Humans, Climate and an Ignitions-Limited Fire Regime at Vaseux Lake

by

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B.A., Whitman College, 2009

A THESIS SUMBITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE
in
The Faculty of Graduate and Postdoctoral Studies
(Forestry)

THE UNIVERSITY OF BRITISH COLUMBIA
(Vancouver)

March, 2017

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ABSTRACT

This study investigated the role of human land use and climate as drivers of the historical fire regime of a 400ha protected area in the Okanagan region of British Columbia. I used fire scars and forest demography data to reconstruct spatiotemporal patterns in fires from 1714 - 2013. I also used paleo-climate reconstructions derived from tree ring series to evaluate whether historical fire-climate relationships changed with the displacement of indigenous peoples.

Fire patterns were closely coupled with the human history of the study area. Fires were more frequent, less synchronous, and burned earlier in the season when indigenous people were stewarding the study area traditionally. Logistic regression showed that fires were also twice as likely during this period, and that topographic factors were not a significant control of the fire regime.

Analysis of fire-climate relationships revealed that human land use superseded the effects of inter-annual and decadal-scale climate as a driver of historical fires. Fires occurred during a variety of conditions when indigenous people were stewarding the study area traditionally, while fires after indigenous people were displaced were associated with El Niño years, which tend to bring warm/dry conditions to the region.

The historical fire regime at Vaseux was of mixed-severity in time and space, and this variability helped generate a complex forest structure. Historical fires acted to control tree establishment and mortality, and the forest is now denser than it was historically due to reduced fire frequency in the late 20th century. Continued infilling could shift the fire regime towards a greater component of high-severity fire.

The results suggest that indigenous traditional land stewardship was the dominant control of historical fire dynamics at Vaseux. Managers wishing to preserve habitat and forest structures generated by the historical fire regime will need to account for the influence of indigenous burning, and modern lightning intervals will not be a sufficient baseline for setting treatment intervals. Proactive management designed to maintain a fire regime of frequent mixed-severity fires will be necessary to promote ecological resilience in an uncertain future.

PREFACE

This research was conducted using resources and equipment provided by The Tree Ring Laboratory at the University of British Columbia, Vancouver. I developed the sampling design for the project in collaboration with LD Daniels and GA Greene. I collected and processed fire scar samples and increment cores from the study area with assistance from several members of The Tree Ring Laboratory (J Liu, R Baston, H Erasmus, S Kallos, R Chavardes, GA Greene, E Heyerdahl, and LD Daniels), and I crossdated all fire scar samples and increment cores. All figures and tables are my own original work, but benefited from review by LD Daniels. In both data chapters I was responsible for designing and performing analyses, and manuscript composition, with input from LD Daniels, GA Greene, E Heyerdahl, and V LeMay. Manuscript edits were provided by LD Daniels, S Lavallee, B Larson, and K Lertzman.

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ACKNOWLEDGEMENTS

To Dr. Lori Daniels: Lori, thank you for sharing your knowledge, insights, and passion for fire ecology. I feel lucky to have worked with such a capable and accomplished supervisor whom I could relate to so easily. Your ideas and suggestions were always spot-on, and I have learned an immeasurable amount from you in the few years we have worked together.

To the members of my committee, Dr. Suzie Lavallee and Dr. Bruce Larson: Suzie and Bruce, thank you both for your feedback, candid insights, and excellent sense of humor throughout the thesis process. You've both helped me broaden my perspective on fire ecology and forest dynamics. Thank you also to Dr. Ken Lertzman for thoughtful manuscript edits and feedback, and for acting as my interdepartmental examiner, and to Dr. Emily Heyerdahl for assistance in study design and insights in the field.

I would also like to thank Ellen Simmons and members of the Penticton Indian Band for sharing their knowledge of traditional practices, allowing me to share my findings with them, and for guiding me in the most respectful way to discuss the results of my research.

Thank you also to the Canadian Wildlife Service for permission to sample on their property, and to the Natural Sciences and Engineering Research Council of Canada (NSERC) for funding the project.

To my colleague, Greg Greene: Greg, I am floored by how much you know about so many subjects, and how generous you are with your time. To say that I benefitted from your help would be the understatement of the century. Your friendship and collaboration throughout this project were essential.

To my awesome field crew, who worked with me, rain or shine, to collect a lot of samples and carry them a lot of miles back to the vehicles: you guys are the best! Special thanks to Rodrigo Baston, Hans Erasmus, and Sebastian Kallos. Your humor and excellent spirit were so appreciated and I will never forget the fun and challenges we faced out there. I would also like to thank my lab assistant Jenny Liu. Jenny, you were so careful and thorough. Thank you for treating my samples as if they were your own. Thank you also to my colleague Raphael Chavardes, for your suggestions, friendship, help in sample processing, and insights about fire-climate relationships.

