI were calculated as MFRI 4.48 years for all fire scars and MFRI of 18.57 years for the 25% scarred filter. My study design does not infer spatial extent to these values. The MFRI for all scarred trees means that the MS BEC zone within my study area experienced a fire that scarred a tree every 4.48 years over the course of the recording period. Larger fires that scarred 25% of the trees occurred every 18.57 years. These values can best be thought of as representing all low severity fire that leave fire scars but do not result in tree mortality. These fires would have occurred as a mix of individual fires of discrete fire types (surface versus crown) or as different fire types within a single fire. The reported frequencies for the temporal periods I chose show a decreased fire frequency (MFRI 8.33) in the settlement period (1847 -1927) compared to (MFRI 3.55) the pre-settlement period (1767-1846).

Table 3.4 CSFI metrics as calculated by FHX2: time period of record, number of fire years in record, minimum fire return interval, maximum fire return interval and mean fir return interval.

Plot	Time Period	No. Fire Years	Minimum FRI	Maximum FRI	Mean FRI
Study Area	1679 - 2009	30	1	19	4.48
Study Area 25% Scarred	1679 - 2009	8	2	48	18.57
Study Area 1766 – 1846	1767 – 1846	7	2	19	8.33
Study Area 1847 - 1927	1847 – 1926	23	1	10	3.55

3.6 Fire Severity Controls

Limited relationships were established between fire severity groups and bottom up controls while some significant relationships were established with stand-dynamic attributes. Relationships between fire severity groups and plot attributes that have been known to be bottom up fire severity drivers (Beaty and Taylor 2001; Heyerdahl, Brubaker et al. 2001; Cochrane 2007; Nesbitt 2010; Greene 2011; Marcoux 2013) were determined utilizing ANOVA. Analysis revealed no significant relationships between my fire severity groups and: elevation ($p = 0.943$), landscape slope aspect ($p = 0.627$), landscape slope angle ($p = 0.641$), site slope aspect ($p = 0.928$) and site slope angle ($p = 0.844$). Comparisons of stand-origin date and fire severity groups showed significant differences. ($p = 0.001$). While not significant the trends of high-severity plots to occur on cooler slopes both at the landscape and site scale is worth noting (Figure B-2).

Relationships between fire severity groups and species relative density were marginal. ANOVA analysis showed no significant relationships between fire severity groups and the percentage of the stand composed of: white spruce (p = 0.496), lodgepole pine (p = 0.434) and Douglas-fir (p = 0.447). While not significant there were interesting trends (Figure B-3) in species composition with white spruce and lodgepole pine playing opposite roles with respect to fire severity. Several structural attributes were significantly different among fire severity groups. Tree density was highest on high-severity plots decreasing through mixed-severity with lowest densities at plots of unknown disturbance. High-severity plots had smaller age ranges and formed tightly clustered age cohorts. Mixed-severity plots had the widest age ranges and the lowest levels of age class continuity while unknown plots were intermediate. ANOVA's comparing stand-dynamics among fire severity groups revealed marginal differences between fire severity groups and tree density (p = 0.054) and significant differences between: continuity index (p = 0.033) and age class range (p = 0.007) among fire severity groups. Analysis related to tree size revealed no difference between DBH range (p = 0.054) and DBH maximum (p = 0.065) among fire severity groups. DBH average was significantly different among fire severity groups (p = 0.045: Figure B-4).

Chi square analysis on class variables revealed no significant relationships between fire severity groups and: ELC Ecosection classes (p = 0.770) and moisture regime classes (p = 0.879). No further analysis was completed for these variables.

3.7 Stand-origin and Vegetation Resource Inventory Accuracy

The accuracy of Masters stand-origin and Vegetation Resource Inventory (VRI) stand age varied with fire severity group and the age of the forest. Stand age values from Masters stand-origin and VRI stand age were assessed against each of the stand-dynamic attributes measured in the field: oldest tree, median age and largest cohort (Table A-3) and analyzed to characterize the range, average and standard deviation for each combination of data source and fire severity group (Figure 3.6: Table 3.5). Both Masters stand-origin and VRI stand age data are most accurate for the high-severity fire group with decreasing accuracy for mixed-severity and unknown fire history. The data sources are both most accurate for largest cohort and least accurate for oldest tree.

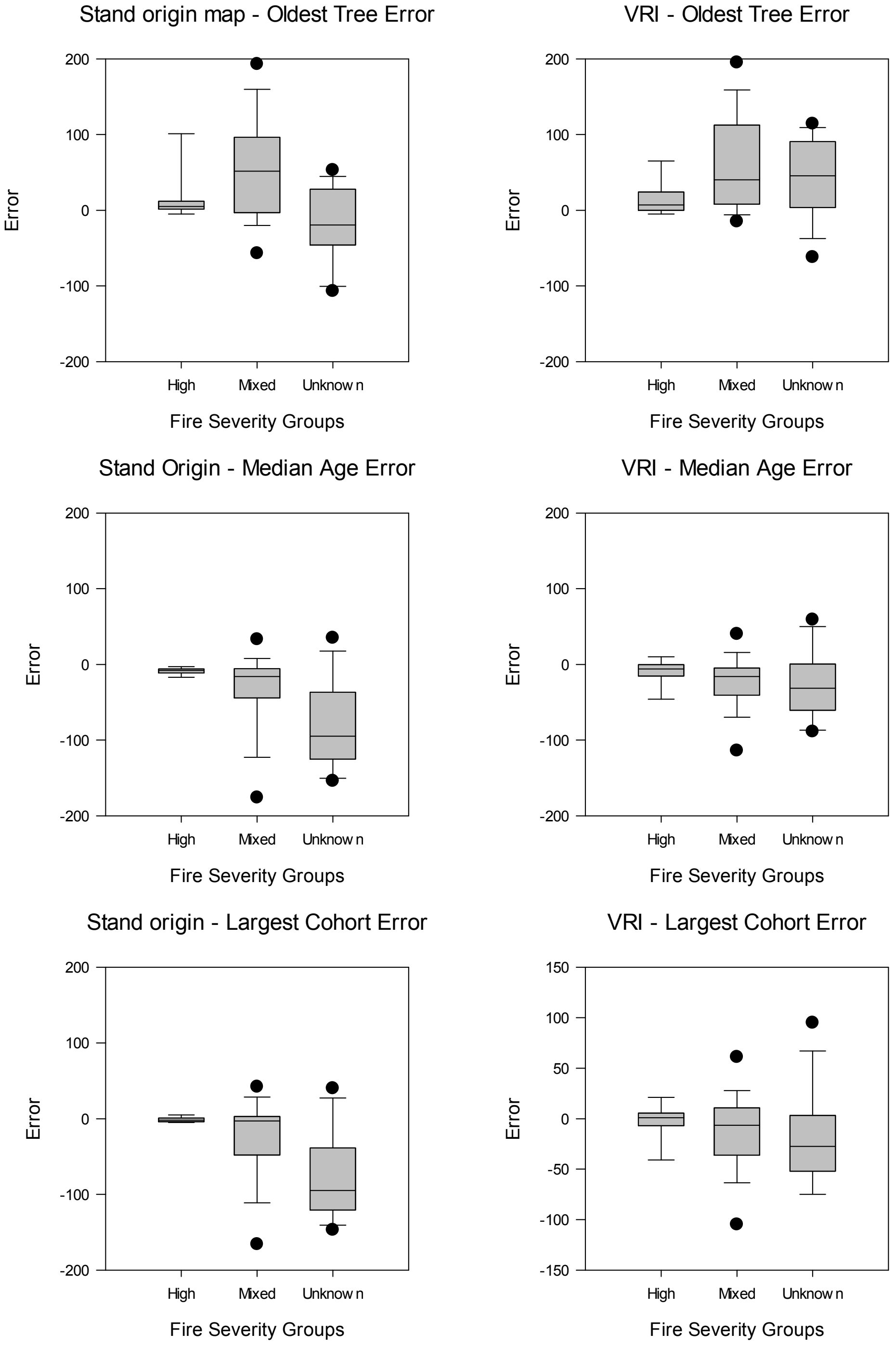


Figure 3.6 Errors associated with stand-origin and VRI stand age for stand-dynamic attributes: oldest tree, median age and largest cohort by Fire Severity Group

Table 3.5 Stand-origin and Vegetation Resource Inventory error: ranges, averages and standard deviations for each combination of stand-dynamic variable and fire severity group.

	Stand-Dynamic Variable	**Range**	**Average (Standard Deviation)**
High	Stand-origin - Oldest Tree	101 to -5	15.4 (± 32.6)
	Stand-origin – Median Age	-3 to -17	-8.8 (± 4.1)
	Stand-origin – Largest Cohort	5 to -5	-1.3 (± 3.3)
	VRI – Oldest Tree	65 to -5	14.7 (± 21.6)
	VRI – Median Age	10 to -46	- 9.6 (± 15.8)
	VRI - Largest Cohort	21 to -41	- 2.1 (± 16.8)
Mixed	Stand-origin - Oldest Tree	193 to -57	53.3 (± 66.1)
	Stand-origin – Median Age	33 to -176	-31.4 (± 48.2)
	Stand-origin – Largest Cohort	42 to -166	-21.2 (± 49.9)
	VRI – Oldest Tree	195 to -15	59.7 (± 63.3)
	VRI – Median Age	40 to -114	- 22.6 (± 33.4)
	VRI - Largest Cohort	61 to -105	- 12.1 (± 37.6)
Unknown	Stand-origin - Oldest Tree	53 to -107	- 17.7 (± 48.1)
	Stand-origin – Median Age	35 to -154	-83.6 (± 56.6)
	Stand-origin – Largest Cohort	40 to -147	-75.0 (± 59.4)
	VRI – Oldest Tree	114 to -62	42.3 (± 51.9)
	VRI – Median Age	59 to -89	- 27.4 (± 42.9)
	VRI - Largest Cohort	95 to -75	-19.1 (± 45.3)

There were significant differences for most of the stand-dynamic error classes amongst the fire severity groups indicating that the stand-origin data from both sources is most accurate for the high-severity group with decreasing accuracy for mixed-severity through unknown fire history. Contingency Table analysis on class variables revealed significant differences among fire severity groups for: VRI - oldest tree error class (chi square p = 0.021), VRI - median age error classes (chi square p = 0.012), stand-origin - oldest tree error class (chi square p = .006), stand-origin - median age error classes and stand-origin - largest cohort classes (chi square p = 0.000) There was no significant difference amongst fire severity groups for VRI - largest cohort classes (chi square p = 0.163). Graphs of disturbance groups and error classes are contained in Figure B-5.

There were also significant differences between the stand-dynamic error classes and stand age for both data sources indicating that the stand-origin data is most accurate for younger forest age classes and less so for older. An ANOVA to determine the differences amongst error classes for the stand-origin and VRI stand age was completed revealing five significant differences for mean stand age among: VRI largest cohort error class (p = 0.021), VRI - median age error class (p = 0.009), VRI - oldest tree error class (p = 0.008), stand-origin - median age error class and stand-origin - largest cohort error class ($p \leq 0.0001$). There was no significant difference for mean stand age among the stand-origin oldest tree error classes (p = 0.557). Graphs of stand-origin years and these plot variables are contained in Figure B-6.

The VRI did not accurately predict leading species as evidenced by the confusion matrix generated overall accuracy of 60.5% and a kappa statistic of $\kappa = 0.39$. The confusion matrix (Table 3.6) utilized to compare VRI leading species to leading species as determined by stand-dynamic data identified producers accuracies as SW = 50.0%, PL = 73.3% and FD = 75.0%. Producer's accuracies represent a reference-based accuracy that in this case determines the probability that the leading species in the field will be correctly identified by the VRI. For my study area there would be a 75% probability of standing in a Douglas-fir forest and having it correctly identified by the VRI with decreasing accuracy for lodgepole pine and white spruce. User accuracies were SW = 80.0%, PL = 64.7% and FD = 27.2%. User accuracies represent a map based accuracy that determines the probability that leading species as predicted by VRI would be accurately represented in the field. For my study area there would be an 80.8% probability of determining a white spruce stand from the VRI and finding it at the predicted location in the field with decreasing accuracy for lodgepole pine and Douglas-fir. The kappa statistic represents the percentage that VRI accuracy is better than chance alone.

Table 3.6 Confusion matrix comparing leading species classified from the Vegetation Resource Inventory to leading species derived from stand-dynamic data.

CONFUSION MATRIX		**Leading Species determined by Stand-Dynamics Data**			**Sum**	**Users Accuracy**
		SW	**PL**	**FD**		
VRI Leading Species	SW	12	2	1	15	**80.0%**
	PL	6	11	0	17	**64.7%**
	FD	6	2	3	11	**27.2%**
	Sum	24	15	4	43	
	Producers Accuracy	**50.0%**	**73.3%**	**75.0%**		

Chapter 4 Discussion

4.1 Introduction

In this chapter, I review my findings and interpret them in relation to the literature on historical fire reconstruction in mixed-severity fire regimes. I conducted this research to better understand the fire history of the Kootenay Valley and in turn to provide more accurate objectives for fire management in the area.

I was able to address the three research questions I originally set out to explore:

> Q.1.Does the fire regime of the Kootenay Valley have a mixed-severity signature detectable by linking age cohort information to fire event evidence?
>
> .
>
> Q.2. Does the spatial pattern of high severity and mixed severity fire in the study area differ by topographic attributes?
>
> Q.3. Does the accuracy of the stand-origin map vary with fire severity or stand age?

My hope is also that this study contributes to a broader discussion on fire and forest management in mixed-severity fire regimes. The focus of this chapter is initially on my classification scheme for historic fire severity as this provides the setting for further discussion. I go on to discuss fire frequency and the relationship of fire severity to topography, forest species and forest structure attributes. I discuss the results of my study with respect to interpreting the accuracy of both the stand-origin map and Vegetation Resource Inventory data relative to my findings. To conclude my review and interpretation, I give an outline of the primary implications of my research for fire and forest management and make recommendations on how my research findings might be used for better managing mixed-severity forest systems.

4.2 Historic Fire Severity

By using fire scar and age cohort data collected during my study, as well as the stand-origin map for Kootenay National Park (Masters 1990), I established the presence of a mixed-severity fire regime in the MS BEC zone of the Kootenay Valley. My study is to the best of my knowledge, the first fire history study able to deploy an existing data layer that assigned stand-origin dates focussed on high-severity fire (Masters 1990), and overlay a systematic study design to establish fire severity across the study area. The study design allows me to confidently extend these findings to the entire study area and to assign fire severity over time, not just based on the last fire, ensuring these findings are relevant throughout a significant historical time interval. Based on my findings I would characterize the historic disturbance regime to have been mixed disturbance dominated by fire. The historic fire regime was mixed-severity over time dominated by individual high severity fire events and with some areas that experienced low severity fire events. Based on my findings, I assign a simple spatial allocation of the 3 fire severity groups as: high-severity representing 21% (9/43 plots) of the landscape: mixed-severity representing 42%: and unknown fire history representing 37%. These representations are simplifications that would require further research to apply explicit spatial limits. They can serve as guidelines to provide perspective on how the mixed-severity fire regime was allocated across the landscape. There is strong evidence that the study area has experienced non-fire disturbance: primarily mountain pine beetle, that has affected stand age distribution. I did not attempt to independently assess the extent and influence of non-fire disturbances. Further research would be required to better understand the spatial and temporal parameters of non-fire disturbance and to understand the influence of these disturbances on the forest. For the study area this research would have a starting point in differentiating the unknown fire history category into fire disturbance and non-fire disturbance. The centre of my study area would provide an excellent landscape to explore this area of research as it provides a complex mix of fire and non-fire disturbance driven forest.

4.3 Historic Fire Frequency

I was able to establish that fire occurred frequently in my study area between 1679 and 1926 but then was virtually eliminated from the ecosystem. Despite working in a forest system with limited species that are known to form multiple fire scars my systematic sampling design enabled me to collect strong direct evidence of mixed-severity fire. Fire scar evidence yielded 83 fire scarred trees at 26 of the 43 plots, with two or more fire scars occurring at 15 plots. Many fire history studies in North America have occurred in forest systems thought to be low-severity fire regimes; utilized targeted study designs and occurred in forest systems with tree species known to collect multiple fire scars. My results are of interest: they occurred in a forest system thought to be affected primarily by high-severity fire, utilized a systematic study design and occurred in a forest system with limited tree species known to collect multiple fire scars.

It is challenging to compare this fire frequency to other studies given that the measure is not reported consistently across the literature. This is a problem that has had limited accepted solutions (Fall 1998). Recent studies (Cochrane 2007, Nesbitt 2010, Greene 2011, Marcoux 2013) completed in nearby forests in south-eastern British Columbia attempted to deal with this by applying stratified-random or systematic study designs and consistent plot sizes. I compare results to my fire frequency results (Table 4.1) for composited plot scale metrics. Given similarities in study designs and plot layouts these comparisons are valid. Composited plot fire frequencies across the study areas represent much higher frequency fire thin is commonly associated with high-severity fire regimes. This provides a line of evidence supporting the classification of some fire regimes in south-eastern BC formerly thought to be high-severity as mixed-severity and adds important detail to define these regimes.

While not common some plots in my study area trend toward fire frequencies and associated forest structures associated with low-severity fire-dominated systems. Several of my plots scattered across the study area (21, 101, 133) have structural and fire frequency attributes that resemble the sites with old forest structure sampled by Cochrane (2007). This similarity indicates that this forest structure, and in turn, the disturbance processes that established and maintained this forest structure, occur at a minimum to the northern extent of my study area in the Kootenay Valley. The use of a systematic sampling design enabled me to establish that, while these multi-scarred plots do occur, they are relatively rare (3 of 43 plots). The limited number of locations for these multi-scarred plots does not enable the determination of their spatial character.

These plots likely represent fire frequencies that cannot be explained by lightning fire alone. For example Plot 101 with a Cumulative Plot Fire Interval (CPFI) of 17.33 years likely burned too frequently to be attributed to lightning fire alone. This site is located in the general area of Kootenay Crossing that was noted as a known camping and burning site of the kyaknu╪i?it band by elder Xavier Eugene (personal communication, August 17, 2013). It is possible that some of these multi-scarred plots were established and maintained by aboriginal burning. It is also possible that some of these plots are refugia from high-severity fire. Fire refugia would be sites located in topographic situations that limit the probability of high-severity fire affecting the site but are still affected by low-severity fire. This would leave a record of multi-scarred trees but result in limited tree mortality and, therefore, leave a limited age cohort signature. This may be the case at plot 133, which has a very strong age cohort related to an event in the 1760’s followed by 4 fires that had little impact on age cohorts. The determination of the spatial drivers and ignition sources for these multi-scarred sites would require more focussed research to test these hypotheses. While they are relatively rare, these sites represent the high-frequency low-severity component of the mixed-severity fire regime in the MS BEC zone of the Kootenay Valley.

The most important element of changes in fire frequency over time is the elimination of fire from the system after 1926. No fire scars were encountered dating to the modern fire suppression period, and based on Park fire records fire has virtually been eliminated from this landscape. This reduction in frequent fire in a mixed-severity fire regime is the critical issue that requires attention. The difference in the CSFI values between the pre-settlement period (8.33 years) and the settlement period (3.55 years) is interesting. It is possible that this fire frequency change is associated with land use change as has been reported in other areas (Johnson et al., 1990). These results should be used with caution given the size of my study area and the fact it was dominated by two large fires (1917/1926) in the settlement period that affected approximately 50% of the study area. Further analysis over a greater area would be required to determine if these differences are consistent.

The determination of fire frequency for the study area will continue to be complicated by scale issues. My study determined that fire occurred very frequently with a CSFI of 4.8 years but this measure cannot easily be converted to explicit spatial relationship. The 25% scarred CSFI of 18.57 years provides a non-spatial parameter that allows us to understand that larger fires affecting more than 25% of the trees in the study area occurred relatively frequently. The 25% filter provides a consistent basis for comparison that compensates for study area size (Van Horne and Fule 2006). From individual plots we can describe fire frequencies as ranging from 4 -86 years with some plots (21, 101, 133) experiencing relatively sustained fire at frequencies of 17, 33 and 46 years. Evidence from Masters (1990) defines stand-replacing fire frequency as ranging from 60-130 years. Masters frequency estimates are broadly supported by Van Wagner et. al. (2006) who completed analysis of combined stand age data sets for multiple parks and determined a fire frequency of 71- 131 years. Based on the above I would describe the historic fire frequency as high-severity fire events every 60 -130 years with some areas that experienced low severity fire events every 20 – 40 years. Further work will be required to develop spatial extents and objective area burned targets to match these frequencies.

4.4 Classifying Historic Fire Severity

My classification scheme based on multiple fire scars as evidence of mixed-severity fire and stand age (establishment cohorts and/or remnant trees) linked to fire evidence (fire scars or stand-origin date) provides a novel tool that can be used to define fire severity in forest types that have strong post-fire establishment cohorts. The scheme shares elements with studies that have established break points for defining fire severity utilizing age cohort data (Ehle and Baker 2003; Sherriff and Veblen 2006; Amoroso, Daniels et al.