Lastly, I would like to thank my family and friends, who are the spice of my life! Special thanks to Mom, Dad, Kath, Molly, Spencer, Paige, Róka, Joane, Kirsten, and most of all Sebastian. I'm too lucky to have all of you in my life. I can't believe you put up with me!

“Those who dwell…
among the beauties and mysteries of the earth
are never alone or weary of life.”
-Rachel Carson

CHAPTER ONE: INTRODUCTION

Although often portrayed ominously in the news media, disturbances are integral processes in ecosystems. The manner and timing of disturbances act to shape ecosystem structure and composition, nutrient cycling, and on a broader scale, landscape pattern. Disturbances are thus inextricably linked to ecosystem function and patterns of succession (Franklin et al. 2002, Turner 2010). In that disturbances can alter system states and their distribution, disturbances can also be seen as key drivers of spatial and temporal heterogeneity and complexity within landscapes (Landres et al. 1999, Hessburg et al. 2000, Turner 2010). Research increasingly recognizes that variability on multiple scales may be of intrinsic value to ecosystem health, resilience, and biodiversity (Drever et al. 2006, Turner 2010).

Given that disturbances play such a pivotal role in structuring and driving ecosystems—particularly in generating heterogeneity and complexity at multiple scales—it is essential that land management and conservation initiatives incorporate contemporary knowledge and concepts of disturbance. Integrating disturbances and the patterns they impart may be particularly critical to maintaining biodiversity given that habitat requirements may vary widely between species within a given community as well as throughout different life history stages (Franklin et al. 2002, Perry et al. 2011). Land use, particularly the management of forests for timber, can directly alter important patterns of spatial and temporal heterogeneity; homogenizing at some scales and introducing novel patterns at others (Long 2009, Turner 2010). Land use can also indirectly reduce ecosystem variability by changing disturbance regimes or removing certain kinds of disturbance from the landscape altogether (Long 2009). Managers need criteria for evaluating whether land-use practices have the potential to alter ecosystem structure and function, and thus whether biodiversity and productivity may be threatened in the long-term. In areas where ecosystems have been degraded, managers also need a method to design and target restoration strategies. By seeking to understand the role of disturbances as ecosystem processes that generate heterogeneity and shape structure and composition, researchers and managers can find a valuable framework for answering some of these questions (Drever et al. 2006, Long 2009, Turner 2010).

Understanding disturbance processes will only become more important in the context of a changing global climate. Given that global circulation patterns and temperature are major drivers of many forms of disturbance, rapid changes to climate will likely be accompanied by rapid and potentially unpredictable changes in disturbances as well (Millar et al. 2007, Bowman et al. 2009, Turner 2010). Although disturbances are likely to manifest themselves in novel ways due to climate change, understanding their drivers and patterns as they occur today and occurred in the past provides the best possible means to predict their range of future behaviors (Turner 2010). If we wish to maintain certain critical ecosystem services, species, and habitats, researchers and managers will need to be able to anticipate these changes as well as implement strategies that are flexible enough to deal with surprises. Managing for resilience of particular systems rather than specific structures is emerging as a more practical approach to adaptive management in the face of climate change (Drever et al. 2006, Millar et al. 2007). Understanding the relationship between disturbance and resilience will thus be an important step in generating successful new management approaches.

In western North America, fire is a prominent and influential form of disturbance (Agee 1993, Westerling et al. 2006), and is particularly effective at imparting heterogeneity onto stands and landscapes owing to its inherently patchy and variable effects (Agee 1993, Lertzman et al. 1998, Turner et al. 2003). Global climate and local weather patterns are also major drivers of fire behavior and extent, and fire is a disturbance agent likely to experience significant change as global circulation patterns shift and temperatures rise (Dale et al. 2001, Westerling et al. 2006, Turner 2010). Fire as a process has also been subject to marked anthropogenic impacts in the last century related to such factors as grazing, timber management, and most notably active fire suppression (Agee 1993). Understanding the ecological role of fire and its drivers, as well as the potential for global climate and land use to alter these patterns, will be increasingly critical to sustainable land management and conservation in western North America—particularly in forested regions.

Like other forms of disturbance, wildfires can vary significantly in their behavior, magnitude, effects, and seasonality depending on the interaction of multiple drivers and local factors (Agee 1993, Lertzman et al. 1998, Schoennagel et al. 2004). Although the nature and timing of fires may vary, researchers are still able to recognize certain recurring patterns in fires associated with particular ecosystem types, regions, landscapes, and sites. Thus the concept of a “fire regime” is used to classify and characterize the ecological role of fire in a given system through time (Agee 1993, 1998, Schoennagel et al. 2004). Not only is the concept of a fire regime useful in order to compare and discuss differences in fire occurrence through space and time, fire regimes may be an intuitive and relevant framework by which to evaluate management schemes and tailor restoration programs (Schoennagel et al. 2004, Brown et al. 2004).