2011; Heyerdahl, Lertzman et al. 2012; Marcoux 2013), data collected from air photo interpretation (Hessburg, Salter et al. 2007), and fire scar evidence (Heyerdahl, Lertzman et al. 2012). All of these studies developed classification schemes based on the fire severity classification outlined by Agee (Agee 1990; Agee 1993). Several (Sherriff and Veblen 2006; Hessburg, Salter et al. 2007; Amoroso, Daniels et al. 2011) used schemes with explicit age cohort breakpoints assigned to fire severity. These studies took place in systems that were dominated by ponderosa pine (Ehle and Baker 2003; Sherriff and Veblen 2006), a much-studied focal species for wildfire management in the western North America, and also contained a mix of other species known to collect multiple scars (Heyerdahl, Lertzman et al. 2012; Marcoux 2013). Some were carried out at a much different scale then my study for the purpose of assigning severity to broad landscapes (Hessburg, Salter et al. 2007). One additional study (Amoroso, Daniels et al. 2011) explored a fire severity classification scheme for a lodgepole pine-dominated system. While my scheme is related to those outlined above, the specific parameters I employed represent improvements specific to forest types with strong post-fire establishment cohorts

The use of fire scars as an indicator of fire severity must take scale into consideration. We can recognize that the use of fire scars to define mixed-severity is built on the secure assumption that the presence of multiple fire scars is an indicator of multiple fires that are not resulting in the mortality of all trees. However, care must be taken to define this indicator carefully. The fire-scar criterion was an important element in the mixed-severity classification with 8 of 18 plots being designated based on this criterion. Three of these plots would have been assigned mixed-severity based on cohort criteria leaving 5 plots that were assigned based on the fire scar criterion only. The use of the fire scar criterion primarily affected high-severity plots with 4 of the 5 plots having age cohorts that indicated high-severity. Three of the 4 plots had strong ≥80% establishment cohorts and all 4 had been burned by the 1917 and 1926 fires that clearly left a signature of high-severity fire in the age cohort. One plot (133) moved from the unknown group. It was one of the more interesting plots in the study area with a strong ≥70% establishment cohort dating to 1761, which was not related to a known fire event.

Within-fire heterogeneity is well established at the stand level (Turner, Hargrove et al. 1994; DeLong and Tanner 1996; Stuart-Smith and Hendry 1998). The only other study explicitly involving fire scars to assign severity (Heyerdahl, Lertzman et al. 2012) used scars as a discrete criterion for high-severity and unknown fire severity. For Heyerdahl et. al. (2012), the presence of a fire scar indicated a site was not high-severity or unknown and moved it into either a mixed-severity or low-severity group. With respect to high-severity fires the use of this criterion by Heyerdahl et al. (2012) would appear to be based on the assumption that a single fire scar implies survivorship at a scale that would require the site to not be classified as high-severity. With respect to unknown fire severity the use of the fire scar criterion by Heyerdahal et al. (2012) would appear to imply that the presence of a single fire scar indicates that fire is the primary disturbance process driving stand-dynamics of the site. If my classification scheme had considered every fire scar unrelated to an establishment cohort as an indicator of mixed-severity fire, then three plots would have moved from high-severity and 7 plots would have moved from unknown fire severity. Given the strong evidence for within-fire heterogeneity (Turner, Hargrove et al. 1994; DeLong and Tanner 1996; Stuart-Smith and Hendry 1998), the presence of multiple disturbance agents (Canadian Forest Service 1980-2006; Shrimpton 1994) that affect stand-dynamics (Dykstra and Braumandl 2006; Dordel, Feller et al. 2008; Axelson, Alfaro et al. 2009) in lodgepole pine-dominated systems, it does not seem reasonable to use the presence of fire scars as a discrete criterion for classifying fire severity.

The ≥ 3 scars criterion is supported by other evidence that links these plots to the stand-dynamic and species attributes commonly associated with mixed-severity including a mix of age ranges, ongoing tree establishment and Douglas-fir dominated species composition. Age class range and age class continuity index differed amongst fire severity groups with age class range being greatest for the mixed-severity group while the age class continuity index was the lowest. Based on the general characterization of species relationships to fire (Wright and Bailey 1982; Agee 1993), Douglas-fir is associated with multiple fires. While not a statistically significant relationship, the trend indicated by the species relative density for Douglas-fir is that there is a link to mixed-severity plots and this relationship provides supporting evidence that the classification scheme is correctly assigning mixed-severity. The utilization of ≥3 scars as a breakpoint for the assignment of mixed-severity appears sound but would benefit from future research to better refine the number of scars present relative to other indicators of mixed-severity.

Using a classification scheme focussed on recent establishment cohorts in forest systems that have species exhibiting strong post-fire establishment pulses provides a simple and effective way to classify fire severity. The post-1859 age cohort criterion formed the fundamental basis of my classification scheme. Using the ≥70% establishment cohort as a breakpoint to define high-severity is a conservative approach that recognizes fine scale heterogeneity at the site scale. This approach followed other studies (Sherriff and Veblen 2006; Hessburg, Salter et al. 2007; Amoroso, Daniels et al. 2011) but did not align with Heyerdahl et al. (2012) who used both an establishment cohort and a zero remnant tree criteria. The Heyerdahl et al. (2012) approach implies a high-severity fire must have 100% mortality, and does not allow for fine scale heterogeneity as an element of concern. As outlined above with respect to fire scars within-fire heterogeneity is well established for lodgepole pine ecosystems. I considered using an even more conservative 80% establishment cohort breakpoint for high-severity given the known strong establishment cohort potential of lodgepole pine. The use of an 80% criterion would have had little impact on the post 1859 assignment of high-severity: seven of eight plots had establishment cohorts ≥80%. Of these 7 plots ≥80% only four had lodgepole pine as a leading species with three of the plots having white spruce as a leading species. This indicates that spruce can establish strong post fire establishment cohorts in this system which further supports the use of establishment cohort criterion. Sherriff and Veblen (2006) employed a remnant tree criterion which I did not use given I was working in a forest system where high-severity fire played a significant role and I sought to develop a simple classification scheme. The ≥ 70% establishment cohort implies that the remnant trees will be ≤ 30%. All of the 8 plots that were assigned high-severity based on the post 1859 establishment criterion had remnant trees ≤ 15%. Adding remnant tree criteria to a classification scheme in lodgepole pine forests is not required. The pre 1859 element of the classification scheme only determined two plots. It was not adequately utilized during this study and would require further use to determine its viability.

A cautious interpretation with respect to assigning establishment cohorts to fire disturbance is required in forests with multiple disturbance agents. Using a ≥30% establishment cohort breakpoint to link to fire evidence was a conservative approach that was required in my study area. Other studies (Sherriff and Veblen 2006; Hessburg, Salter et al. 2007) utilized a ≥ 20% establishment cohort as a breakpoint between mixed and low severity. Based on the tree species present, I correctly assumed the system I was working in had a limited low-severity element. In addition, the documented mountain pine beetle disturbance history (Canadian Forest Service 1980-2006; Shrimpton 1994) with known impacts to stand age structure (Dykstra and Braumandl 2006; Dordel, Feller et al. 2008; Axelson, Alfaro et al. 2009) necessitated the need for establishment cohorts to be explicitly linked to fire events. The presence of several strong establishment cohorts'post 1926 is a clear indicator that fire is not the only process driving the age class structure in the Kootenay Valley. The need to ensure establishment cohorts are linked to known fire events is critical in this system.

4.4.1 Fire History in Lodgepole Pine forests

The study of mixed-severity fire history in lodgepole pine-dominated systems has several inherent challenges. Lodgepole pine is a thin barked relatively short-lived species not known to accumulate multiple fire scars. This limits both spatially and temporally the number of records of fire that can be established from a lodgepole pine-dominated system. Spatially, this limits the ability of a researcher to develop as accurate an assessment of the extent of an individual low severity fire: there is a limited grid of recording trees on the landscape. Temporally, the relatively short life span of lodgepole pine further limits the ability of a researcher in developing deep chronologies. Even with the application of crossdating methods the temporal depth to which one can build chronologies is fundamentally limited by dead wood longevity. These circumstances may be exacerbated by the presence of other disturbance agents that lead to tree mortality, and can complicate the ability to assign scars, tree establishment or tree mortality to fire disturbance. This was certainly the case in my study area, where recorded mountain pine beetle outbreaks in the 1940's and 1980's resulted in high levels of tree mortality (Shrimpton 1994; Canadian Forest Service 1980-2006).

The 83 fire scarred trees from which my fire record was constructed were dominated by dead trees (63%) and composed primarily of lodgepole pine (81%). Much of this mortality was recent and likely due to mountain pine beetle activity. Only 57% of the scars I collected in the field were determined to be fire scars in the lab: I collected any scar in the field that I felt had the potential to be a fire scar. The presence of twentieth century mountain pine beetle activity resulted in some scars being collected in the field that were discarded in the lab upon review of a full suite of evidence. This evidence included: review of the parks fire record, multiple scar date alignment and scar morphology. Review of the parks fire record was used to determine that scars dating from the 1930's and onwards were not fire related. Multiple scars from a single plot that dated in the same decade but did not date to the same calendar year were carefully reviewed for scar morphology. Scar morphology, viewable via microscope after the disks were sanded, provided further evidence clarifying which samples were non-fire scars. Finally, a general dendrochronological issue not specific to the study of fire is the fact that lodgepole pine does not form very sensitive tree ring records. This makes it difficult to develop accurate long-term chronologies and in turn to cross date samples. These issues make it important to develop multiple evidence approaches to fire history work in lodgepole pine-dominated systems.

4.5 Fire Severity Controls

I established no significant links between fire severity and topographic controls, which I suspect is related to the limited elevation gradient and simple topography in my study area. Several studies have identified links between fire regime characteristics and bottom up controls (Beaty and Taylor 2001; Heyerdahl, Brubaker et al. 2001; Beaty and Taylor 2008). Specific to south-eastern BC studies have found relationships between: fire frequency; and elevation, slope angle and slope radiation (Cochrane 2007), fire frequency; and elevation (Nesbitt 2010), fire occurrence; and elevation, slope aspect and steepness (Greene 2011), fire history groups; and elevation (Marcoux 2013). I found no significant relationship between my fire severity groups and topographic characteristics that have been known to affect fire behaviour (elevation, site slope angle, site aspect) as well as the metrics I designed to represent landscape slope angle and aspect. My study area had an elevation range of approximately 200 metres, while most study areas (Table 4.1) that reported relationships between fire severity and topographic controls had far greater ranges. The closest study (Cochrane 2007) overlapped my study area but had a greater elevation range (approximately 500 metres) and a different study design (stratified random over a large geographic area targeted to old forest structural attributes). In contrast my study area comprised a relatively simple landscape located on the floor of a contiguous U-shaped valley. Topographic controls in similar relatively simple topography (Heyerdahl, Brubaker et al. 2001) have been documented, and may become apparent if analysis were completed over a larger elevation gradient or a larger study area.