A major objective of characterizing fire regimes is to elucidate the relative importance of different controls and how they are manifest in different patterns of effects and frequency through time. Contemporary nomenclature separates these drivers into two categories: “top-down” and "bottom-up" controls (Lertzman et al. 1998, Heyerdahl et al. 2001, Falk et al. 2011). From the top down, spatiotemporal patterns in global and regional climate can influence fire severity and frequency by shaping patterns of seasonality, temperature, precipitation, and lightning ignitions, which are important determinants of fire occurrence and behavior (Agee 1993, Macias Fauria et al. 2011). From the bottom up, physical characteristics of the landscape including topography, vegetation composition, and arrangement (the fuels available to burn), determine fuel combustibility and continuity—important controls on fire spread, behavior, and severity (Agee 1993, Schoennagel et al. 2004, Perry et al. 2011).

In addition to characterizing drivers of fire regimes, researchers are also concerned with describing the nature and effects of fires themselves. Common metrics include fire type, seasonality, intensity, extent, frequency, and severity (Agee 1993). Severity describes the impact of fires on soil and vegetation, and is often measured based on percent mortality to overstory trees (Agee 1993). Severity has attained prominence as a means to broadly classify fire regimes, and three general categories are outlined: low-, high-, and mixed-severity regimes. While these are delineated for the sake of comparison, fire regimes are increasingly understood to lie along a continuous gradient between low and high severity, with mixed-severity fire regimes occupying the many permutations in the middle (Schoennagel et al. 2004, Agee 2005, Perry et al. 2011).

Although this nomenclature only explicitly identifies fire severity, these designations are often meant to imply associated relationships with other metrics such as frequency, as well as characteristic interactions with top-down and bottom-up controls (Schoennagel et al. 2004). Low-severity fire regimes are often associated with drier climates in which fuel moistures are low enough to sustain combustion during any given fire season, yet fuel loads are typically light and discontinuous such that fires often burn as lower intensity surface fires and rarely reach into tree crowns. Conditions in these systems are apt for fire to occur frequently, but severity is typically low due to the low intensity of fires and the co-incidence of adaptations to fire in species typically found in these areas. Thus, low-severity regimes are often described as being "fuels-limited" in that the availability of fuels for combustion is more limiting than climatic factors influencing fuel moisture (Swetnam and Baisan 1996, Schoennagel et al. 2004).

In contrast, high-severity regimes are often found in regions with wetter climates where large amounts of biomass accumulate owing to enhanced productivity, but fuels are often too moist to sustain combustion during a typical fire season. Pronounced and often prolonged drought events—sometimes on multi-season to decadal time scales—may be necessary to sufficiently dry fuels so that fires can ignite and spread. However, when fires in these systems do ignite, they often burn as crown fires of high intensity and are often extensive. Owing to these factors, fires in forests characterized by high-severity regimes tend to burn infrequently and with high degrees of mortality given typical fire behavior. Severity in these systems is enhanced since species in these systems tend to have thin bark and/or lack adaptations to resist fire. High-severity fire regimes are thus characterized as being "climate-limited" in that anomalous climatic events such as droughts are required in order to sustain fire, while fuels loads are sufficiently abundant and continuous during the average fire season (Johnson et al. 2001, Schoennagel et al. 2004, Sibold et al. 2006).

Mixed-severity regimes characterize areas experiencing varying combinations of low- and high-severity effects in space and time, and even within single fire events (Schoennagel et al. 2004, Agee 2005, Perry et al. 2011). Scale is important for describing these regimes, as all fires and regimes are characterized by some degree of heterogeneity depending on the scale at which one looks (Agee 1998, 2005, Turner et al. 2003, Perry et al. 2011). As these systems share attributes with both low- and high-severity fire regimes, mixed-severity regimes are likely limited by both climate, fuels, and their interaction at multiple scales. These relationships are complex and warrant further study (Schoennagel et al. 2004, Agee 2005, Perry et al. 2011, Hessburg et al. 2016). To fully understand mixed-severity regimes and their driving factors, it may be helpful to formulate sub-classifications within "mixed severity" that identify the relative importance of the low vs. high severity component as a defining aspect of these systems (Perry et al. 2011, Marcoux et al. 2013).

Regional variation in fire regimes across western North America has encouraged researchers to associate certain plant communities and structures with particular fire regimes (Schoennagel et al. 2004). However, as studies are conducted in new areas, it becomes apparent that there is substantial variation within each of these fire regime classes. As vegetation and topography vary, even subtly, among regions and along environmental gradients, so too will fire regimes—even within a given forest type (e.g. Brown et al. 1999, Sherriff and Veblen 2007).

One of the best means available to address this variability and accurately characterize local fire regimes is through fire history research (Swetnam and Baisan 1996, Sherriff and Veblen 2007, Falk et al. 2011). Fire history studies seek to reconstruct how and when fires burned in a particular area using various lines of evidence, including fire scar networks, stand structure reconstructions, pollen and charcoal deposits, and aerial photo comparisons (Agee 1993, Swetnam et al. 1999). The onset of European settlement in the late 19th century marked a change in the incidence and nature of fire in many ecosystems of western North America and, thus, fire history studies are also critical in determining whether fire regimes prior to the late 19th century ("historical fire regimes") differed from those observed today (Agee 1993, Swetnam et al. 1999). Research increasingly indicates that land use and particularly fire suppression have not affected all forest and ecosystem types uniformly, and these differences may be best understood from the standpoint of historical fire regimes (Schoennagel et al. 2004).

Fire history studies may also be able to shed light on the relative importance of different ignition sources as historical drivers of local and regional fire regimes. Although anthropogenic changes to fire regimes following European colonization are relatively recent, indigenous peoples have inhabited North America for thousands of years, and many used fire as an integral component of their traditional land stewardship[*] (Agee 1993, Boyd 1999, Turner 1999, Simmons 2012). Little research has explicitly explored whether these human-caused ignitions have been ecologically significant in shaping local and regional fire regimes, and by extension vegetation dynamics in western North America (Veblen et al. 2000, Keeley 2002, Grissino-Mayer and Romme 2004, Fry and Stephens 2006, Lepofsky and Lertzman 2008). Understanding whether human ignitions have been ecologically significant has direct implications for current and future fire management, as modern lightning ignition frequencies may not be sufficient to maintain historical fire patterns and associated vegetation dynamics. It may be necessary to incorporate prescribed burning and other tools to manage for values contingent upon historical fire patterns, such as distributions of wildlife species threatened by the loss of fire-generated habitat.

Another strength of fire history studies—particularly those that make use of dendrochronological records—is that they can illuminate relationships between inter-annual and decadal-scale climate in controlling local and regional fire occurrence. Multiple studies have demonstrated that regional fluctuations in temperature and precipitation, as well as particular phases of global circulation patterns such as the El Niño-Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), and Atlantic Multi-Decadal Oscillation (AMO), have the power to create widespread favorable (or unfavorable) conditions for fire ignition and spread. In some cases, they synchronize “fire years” and/or regeneration events across large areas and even continental regions (Swetnam and Baisan 1996, Kitzberger et al. 2007, Heyerdahl et al. 2008a, 2008b, Morgan et al. 2008). If scientists and managers are to be able to anticipate and plan for changes to fire regimes induced by changes in global climate, it is imperative that they understand how and to what degree global climate has driven and influenced fire in the past. Fire history studies that investigate associations between fire and climate can be instrumental in addressing these challenges.

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[*] The term “stewardship” is used in this thesis to represent the way indigenous people cared for, cultivated, and gave back to the land traditionally. I acknowledge that this term is inadequate to fully express the complex and multi-faceted relationship that indigenous people had and continue to have with their traditional lands.

One location in which fire history research could be particularly valuable is the Okanagan region of British Columbia, Canada. Few studies have investigated fire history in this dry, lower montane portion of the province, and there is controversy surrounding whether the dry forests of the Okanagan were historically shaped by similar fire regimes as in dry forests elsewhere in North America. A great deal of this debate has focused on whether surface fires played an ecologically significant role in these fire regimes, and how frequently surface fires may have burned in the past (Heyerdahl et al. 2007, 2012, Klenner et al. 2008). Dry ponderosa pine-dominated forests in southern British Columbia are at the northern limit of their range, and are thus subject to different stresses and growing conditions than more southerly forests of this type. These differences may prove to be significant from a fire regime standpoint. If surface fires were a prominent feature of historical fire regimes in the dry, southern regions of British Columbia, as they have been in many other dry forests in western North America (e.g. Swetnam and Baisan 1996, Mast et al. 1998, Grissino-Mayer and Romme 2004, Brown 2006, Taylor 2010, Kitchen 2016), this could have significant implications. Most notably for evaluating whether fire exclusion has resulted in structural and compositional shifts to the region's forest and grassland landscapes, as well as whether restoration treatments are and will be necessary in the future.

One such dry forest location in the Okanagan is the Westside Unit of the Vaseux-Bighorn National Wildlife Area (NWA) (49°17' N 119°33' W), near Oliver, BC. This 400 ha protected area is managed by the Canadian Wildlife Service (CWS) with the goal of preserving habitat for multiple species at risk, and hosts grassland plant communities and open forest structures rare in British Columbia (Cooper et al. 2011). This NWA offers a valuable and unique location for a fire history study for several reasons.

Firstly, CWS can directly benefit from specific knowledge of the area's historical fire regime. Managers are currently conducting restoration treatments designed to emulate historical fire patterns with the goal of recreating and maintaining critical habitat structures, yet can only base these treatments on prevailing fire regime classifications for the larger region (Cooper et al. 2011). More specific and detailed knowledge of historical fire frequency, severity, and spatiotemporal variability can help CWS design treatments that will be appropriate and effective for Vaseux in particular.