The species relative densities I established were not significantly different amongst my fire severity groups but did trend toward commonly observed patterns of species relationships to fire severity. Studies in mountain forests have established relationships between fire regime elements and species attributes (Beaty and Taylor 2001; Heyerdahl, Brubaker et al. 2001; Beaty and Taylor 2008; Nesbitt 2010; Marcoux 2013). Many of the trends in my species relative density data follow patterns commonly associated with our understanding of how species are affected by varying fire severity. Specific to the primary species in my study area, this broad understanding considers lodgepole pine most highly associated with high-severity fire, Douglas-fir most highly associated with mixed-severity and white spruce most highly associated with non-fire disturbance or longer time frames since fire (Wright and Bailey 1982; Agee 1993). I found lodgepole pine was most highly associated with high-severity plots and white spruce was most highly associated with unknown fire severity plots. Douglas-fir was most highly associated with mixed-severity but spread across all disturbance groups.

Stand structure attributes differed significantly amongst fire severity groups indicating fire severity has had a strong influence on stand structure. High-severity plots have smaller trees covering a narrower range of DBH. Mixed-severity plots have a few large trees and a wide range of DBH. Unknown plots have similar sized large trees to mixed-severity but more of the stand is made up of large trees. High-severity fire limits the tree size on site to the time since last fire due to the mortality of the majority of the previous stand. It also establishes a narrow range of tree sizes due to the associated tight establishment cohort. Mixed-severity fire allows some trees to survive a fire event and grow larger but does create some mortality limiting the number of large trees. Finally unknown fire history plots have not experienced recent tree mortality through fire disturbance. As with species relative densities, structural attributes generally support the commonly held (Wright and Bailey 1982; Agee 1993) perceptions of the relationships of fire severity to structure dynamics. High-severity fire generates dense stands of relatively small trees in concentrated even aged cohorts, mixed-severity fire supports more open stands of larger trees in dispersed uneven aged cohorts and unknown fire severity leads to very open stands of larger trees with a less organized age cohort assembly. The complex nature of stand structure attributes at some of the unknown fire history plots in my study area is likely due to the mixed drivers of these plots. The presence of strong non-fire establishment cohorts at these plots indicates that other factors are likely driving tree establishment. The documented presence of mountain pine beetle has an impact on stand structure and it can create conditions favourable to tree establishment (Dykstra and Braumandl 2006; Dordel, Feller et al. 2008; Axelson, Alfaro et al. 2009). Some caution should be applied to these results: fire severity may not be the only process driving structural attributes.

4.6 Stand-origin and Vegetation Resource Inventory Accuracy

Using my stand age data I was able to independently assess the accuracy of the stand-origin map (Masters 1990) and the Vegetation Resource Inventory (VRI) stand age data. I determined that both of these data sources predict stand age with higher accuracy for high-severity fire sites and younger forest ages. The reasons for this error are likely linked to the limits of air photo interpretation and the stand age sampling density from which the data sources were derived. It should be noted that accuracy in this case is relative to the three attributes I was able to assess from my field study. The definition of stand-origin remains a fundamental issue that is currently not established and is complicated by the consideration of scale issues related to the heterogeneity of tree mortality at different scales.

The accuracy issues related to Masters stand-origin map are attributable to the study methods utilized to create the map. Masters stand-origin map was derived from a time-since-fire method (Heinselman 1973; Johnson and Gutsell 1994) that utilizes air photo interpretation to establish stand boundaries. These stand boundaries delineate patches of forest of different age assumed to be the result of different fires. Using the time-since-fire method various approaches are employed to assess stand ages and to ensure that the mapped stands are homogenous and related to fire. Similar to the stand-origin map errors in VRI stand age are likely the result of methods used to determine the data. VRI stand age data is generalized from air photo interpretation relating tree heights to stand age. As with the stand-origin map the data have the greatest fidelity to young high fire severity generated stands. This is likely due to the strong air photo signature left by recent high-severity fires. The capability of air photo interpretation to accurately delineate stand boundaries in older mixed-age cohorts is limited (Johnson and Gutsell 1994).

For both data sources the stand age error for the mixed-severity group may be confused in part by the utilization of the ≥3 fire scar criteria in classifying mixed-severity. Four of the 5 plots that moved from high-severity to mixed-severity did so based on the ≥3 scar criterion and were linked to 1917 or 1926 fire events with strong establishment cohorts. These plots had a strong high-severity signature that allowed the accurate assignment of stand age as all of these plots were classified by the stand-origin map to the corresponding fire years by the establishment cohorts. If my scheme had utilized only establishment cohort criteria these plots would have been accurately represented as recent high-severity fires that burned on the site. This strengthens the observation that the stand-origin map strongly predicts high-severity fire. The stand-origin map displays a trend of decreasing accuracy through mixed-severity to unknown fire severity. The combined observations related to the relationship of the stand-origin map to error and the relationship of fire severity groups to error indicate that the stand-origin map is most accurate with respect to predicting stand age in stands that have experienced recent high-severity fire. The stand-origin map displays decreasing accuracy in older stand ages and through mixed-severity to unknown fire severity

The overall accuracy of the VRI with respect to leading species was only 60% which again is likely due to the difficulties associated with differentiating species in older cohorts from air photos and may be exacerbated by mixed-severity and mixed disturbance signatures.

4.6.1 Time-Since-Fire methods in Mixed-Severity Fire Regimes

Limitations of the time-since-fire method in mixed-severity fire regimes bear some consideration given the challenges inherent in assessing fire severity in these complex systems. Masters utilized a method where he determined stand boundaries from aerial photos and completed limiting sampling for stand age and fire scars primarily at stand boundaries. He did not complete a systematic or widespread sampling for stand age within the patches of forest presumed to be of different age. He recognized the limitations of his approach in terms of the accuracy of the stand-origin map particularly in the central Kootenay Valley (Masters 1989). The challenges inherent in using air photos to determine stand boundaries are recognized (Johnson and Gutsell 1994). The ability to utilize air photo interpretation to delineate fire boundaries would be complicated by the presence of non-fire disturbance mechanisms such as mountain pine beet as the ability to use tree height and species differentiations would be confused by the mortality of mature lodgepole pine. These challenges explain why the stand-origin map is most accurate for recent high severity fire where the signature would have been most evident.

These issues elicit a broader concern with respect to the value of the time-since-fire method in mixed-severity fire regimes. The time-since-fire method requires that fire leave a signature detectable by air photo interpretation or that boundaries can be determined by field sampling. Utilizing air photos to determine stand boundaries is of limited value for low-severity fire systems where tree mortality is uncommon and large even aged cohorts are not likely (Baker and Ehle 2001). The applicability of the time-since-fire method to mixed-severity systems remains largely untested. I contend that the time-since-fire method (Johnson and Gutsell 1994) might be fundamentally flawed for mixed-severity systems. There is no defensible method available to assign surface fire evidence (fire scars or age cohort information) a spatial reference (time-since-fire polygon). Johnson and Gutsell (1994) propose several sampling methods to overcome the inability to assign spatial reference to time-since-fire polygons from air photos but these remain untested. There have been limited modern studies (Weir, Johnson et al. 2000) that have developed a time-since-fire map in lodgepole pine dominated forest and these did not describe or consider the implications of mixed-severity fire. Several studies have experimented with novel GIS modelling to extrapolate fire information gathered from a fire scar network to spatially explicit polygons (Hessl, Miller et al. 2007, Heyerdahl, Lertzman et al. 2007, Swetnam, Falk et al. 2011, Greene, 2012). The GIS models used in these studies have not been validated and the studies have been limited to forest systems containing species that are known to capture multiple fires. The mapping of fire boundaries (Andison 2012) and assigning of fire severity (Soverel, Perrakis et al. 2010) remain problematic even with modern technical advances. In lodgepole pine-dominated mixed-disturbance mixed-severity fire systems the ability to assign surface fires spatial extent will continue to be an issue as it is unlikely there will be a sufficiently dense distribution of fire scars or an age class cohort that can be confidently assigned to fire with which to assign spatial extents to low-severity fire. This fundamentally limits the ability to develop an accurate time-since-fire map.

There may be utility in developing a combined method for these systems that determines stand-origin fire boundaries from air photos and utilizes age cohort and fire scar information to confirm stand ages. Mixed-severity fire regimes operate along a severity gradient with some mixed-severity systems experiencing high-severity as the primary contributor to the fire regime while other systems will experience low-severity fire as the primary contributor. For systems where high-severity fire is a significant contributor, a method that combines the time-since-fire mapping of stand boundaries with a systematic stand age survey should enable a much more accurate stand-origin map to utilize to understand high-severity fire. If carefully developed to differentiate between stand-origin and time-since-last-fire this map could be used to develop a fire frequency for stand replacing or high-severity fire. This exercise could be simplified by applying my results which indicate that stand-origin mapping of recent high-severity fires is most accurate. Utilizing a systematic survey would also reveal the low-severity elements of the fire regime that could be assessed using fire interval methods normally utilized in low-severity fire regimes. In essence, one would sample for both high and low severity at the same time using related methods to establish fire frequencies and the spatial extent of both high and mixed-severity fire.

4.7 Management Implications

The results of my study have direct implications for ecosystem management in Kootenay National Park, in south-eastern BC, and in other adjacent and more broadly dispersed areas that have similar forest systems. The confirmation of a mixed-severity fire regime has implications for forest and fire management based on the concept of managing for biodiversity through the emulation of historic disturbance processes (Morgan, Aplet et al. 1994; Bunnell 1995). The historic disturbance regime was comprised of a mixture of disturbance agents dominated by mixed-severity fire. This historic disturbance regime left forest structure and species composition legacies that were dominated by mixed-severity sites containing a range of remnant trees. The specific findings of this study should be used to guide practice with respect to restoration and forest harvesting.

Ecosystem management in the Canadian National Parks (Parks Canada 1994) is driven by a policy of minimal interference to natural processes, while recognizing the need for public safety and the protection of the resources of adjacent land owners. The management of these protected areas recognizes ecological integrity as an overarching objective and that the restoration of ecological processes, guided by science, may be required (Parks Canada 1994; Parks Canada and the Canadian Parks Council 2008). Fire management in Parks Canada occupies an interesting niche in restoration. Personnel are tasked with meeting restoration objectives while managing wildfire in a reactive mode as well as in a proactive mode by applying prescribed fire. The strength of the program lies in the fact that the goals for these exercises are broadly guided by parameters of the historic fire regime and captured in Fire Management Plans.