Secondly, this study area is well suited for investigating the role of human ignitions as a driver of historical fire regimes. The Vaseux site is located within the traditional territory of the *Syilx*[†] people,

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[†] The name *Syilx* is commonly used to refer to the indigenous people of the Okanagan region, based on the name of their shared language. I have used this name throughout this thesis; however, I acknowledge that not all peoples indigenous to the Okanagan identify with this name, and that a single nomenclature for all people of the region is a European construct.

collectively known as the Okanagan Nation Alliance (Armstrong et al. 1994, Okanagan Nation Alliance 2010a, 2010b). *Syilx* oral history and archeological records indicate there was a long-standing village on the southwest shore of Vaseux Lake (Cooper et al. 2011), until European colonization displaced the *Syilx* from their traditional lands in the mid-1800s (Thomson 1978, Carstens 1991). European traders and settlers also used the site as a travel corridor beginning in the early 1800s as part of the Old Brigade Trail (Black 1835, Fraser 1967), and the study area was later purchased and utilized to build a spur of the Kettle Valley Railway from Penticton to Osoyoos, which ran from 1923 – 1977 (Sanford 2002). The rich human history at Vaseux Lake could have resulted in many anthropogenic ignitions through time, which could have had a profound impact on the fire frequency of the site. Particularly, given that the *Syilx* have been living in the area for thousands of years (Armstrong et al. 1994, Okanagan Nation Alliance 2010a), the forest and understory plant communities in the region may be inextricably linked to the way the *Syilx* interacted with and cared for the land historically. Fire Keeper Annie Kruger has shared that the *Syilx* utilized fire as an essential component of their traditional practices, and burned frequently to enhance ecological and cultural values on the landscape (Allison and Michel 2004). If indigenous traditional land stewardship drove the historical fire regime, this would need to be considered when designing any restoration program, as the wildlife species currently utilizing the protected area depend on open forest structures and grassland species that are fire-generated.

Third, regional fire management, overseen by the Penticton Fire Center of the BC Wildfire Service, can also benefit from increased knowledge about the local historical fire regime. Ministry crews are actively involved in CWS restoration treatments, other proactive fuels measures in the region, as well as tasked with fire suppression in the district. The more managers in the region know about how fires burned in the past—particularly with respect to climatic variables—the better equipped they can be to plan and direct current and future operations.

Lastly, as indicated previously, there is ongoing debate as to the significance of surface fires in historical fire regimes in the dry forests of British Columbia—particularly in the Okanagan. A fire history reconstruction at Vaseux Lake could contribute to this discussion, and expand on the broader fire history literature in dry forest systems in a lesser-studied portion of their range.

OBJECTIVES

The goal of this thesis was to reconstruct the fire history of the Westside Unit of the Vaseux-Bighorn NWA property using fire scar and forest demography information. I sought to answer the following research questions:

1. How frequent, severe, and variable were historical fires at Vaseux Lake?
2. Did patterns in fire frequency, seasonality, and synchrony change through time, and did these changes correspond to the timing of events in the human history of the study area?
3. Were local topographic factors (slope aspect, steepness, and elevation) significant controls of the historical fire regime?
4. How does the age structure of the forest relate to patterns in the fire record and land-use timeline, and what does this suggest about the stand dynamics of the study area?
5. Was fire significantly related to inter-annual- and decadal-scale climatic variation?
6. What does the fire history of the study area imply for future management?

Questions 1 - 4 are addressed in Chapter Two, which explores the historical fire regime and relationships between fire and human history in the study area. Question 5 is addressed in Chapter Three, which examines the relationship between historical fires and annual- and decadal-scale climate. Question 6 is addressed in both data chapters and in Chapter Four, which discusses the implications of the results and greater context of this research within the contemporary fire ecology literature.

CHAPTER TWO:
LOCAL CONTROLS OF HISTORICAL FIRES

INTRODUCTION

The three principal ingredients for wildfire are: suitable weather conditions, suitable fuels, and a suitable ignition source (Nash and Johnson 1996, van Wagtendonk and Cayan 2008, Macias Fauria et al. 2011). Although fire regimes are often characterized based on the interaction of climate and fuels, the timing and spatial arrangement of ignitions are also important attributes (Agee 1993, van Wagtendonk and Cayan 2008). Patterns in ignitions can influence fire frequency and seasonality, and can thus be indirectly significant to the vegetation dynamics of a region (Agee 1993, Keeley 2002).

Lightning and humans are the two most common ignition sources, though their patterns and timing differ owing to their contrasting mechanisms. Lightning ignitions are associated with particular local and regional weather phenomena, and are strongly influenced by geographic and topographic features (Agee 1993, Nash and Johnson 1996, Keeley 2002, van Wagtendonk and Cayan 2008). Human ignitions, in contrast, are dependent upon dynamic patterns of human interaction with ecosystems, which have varied considerably through time (Agee 1993).

Indigenous peoples have inhabited North America for thousands of years, and thus traditional land stewardship[‡] may have influenced fire regimes and by extension vegetation dynamics in many regions (Barrett and Arno 1982, Agee 1993, Keeley 2002, Fry and Stephens 2006, Lepofsky and Lertzman 2008, Aldrich et al. 2014). Oral histories and archeological records from across western North America have documented fire as an important land stewardship tool for many indigenous peoples (Agee 1993, Boyd 1999, Turner 1999, Lepofsky and Lertzman 2008). In British Columbia, fire was used for a variety of traditional purposes, including to cultivate food crop species, enhance habitat for wildlife, and encourage forest structural diversity (Turner 1999, Lepofsky and Lertzman 2008, Simmons 2012). European settlement has also had a profound effect on fire regimes in western North America by effectively excluding fire in some areas due to displacement of indigenous peoples, introduced livestock grazing, and fire suppression, and by introducing novel ignition sources in others related to settlement

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[‡] The term “stewardship” is used in this chapter to represent the way indigenous people cared for, cultivated, and gave back to the land traditionally. I acknowledge that this term is inadequate to fully express the complex and multi-faceted relationship that indigenous people had and continue to have with their traditional lands.

and industrialization (Agee 1993). Thus, it is important to consider the human history of a study area when examining spatiotemporal patterns in fire regimes, as anthropogenic influences may confound the relationship between fire occurrence and other drivers such as topography and climate.

Ignition sources not only vary in their spatial arrangement but also in seasonal timing, and examining patterns in fire scar seasonality may be useful in assessing anthropogenic impacts on historical fire dynamics (Grissino-Mayer and Romme 2004, Fry and Stephens 2006, Lepofsky and Lertzman 2008). Oral histories shared by the indigenous peoples of British Columbia indicate that fires were often set in the spring or fall, as this was conducive to fire control and optimized growth of desired food crop species (Turner 1999, Simmons 2012). In contrast, lightning ignitions in the Pacific Northwest are often associated with thunderstorms occurring most frequently in July and August (Agee 1993). Fires ignited unintentionally by railways and settlers moving along historical travel corridors would also have been most likely during the height of the fire season in July and August, as this is the window when fire weather conditions are usually optimal for producing a sustained ignition (Agee 1993, Johnson and Miyanishi 2001, Macias Fauria et al. 2011). Thus, fire history studies conducted in areas with well-documented land-use histories may be used to infer a human signature on fire regimes by examining seasonality of recorded fires, in addition to their spatial arrangement and frequency (Grissino-Mayer and Romme 2004, Fry and Stephens 2006, Lepofsky and Lertzman 2008).

Fire history studies can be especially powerful when they utilize multiple lines of evidence, such as fire scars and forest demography data. Fire scars offer direct evidence of surface fire, while information about forest structure can provide complementary data from which to infer higher-severity effects and to analyze relationships between fire and stand dynamics through time (Brown and Wu 2005, Heyerdahl et al. 2012, Marcoux et al. 2015, Chavardes and Daniels 2016). Although fire scars provide concrete evidence that fire *occurred* at a particular point in a given year, the absence of a fire scar does not conclusively indicate that fire *did not* occur at that point. Fire can be present at the base of a tree and fail to injure the cambium, or evidence can be lost due to decay, mechanical damage, and subsequent higher-severity fires (Baker and Ehle 2001, Swetnam et al. 2011). Knowledge of tree establishment dates and site history can help illuminate potential explanations for why a fire scar was not found, and allow for more robust inferences about forest dynamics than would be possible with fire scar information alone.

Although fire history information is available for many dry forests in the Pacific Northwest (e.g. Heyerdahl et al. 2002, 2008b, Hessl et al. 2004, Hessburg et al. 2005, 2007), few studies have investigated fire dynamics in dry portions of southern British Columbia, Canada (Heyerdahl et al. 2007, 2012, Klenner et al. 2008). Studies also debate whether surface fires were a meaningful component of historical fire regimes in southern BC, and thus whether fire exclusion has altered forest structure (Klenner et al. 2008, Heyerdahl et al. 2012). More fire history research is needed in additional locations to contribute to this discussion and provide information about past fire dynamics at a finer resolution.

One location that could be ideal for fire history research is the Westside Unit of the Vaseux-Bighorn National Wildlife Area (NWA) (49°17’ N 119°33’ W), near Oliver, BC (figure 2.1). This study area is particularly well suited to investigate the influence of anthropogenic ignitions on historical fire patterns, owing to its rich and well-documented human history. The study area lies within the traditional territory of the *Syilx* people[§], known collectively as the Okanagan Nation Alliance (Okanagan Nation Alliance 2010b), and was later utilized as a travel corridor for European settlers and the Kettle Valley Railway (Black 1835, Sanford 2002). The property is managed by the Canadian Wildlife Service (CWS), and CWS is implementing a management plan based on frequent prescribed burns and scheduled thinning (Cooper et al. 2011). They can benefit, however, from specific information about historical fire frequency, severity, and spatiotemporal variability, to ensure their treatments are appropriate and effective. If *Syilx* traditional burning drove the historical fire regime, this would have significant implications, as modern lightning densities will not be sufficient to maintain historical forest dynamics or provide a good baseline for setting treatment intervals.