My results provide specific historical fidelity guidance for the restoration of fire in the Kootenay Valley to tailor restoration efforts to a mixed-severity fire regime. Overarching objectives should be to replicate historic fire frequencies for both high-severity and low-severity fire and to maintain the forest structure attributes established and maintained by these fire events. Fire management in most agencies in the world including Parks Canada, over the last 80 years has been guided by a suppression prerogative that did not allow the process of mixed-severity fire to play its full historic role on the landscape. Under this paradigm, high-severity fire events dominate the fire occurrences: these were the fires that escaped initial attack under the more extreme fire weather conditions. A full suppression paradigm will not restore or maintain mixed-severity patterns: it will significantly trend toward high-severity fire regime elements. Over time this will have impacts on biodiversity (Halofsky, Donato et al. 2011; Perry, Hessburg et al. 2011), as the forest structure and species composition elements of the lower-severity component of the fire regime will be removed. The present Lake Louise Yoho Kootenay Fire Management Plan (Parks Canada Agency 2011) outlines fire management zoning for the Kootenay Valley that would allow unplanned wildfire to play a role in fire restoration under relatively conservative prescription. The conservative prescriptions should provide a wide range of fire behaviour and fire effects and maintain mixed-severity forest structure and species attributes. High-severity fires are likely to continue to occur as unplanned wildfires burning in prescription, and as wildfires that are not burning in prescription. This management milieu should provide the opportunity to manage for the full range of mixed-severity fires and associated forest attributes.

Restoration of the historic mixed-severity fire regime in the Kootenay Valley will likely require planned prescribed fire in addition to unplanned wildfire. This management action should focus on the restoration and maintenance of the lower-severity elements of the fire regime as well as maintaining landscape scale anchors that maximize the potential for unplanned wildfire to play a role. While my study determined limited spatial parameters to guide where on the landscape lower-severity restoration and maintenance should be accomplished, it does provide guidance that this part of the fire regime existed and should be explicitly recognized. Given the relationship between forest structure and sites with mixed-severity fire histories, Douglas-fir led older multi-age class stands would provide a reasonable starting point to consider forest restoration of lower-severity fire regime areas within the Kootenay Valley. It would be prudent to manage for these sites so as to avoid losing the structural elements that are long lived and would be very difficult to recreate. These sites may require pre-fire treatment to re-establish forest structure, primarily stand densities, to a point where prescribed fire will maintain the older age cohorts and not result in their mortality. There may an important engagement opportunity in pursuing this ecological restoration with First Nations re-establishing traditional practices on the landscape. The next steps in this process would be to develop explicit spatial objectives to establish long term goals.

Paleoecological estimates of fire frequency based on macroscopic charcoal analysis of lake cores (Hallett and Walker 2000) defined millennial fire cycle estimates that serve as a backdrop to remind us that long-term climatic change must be considered in the process of restoration. The emulation of historic disturbance processes to maintain biodiversity considers a range of variability commonly referred to as the historic range of variability (HRV), which is determined by understanding the attributes of historic disturbance processes such as fire frequency and fire severity. The establishment of HRV is generally the first step in developing a restoration project (Fule, Covington et al. 1997). Concern exists over how climate change will affect restoration efforts and how relevant HRV objectives will be in light of climate change (Harris, Hobbs et al. 2006; Hobbs, Arico et al. 2006; Lindenmayer, Fischer et al. 2008; Seastedt, Hobbs et al. 2008, Hobbs, Higgs et al. 2013). There are challenges and advantages (Keane, Hessburg et al. 2009) in continuing to utilize HRV concepts to set ecosystem management objectives. The use of HRV elements is strongly supported (Harris, Hobbs et al. 2006; Millar, Stephenson et al.

2007) as being of value in setting ecosystem management objectives. However many researchers (Hobbs, Arico et al. 2006; Millar, Stephenson et al. 2007) point out the importance of utilizing a framework that enables managers to consider alternate paradigms than that of managing solely for HRV in the light of growing concern over the impacts or rapid climate change.

The need to incorporate socio-economic considerations is generally well-supported and has led to the consideration that a more appropriate context for restoration planning may be to consider a broader value based future range of variability (FRV: Duncan, McComb et al. 2010). FRV is the estimated range of a given ecological condition in the future that is shaped by an ecological range of variability and a social range of variability. The ecological range of variability includes biophysical forces such as fire and flood, as well as ecological change driven by humans such as burning, harvesting and development. The social range of variability is the range of an ecological condition that society finds acceptable. While my study establishes attributes to define the pattern of the historic fire regime over the last 300 years further work will be required to understand and value these attributes in an FRV framework to establish long term restoration objectives.

My results have implications for forest management in British Columbia as they provide another example (Cochrane 2007; Nesbitt 2010; Greene 2011; Marcoux 2013) of the limitations of the current Natural Disturbance Type framework. The MS BEC zone falls into the NDT3 class, that describes a mean disturbance interval of 150 years with relatively large patch sizes (BC Ministry of Forests 1995). The NDT3 description also includes reference to multiple disturbance agents and to mature Douglas-fir stands as indicators of structural diversity. The NDT3 type does align with my findings that the historic disturbance regime is characterized as mixed-disturbance dominated by fire. The key aspect that limits the NDT3 description is that it characterizes the fire regime as based solely on the high-severity component. My findings support revisiting the NDT3 description to broaden out the description to include an explicit recognition of the mixed-severity fire regime. This should include recognition of the high frequency of fire disturbance and the structural legacies that it left. My study provides guidance that could be used to steer current forest management with respect to the structural diversity inherent in the historic mixed-severity fire regime. The next steps in this process would be to develop objectives to define remnant tree and multi-age cohort objectives for forest harvesting. Further research into the structural legacies of mixed-severity fire regimes at the landscape scale would benefit this discussion.

4.8 Conclusion

In this research I was able to establish the presence of a mixed-severity fire regime and to characterize the frequency, general extent and relationships to species composition and forest structure of the regime. This study establishes another example of a mixed-severity fire regime in a forest type formally considered to be high-severity. This is an important finding that should enable land management to reach biodiversity conservation objectives both from a fire and forest management perspective. My results characterize the historic disturbance regime to have been mixed disturbance dominated by a mixed-severity fire regime. This fire regime was driven by individual high severity fire events occurring at a frequency of 60-130 years with some areas that experienced lower severity fire events occurring at a frequency of 20 - 40 years. The results of these historic disturbance processes are that 21% of the current landscape was dominated by high-severity fire, 42% by mixed-severity and 37% had an unknown fire history.

I had the unique opportunity to develop a systematic field-based fire history study in an area that had already undergone a time-since-fire study. In essence I was able to combine time-since-fire methods with a systematic study design following well established fire interval based methods. This combination provided a tool to explore mixed-severity fire characteristics in a complicated mixed-disturbance forest. I would suggest that this combined study method might prove to be a helpful tool to study forest systems of mixed-severity fire where the legacy of fire is not obviously apparent utilizing either of the methods in isolation. Specifically in areas of relatively contiguous forest cover that have elements of high-severity fire sufficient to leave an imprint observable through air photos and also have low-severity fire indicators such as individual trees with multiple scars. An efficient method using the results of my study would establish a systematic study grid to sample across the whole study area with a more intensive grid in stands that appear to have mixed structural attributes and/or comprise older forest.

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Appendix A

Tables

Table A-1 Physical attributes of the 43 plots located in the Montane Spruce biogeoclimatic zone of the Kootenay River valley in Kootenay National Park. Topographic attributes were measured at the site level in the field and the landscape level using a geographic information system. The moisture regime and site series were determined according to biogeoclimatic ecosystem classification (source). Ecosections are based on the Ecological Land Classification; abbreviations are FR = Fireside, DR = Daer, AT = Athabasca and VL = Vermillion Lakes.

Plot Number	**Elevation (m.a.s.l.)**	**Site Slope Angle (degrees)**	**Site Slope Aspect (degrees)**	**Landscape Slope Angle (degrees)**	**Landscape Slope Aspect (degrees)**	**Moisture Regime**	**MSDK Site Series**	**ELC Ecosite**
15	1159	0	0	3.0	90	4	5	FR3
19	1304	6	44	16.1	47	5	5	DR3
20	1127	0	0	1.2	72	4	4	DR7
21	1208	16	83	2.0	179	3	3	DR3
24	1214	0	0	2.8	244	4	1	DR2
27	1329	40	70	14.7	63	3	4	DR2
28	1101	0	0	1.5	324	2	3	AT1
33	1186	1	208	3.4	13	4	1	DR8
38	1280	6	9	8.4	54	6	6	DR6
39	1137	6	45	1.5	64	3	4	DR8
44	1327	7	36	12.3	33	5	5	DR6
45	1124	0	0	1.5	45	5	5	AT4

51	1165	0	0	3.7	20	5	5	FR3
52	1186	0	0	8.1	239	4	1	DR3
53	1297	7	240	4.1	241	2	3	DR3
58	1222	9	50	13.0	47	3	3	DR6
59	1141	0	0	3.4	174	4	1	FR3
60	1213	0	0	7.9	238	3	4	DR8
66	1375	22	76	19.8	63	5	5	DR3
67	1150	0	0	1.6	259	5	5	FR3
68	1169	0	0	0.9	17	4	1	DR3
74	1160	16	242	1.4	48	2	3	AT1
75	1190	10	250	2.5	231	4	1	DR8
81	1207	12	124	3.1	91	4	1	DR6
82	1164	0	0	0.5	188	4	4	AT1
83	1256	20	236	8.8	232	2	3	DR2
89	1264	8	84	2.6	184	5	5	DR6
90	1231	3	244	1.1	243	2	3	DR7
91	1171	0	0	3.7	235	5	1	DR5
98	1301	5	54	5.8	82	5	1	FR1
99	1248	0	0	4.4	58	1	4	DR8
100	1177	0	0	0.9	88	6	6	VL6
101	1310	12	245	11.3	244	2	4	DR2
108	1288	0	0	3.0	48	5	1	DR8

109	1177	0	0	0.5	79	7	7	VL2
110	1258	5	360	5.4	310	2	3	DR8
111	1257	11	47	9.3	61	5	5	DR7
117	1268	11	70	6.0	66	4	4	DR2
118	1267	28	296	0.7	12	4	1	DR7
120	1250	0	0	4.5	182	1	3	DR7
126	1282	22	284	18.5	245	4	1	DR5
130	1254	10	127	13.5	145	4	3	DR7
133	1300	20	254	13.8	271	4	1	DR5

Table A-2 Fire event and cohort information utilized to classify plots into fire severity groups: plot number, stand-origin year (Masters 1990, fire scar years, year of largest establishment cohort linked to a fire event, percentage; establishment cohort and remnant trees associated with year or strongest fire event and disturbance group.

Plot Number	Stand Origin Year	Fire Scar Years	Year of Strongest Fire Event Establishment Cohorts	Establishment Cohort %	Remnant Trees %	Disturbance Group
15	1917	None	1917	35%	15%	2
19	1748	1917	1917	61%	33%	2
20	1917	1917 ,1831	1917	80%	15%	1
21	1828	1917,1878, 1846,1810	1828	30%	15%	2
24	1917	1798	1917	85%	10%	1
27	1917	1917	1917	95%	5%	1
28	1917	1917	1917	94%	6%	1
33	1917	None	1917	93%	3%	1
38	1828	None	1828	65%	4%	1
39	1917	1917, 1853, 1834	1917	80%	2%	2
44	1828	None	No Fire Cohort	<30%	n/a	3
45	1800	None	No Fire Cohort	<30%	n/a	3
51	1808	None	No Fire Cohort	<30%	n/a	3
52	1800	1873	No Fire Cohort	<30%	n/a	3
53	1808	1883,1869	No Fire Cohort	<30%	n/a	3
58	1828	None	No Fire Cohort	<30%	n/a	3
59	1800	1905,1883, 1848	1905	63%	21%	2
60	1800	1883, 1869	No Fire Cohort	<30%	n/a	3
66	1828	None	No Fire Cohort	<30%	n/a	3
67	1820	None	No Fire Cohort	<30%	n/a	3

68	1820	None	No Fire Cohort	<30%	n/a	3
74	1820	1881	No Fire Cohort	<30%	n/a	3
75	1868	1889,1869	1889	30%	20%	2
81	1828	None	No Fire Cohort	<30%	n/a	3
82	1868	None	1868	55%	0%	2
83	1868	None	No Fire Cohort	<30%	n/a	3
89	1868	1875, 1869	1869	30%	0%	2
90	1926	None	1926	32%	37%	2
91	1858	1889, 1869	No Fire Cohort	<30%	n/a	3
98	1926	None	1926	88%	0%	1
99	1868	1926, 1900, 1896	1926	89%	11%	2
100	1878	1926, 1872	1872	35%	0%	2
101	1868	1926,1889, 1869,1864, 1852,1848, 1822	1926	41%	59%	2
108	1926	1926, 1863	1926	55%	35%	2
109	1926	1926	1926	65%	40%	2
110	1926	1926	No Fire Cohort	<30%	n/a	3
111	1926	1926,1913, 1904	1926	88%	12%	2
117	1926	None	1926	67%	6%	2
118	1926	1926	1926	90%	5%	1
120	1926	None	1926	71%	0%	1
126	1926	1926, 1896, 1884	1926	72%	28%	2
130	1926	1926	No Fire Cohort	<30%	n/a	3
133	1803	1926,1918, 1869,1796	No Fire Cohort	<30%	n/a	2

Table A-3 Stand origin and Vegetation Resource Inventory (VRI) stand age – stand age dynamic error classes. Stand-origin and VRI calendar year compared to the calendar year that the stand age dynamic attributes occurred: oldest tree, median age, and largest cohort calendar years. Error classes: 1 = < 20, 2 = 20 -39, 3 ≥ 40.

Plot	**Stand Origin Year**	**VRI Stand Age (converted to calendar year)**	**Oldest Tree (calendar year of origin of oldest tree)**	**Stand Origin Oldest Tree Error Class**	**VRI Oldest Tree Error Class**	**Median Age (calendar year of median age of stand)**	**Stand Origin Median Age Error Class**	**VRI Median Age Error Class**	**Largest Cohort (calendar year of oldet tree in the largest cohort)**	**Stand Origin Largest Cohort Error Class**	**VRI Largest Cohort Error Class**
15	1917	1871	1835	3	2	1936	1	3	1929	1	3
19	1748	1871	1728	2	3	1924	3	3	1914	3	3
20	1917	1881	1816	3	3	1927	1	3	1922	1	3
21	1828	1891	1768	3	3	1851	2	3	1830	1	3
24	1917	1921	1909	1	1	1925	1	1	1920	1	1
27	1917	1921	1901	1	2	1920	1	1	1918	1	1
28	1917	1911	1911	1	1	1925	1	1	1920	1	1

33	1917	1921	1914	1	1	1923	1	1	1915	1	1
38	1828	1851	1823	1	2	1841	1	1	1830	1	2
39	1917	1911	1867	3	3	1929	1	1	1920	1	1
44	1828	1871	1793	2	3	1856	2	1	1864	2	1
45	1800	1921	1814	1	3	1917	3	1	1923	3	1
51	1808	1871	1800	1	3	1957	3	3	1946	3	3
52	1800	1921	1871	3	3	1954	3	2	1947	3	2
53	1808	1861	1810	1	3	1927	3	3	1921	3	3
58	1828	1911	1816	1	3	1852	2	3	1816	1	3
59	1800	1871	1816	1	3	1917	3	3	1905	3	2
60	1800	1901	1898	3	1	1927	3	2	1918	3	1
66	1828	1891	1856	2	2	1921	3	2	1920	3	2
67	1820	1901	1860	3	3	1940	3	2	1941	3	3
68	1820	1881	1779	3	3	1917	3	2	1918	3	2
74	1820	1865	1927	3	3	1954	3	3	1940	3	3
75	1868	1921	1815	3	3	1919	3	1	1913	3	1
81	1828	1845	1853	2	1	1921	3	3	1901	3	3
82	1868	1895	1871	1	2	1882	1	1	1871	1	2

83	1868	1921	1916	3	1	1931	3	1	1916	3	1
89	1868	1885	1875	1	1	1910	3	2	1875	1	1
90	1926	1920	1899	2	2	1934	1	1	1899	2	2
91	1858	1895	1890	2	1	1922	3	2	1905	3	1
98	1926	1926	1926	1	1	1934	1	1	1926	1	1
99	1868	1920	1925	3	1	1929	3	1	1925	3	1
100	1878	1895	1882	1	1	1896	1	1	1882	1	1
101	1868	1870	1675	3	3	1909	3	2	1929	3	3
108	1926	1925	1770	3	3	1931	1	1	1925	1	1
109	1926	1895	1786	3	3	1921	1	2	1917	1	2
110	1926	1895	1893	2	1	1916	1	2	1904	2	1
111	1926	1920	1858	3	3	1933	1	1	1928	1	1
117	1926	1921	1924	1	1	1932	1	1	1924	1	1
118	1926	1926	1921	1	1	1932	1	1	1921	1	1
120	1926	1926	1931	1	1	1943	1	1	1931	1	1
126	1926	1816	1831	3	1	1930	1	3	1921	1	3
130	1926	1846	1873	3	2	1891	2	3	1886	3	3
133	1803	1816	1702	3	3	1770	2	3	1761	3	3

Table 4.1 Fire frequencies summaries for fire history studies in south-eastern B.C.: study areas, authors, BC BEC forest types (MS = Montane Spruce, ESSF = Engelmann Spruce – Subalpine Fir, ICH = Interior Cedar-Hemlock, IDF = Interior Douglas-fir), plot elevation, study area size and sampling design, time period and frequency descriptor.

Study Area	**Author**	**Forest Type(s)**	**Plot Elevation Range (m.a.s.l.)**	**Study Area Size (Sampling Design)**	**Time Periods**	**Frequency Descriptor**
Columbia// Kootenay Valleys	Cochrane, 2007	MS	1097 – 1554	60,602 ha (Stratified Random)	1509 – 2006	**CPFI** 16.8 -110 years
West Arm Kootenay Lake, West Kootenays	Nesbitt, 2010	ICH ESSF	611 – 1725	35,116 ha (Stratified Random)	1642 - 2009	**WMPI** 10.5 - 21.3 years
Darkwoods Creston, East Kootenays	Green, 2011	ICH ESSF	727 -1869	4,000 ha (Systematic)	1703 - 1996	**CPFI** 21.8 -66.5 years
Joesph/Gold Creeks, Cranbrook, East Kootenays	Marcoux 2013	IDF MS ESSF	1168 – 1981	15,400 ha (Stratified Random)	1600 -2009	**CPFI** 7 -56 years
Kootenay Valley, Kootenay National Park	Kubian, 2013	MS	1101 -1310	35,400 ha Systematic	1679 - 2009	**CPFI** 6 -86 years

Appendix B

Figures

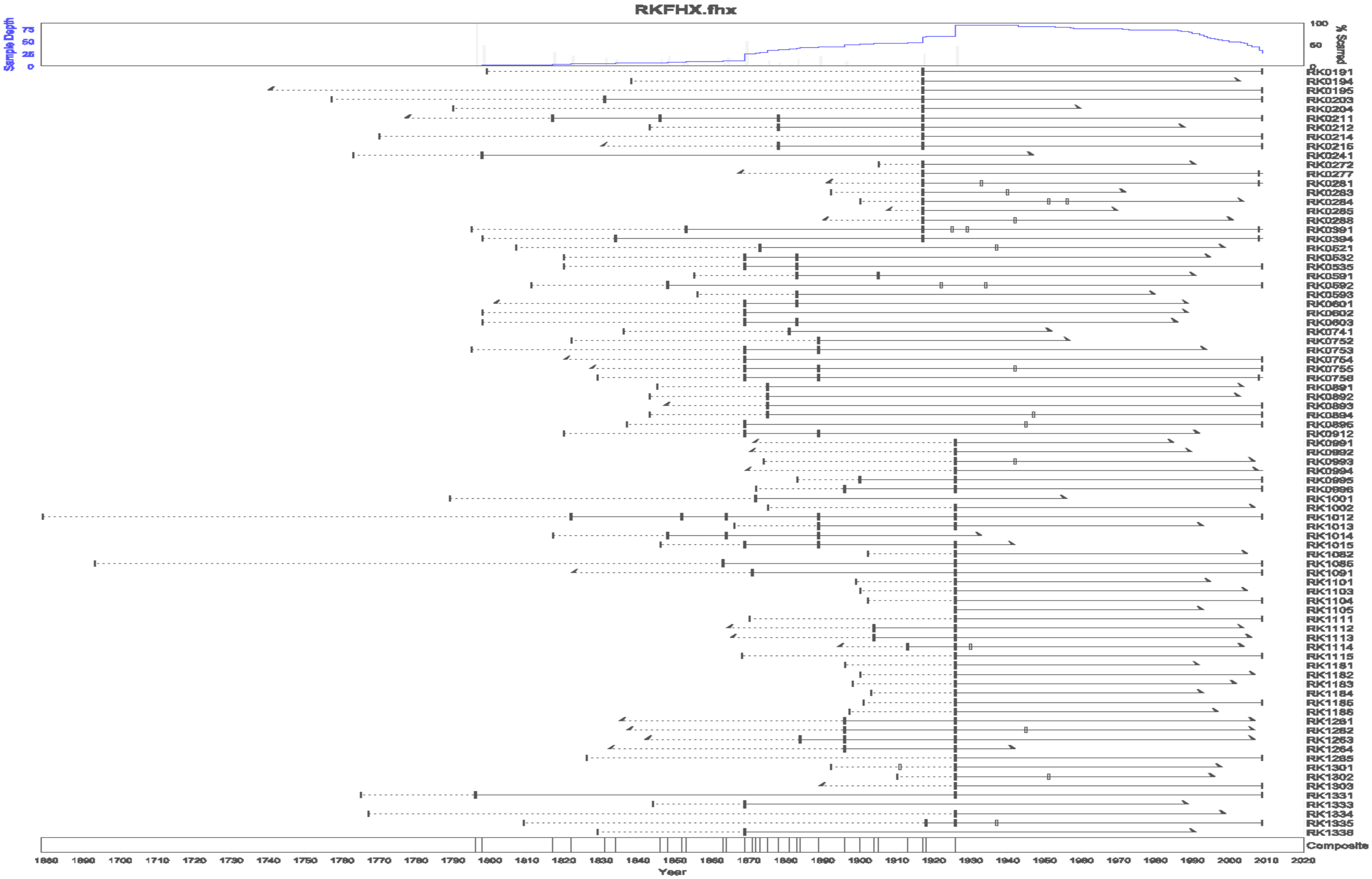


Figure B-1 FHX output for all scar samples detailing individual tree chronologies. Symbols used: ▌ = fire scar year, ▯ = other scar year, ◀pith year estimated, ►year of death estimated, | pith year/year of death known,