OBJECTIVES

I sought to evaluate local controls of the historical fire regime of the Westside Unit of the Vaseux-Bighorn NWA by examining spatiotemporal patterns in the fire record and forest age structure. I was interested in elucidating whether human history influenced the historical fire regime, whether local topographic factors affected the likelihood of fires spatially, and whether changes in the fire regime may have altered forest structure. I sought to answer three main questions:

i) Did patterns in fire frequency, seasonality, and synchrony change through time, and did these changes correspond to the timing of events in the history of the study area?

[§] The name *Syilx* is commonly used to refer to the indigenous people of the Okanagan region, based on the name of their shared language. I have used this name throughout this chapter; however, I acknowledge that not all peoples indigenous to the Okanagan identify with this name, and that a single nomenclature for all people of the region is a European construct.

ii) Were local topographic factors (slope aspect, steepness, and elevation) significant controls of spatial variability in fire likelihood?

iii) How did the forest age structure relate to patterns in the fire record and land-use timeline, and what does this suggest about the stand dynamics of the study area?

Given oral history of frequent burning in the region by the *Syilx* people prior to the late 19th century, and the *Syilx* practice of spring burning (Allison and Michel 2004), I expected that fires would be more frequent, and that a greater proportion of fire scars would occur in the earlywood of annual growth rings of sampled trees during the period when the *Syilx* were stewarding the study area.

Given the potential for anthropogenic ignitions to have driven the fire regime, I also hypothesized that fire likelihood would not vary significantly with aspect, elevation, and slope steepness, although studies have found topography to be significant controls of fire likelihood in other areas of southern British Columbia (Cochrane 2007, Heyerdahl et al. 2007, Greene 2011). If purposeful human ignitions were the primary driver of historical fire dynamics at Vaseux, this may have superseded the effects of topographic controls in determining the location of sustained fire ignition and spread.

If traditional burning by the *Syilx* drove the historical fire regime, I would also expect their displacement from the study area to have had an indirect impact on forest structure. I expected that a large proportion of trees in the study area would have established since the time when the *Syilx* were displaced, due to reduced fire frequency.

METHODS

Study Area

The Westside Unit of the Vaseux-Bighorn NWA (Figure 2.1) measures approximately 400ha and is bounded by steep cliffs and slopes to the west, north, and south, with Vaseux Lake to the east. The study area lies within the northern extent of the Great Basin Desert, extending into southern Canada from the northwestern United States as a contiguous mosaic of grassland ecosystems. The study area resides on a local boundary between the Bunchgrass and Ponderosa Pine Zones, according to biogeoclimatic ecosystem classification (Meidinger and Pojar 1991), and three variants of these zones are classified within the study area: BGxh1 (bunchgrass very dry hot Okanagan), PPxh1 (ponderosa Pine very dry hot Okanagan), and PPxh1a (grassland phase of the ponderosa pine very dry hot Okanagan) (MacKenzie 2012). The study area hosts numerous grassland plant species, including bluebunch wheatgrass (*Pseudoroegneria spicata* (Pursh) Á.Löve), antelope brush (*Purshia tridentata* (Pursh) DC.),