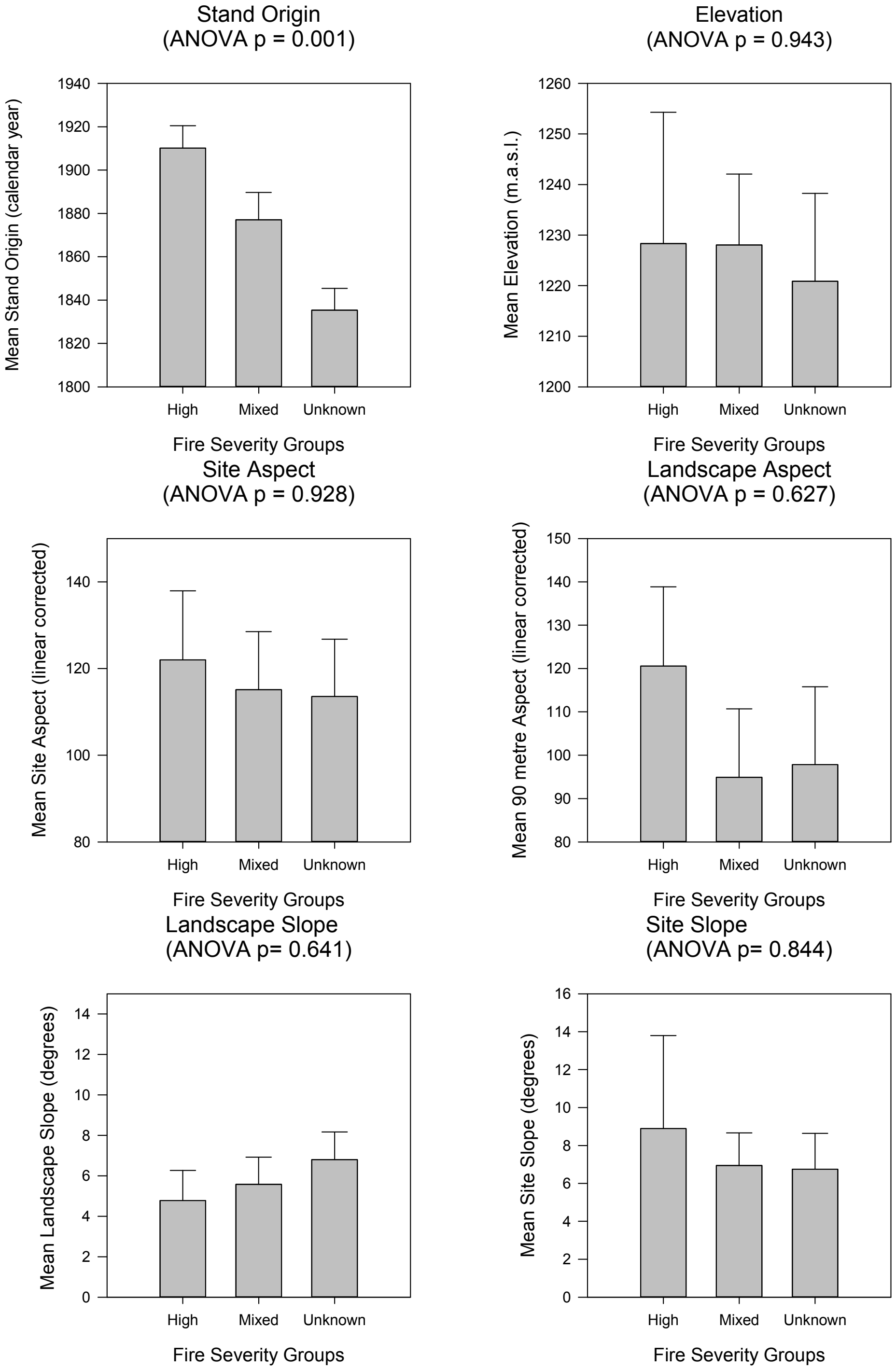
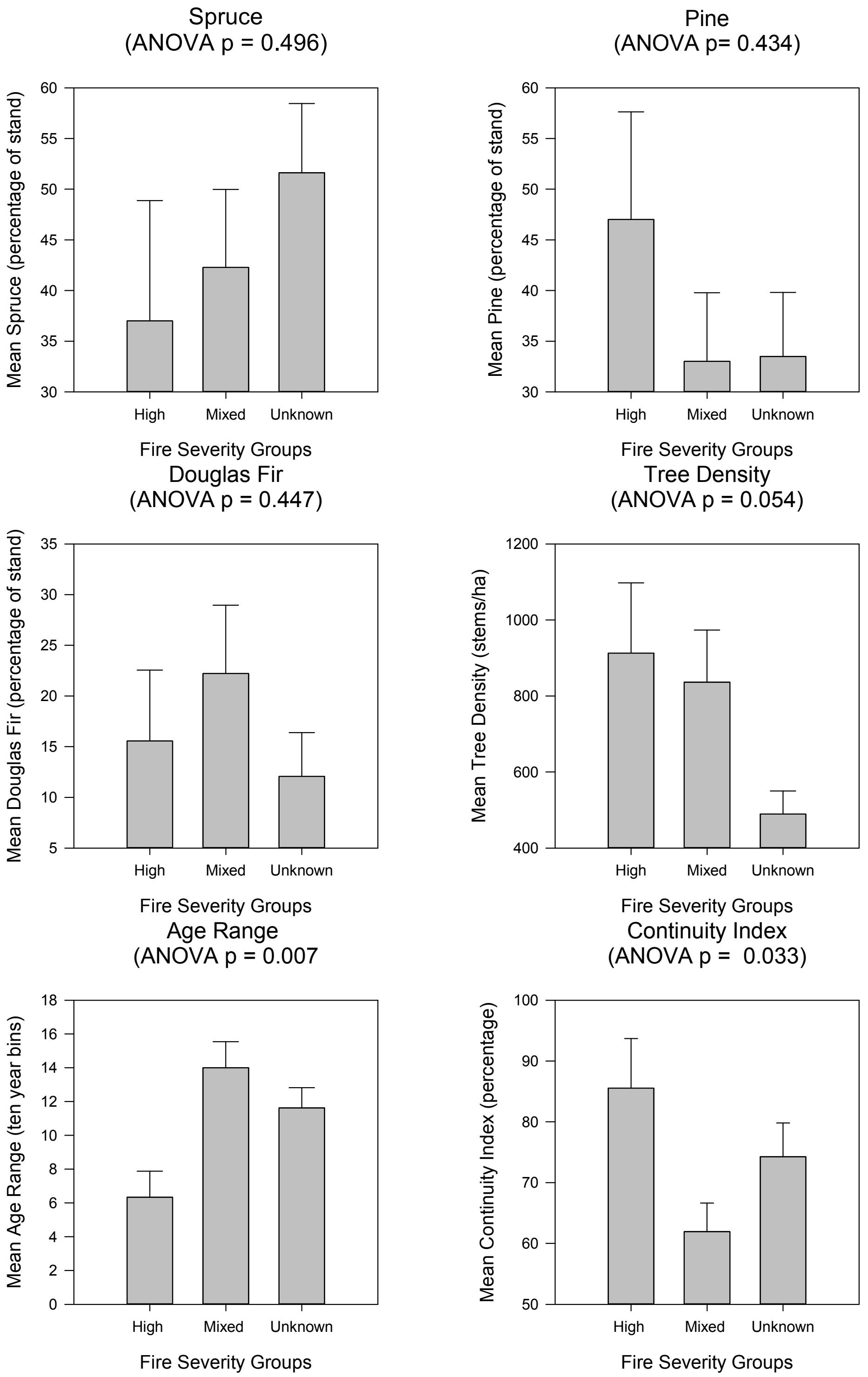


Figure B-2 ANOVA results for topographic variables and stand age compared to fire severity groups.



Spruce (ANOVA p = 0.496)

Pine (ANOVA p= 0.434)

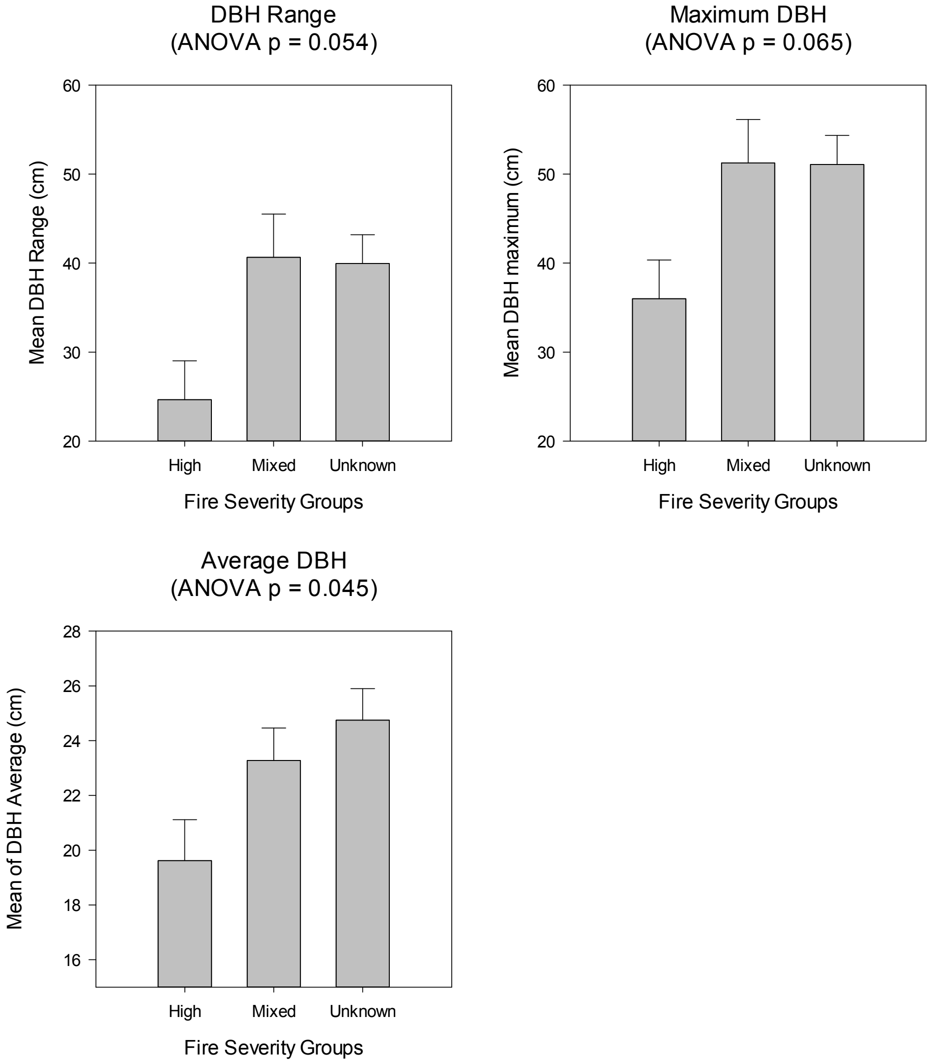
Douglas Fir (ANOVA p = 0.447)

Tree Density (ANOVA p = 0.054)

Age Range (ANOVA p = 0.007

Continuity Index (ANOVA p = 0.033)

Figure B-3 ANOVA results for species composition and stand structure attributes compared to fire severity groups.

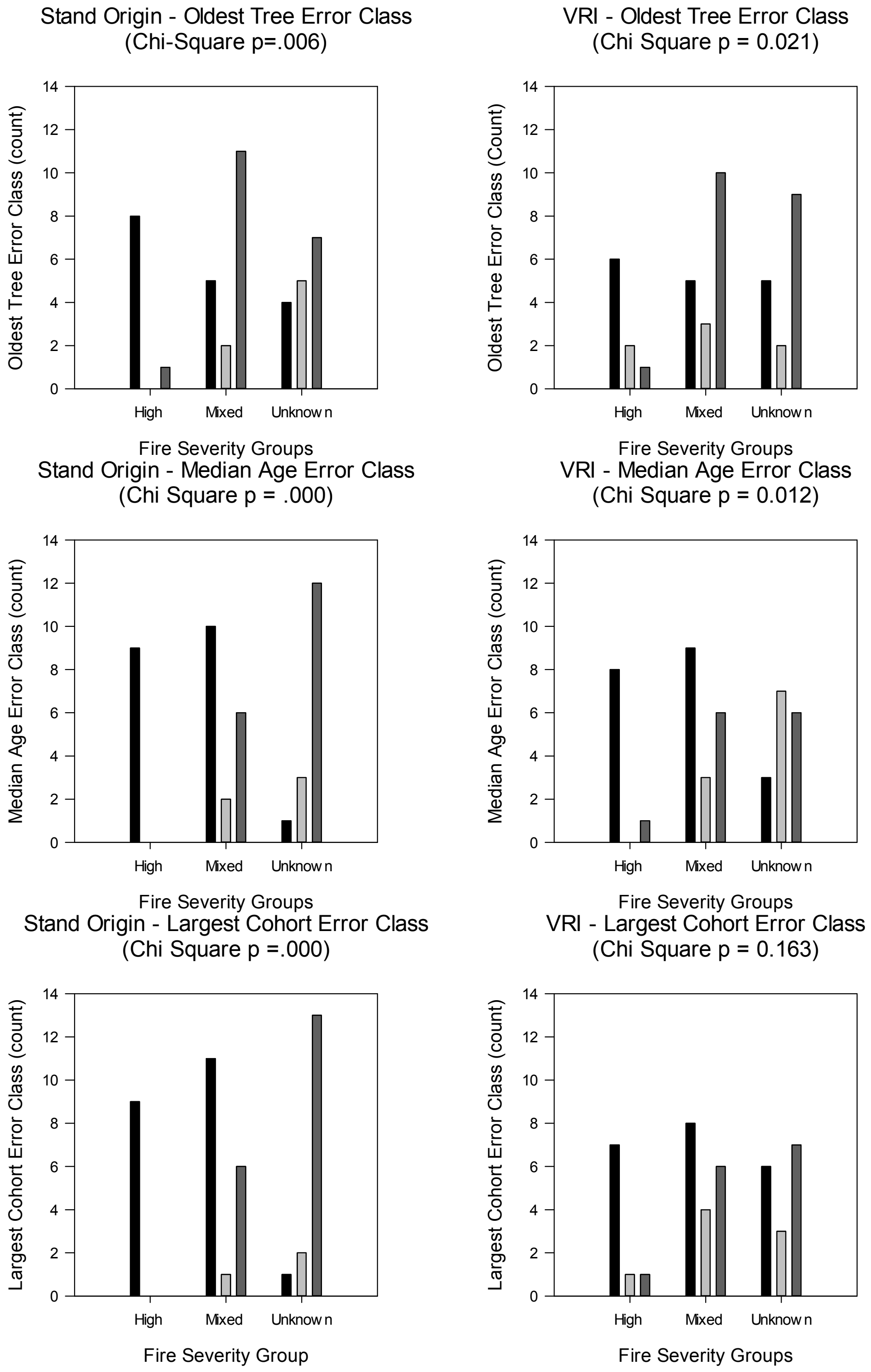


DBH Range
(ANOVA p = 0.054)

Maximum DBH
(ANOVA p = 0.065)

Average DBH
(ANOVA p = 0.045)

Figure B-4 ANOVA results for DBH attributes compared to fire severity groups.



Stand Origin - Oldest Tree Error Class
(Chi-Square p=.006)

VRI - Oldest Tree Error Class
(Chi Square p = 0.021)

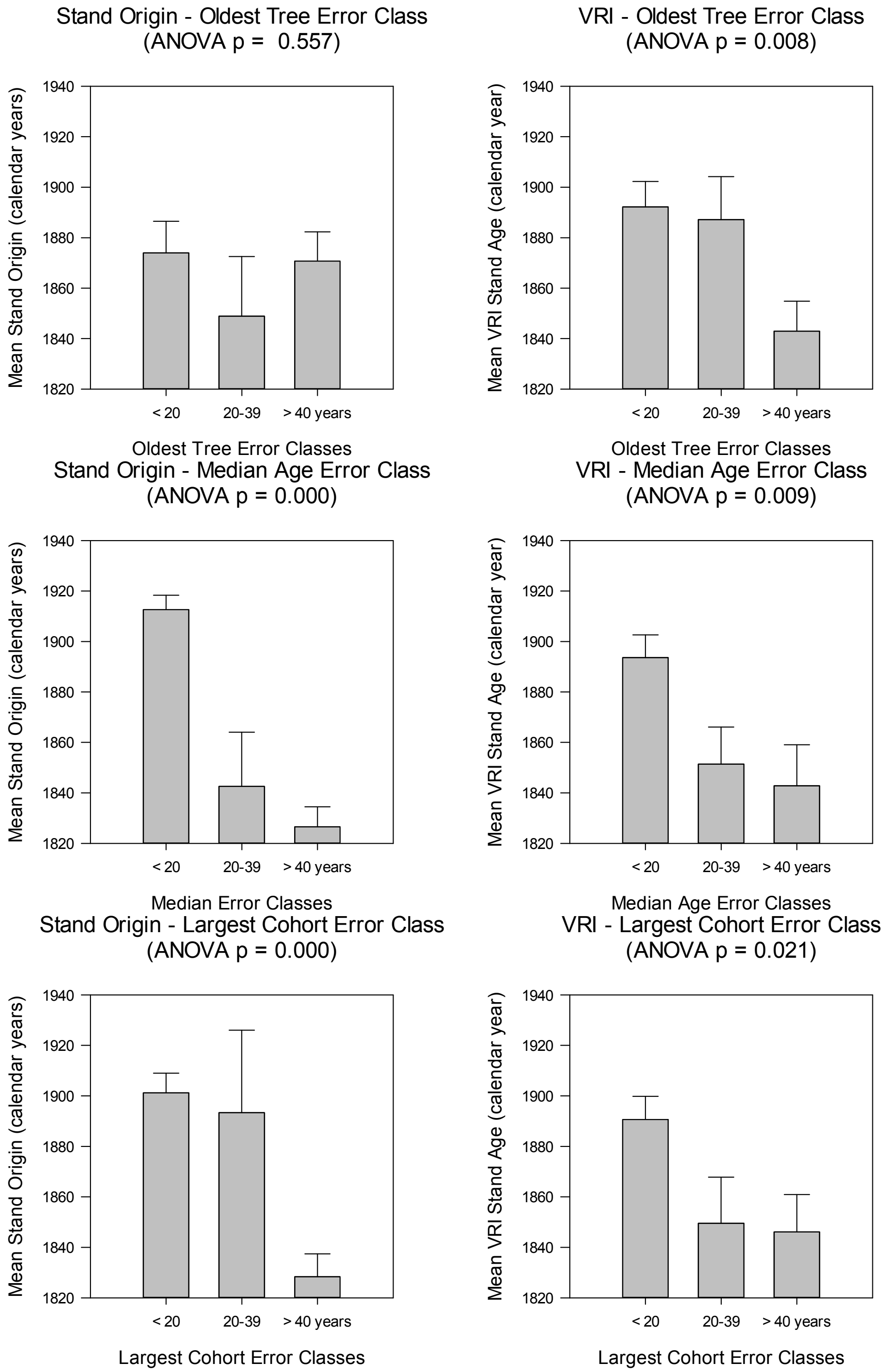
Stand Origin - Median Age Error Class
(Chi Square p = .000)

VRI - Median Age Error Class
(Chi Square p = 0.012)

Stand Origin - Largest Cohort Error Class
(Chi Square p =.000)

VRI - Largest Cohort Error Class
(Chi Square p = 0.163)

Figure B-5 Contingency Table Results for Stand-origin and VRI compared to Fire Severity Groups



Stand Origin - Oldest Tree Error Class (ANOVA p = 0.557)

VRI - Oldest Tree Error Class (ANOVA p = 0.008)

Stand Origin - Median Age Error Class (ANOVA p = 0.000)

VRI - Median Age Error Class (ANOVA p = 0.009)

Stand Origin - Largest Cohort Error Class (ANOVA p = 0.000)

VRI - Largest Cohort Error Class (ANOVA p = 0.021)

Figure B-6 ANOVA results for stand-origin map and VRI stand age compared to stand-dynamic attributes.