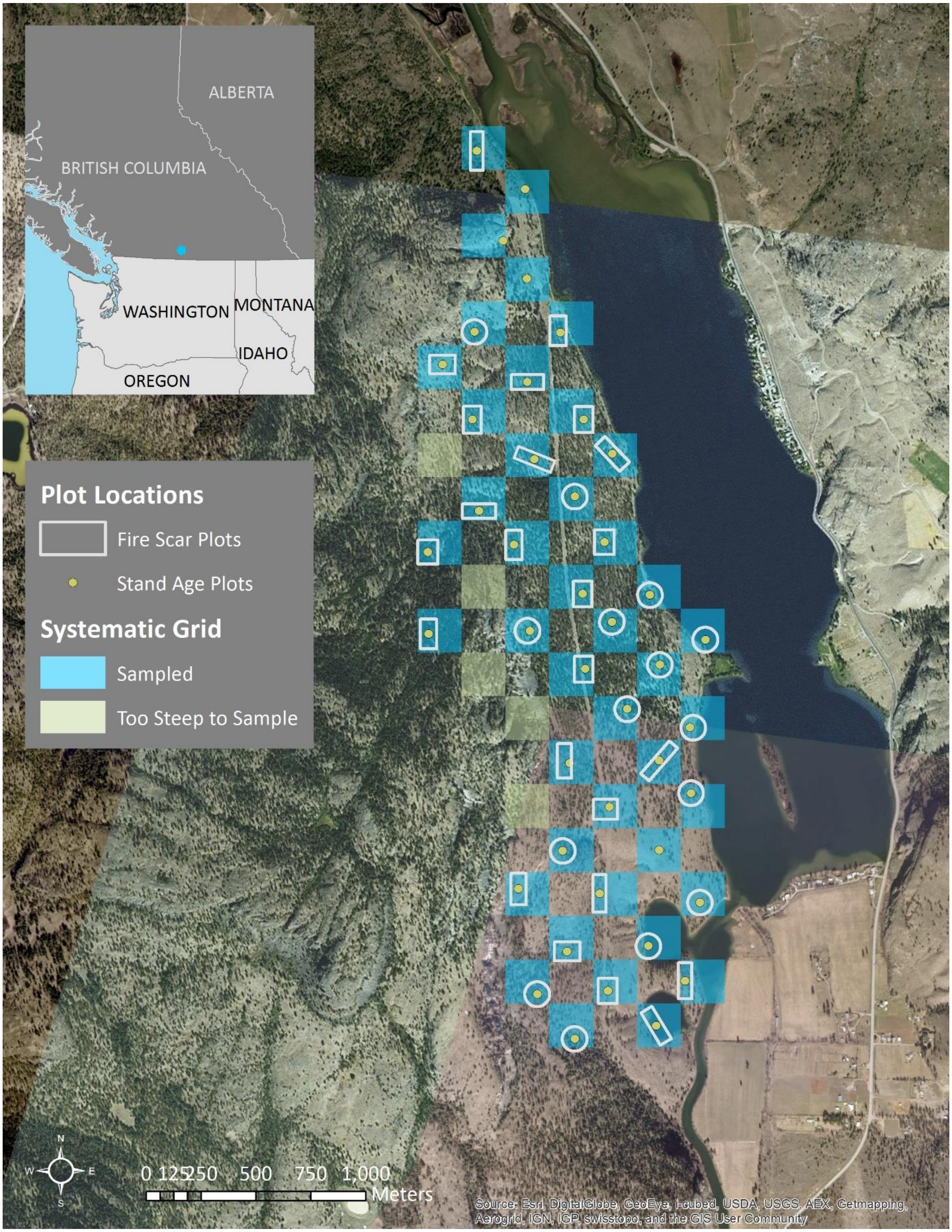

Figure 2.1: Regional location of the study area, systematic sampling grid, and plot layout. Alternate grid cells were surveyed and sampled for fire scars and forest demography ("stand age plots").

and arrowleaf balsamroot (*Balsamorhiza sagittata* (Pursh) Nutt.). Trees present are ponderosa pine (*Pinus ponderosa* Douglas ex. C. Lawson), and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco*)* (Cooper et al. 2011). The study area also supports habitat for 39 at-risk wildlife species that are dependent on grassland plant communities (Cooper et al. 2011). These include bighorn sheep (*Ovis canadensis* Shaw, 1804), the Behr's Hairstreak butterfly (*Satyrium behrii* (W.H. Edwards, 1870), Lewis's and white-headed woodpeckers (*Melanerpes lewis* (Gray, 1849)) (*Picoides albolarvatus* (Cassin, 1850)), the blue racer snake (*Coluber constrictor foxii* (Baird & Girard, 1853)), and the Pacific rattlesnake *(Crotalus oreganus* (Holbrook, 1840)*)* (Cooper et al. 2011).

The study area features gentle undulating topography along the lake, with milder slopes giving way to a network of rock steps and prominent cliffs to the west. Most slopes on the study area are east facing, though varied terrain provides for minor slopes of all aspects. Elevations in the study area range from 326 – 675m above sea level (a.s.l.). Slope steepness at plot locations varied from 0-50 degrees, and east-facing vertical rock faces of varying heights are common on the westernmost third of the property. Elevation generally increases moving west from the shores of Vaseux Lake, and moving towards the center from the north and south.

The study area has a dry climate classified as a mid-latitude step (BSk) in the Köppen system (Köppen 1936), with a mean annual precipitation of 310 mm, mean annual temperature of 9.5°C, and average summer maximum temperature of 27°C (1981-2010; Wang et al. 2012). The study area is located within the Penticton Fire Zone, which typically experiences an active wildfire season from late spring through early fall, with an average of 41 lightning ignitions per year. Between 1950 and 2012, 74% of lightning ignitions occurred during July and August, when weather tends to be hottest and driest (BC Wildfire Service, unpublished data).

Human History

The study area was historically inhabited and stewarded by the *Syilx* indigenous peoples (Figure 2.2). Oral history (Armstrong et al. 1994) and archeological records (Cooper et al. 2011) indicate that a *Syilx* village was located at the twin bays on the southwestern shore of Vaseux lake (see Figure 2.1 for location of the twin bays and peninsula). The *Syilx* have inhabited the Okanagan region for thousands of years (Armstrong et al. 1994, Okanagan Nation Alliance 2010a), and utilized fire as an integral component of their traditional land stewardship (Allison and Michel 2004, Simmons 2012). Oral history recounted by Fire Keeper Annie Kruger (Allison and Michel 2004) indicates that the *Syilx* burned in both the spring and fall, and that burns were designed to enhance ecological and cultural values. These

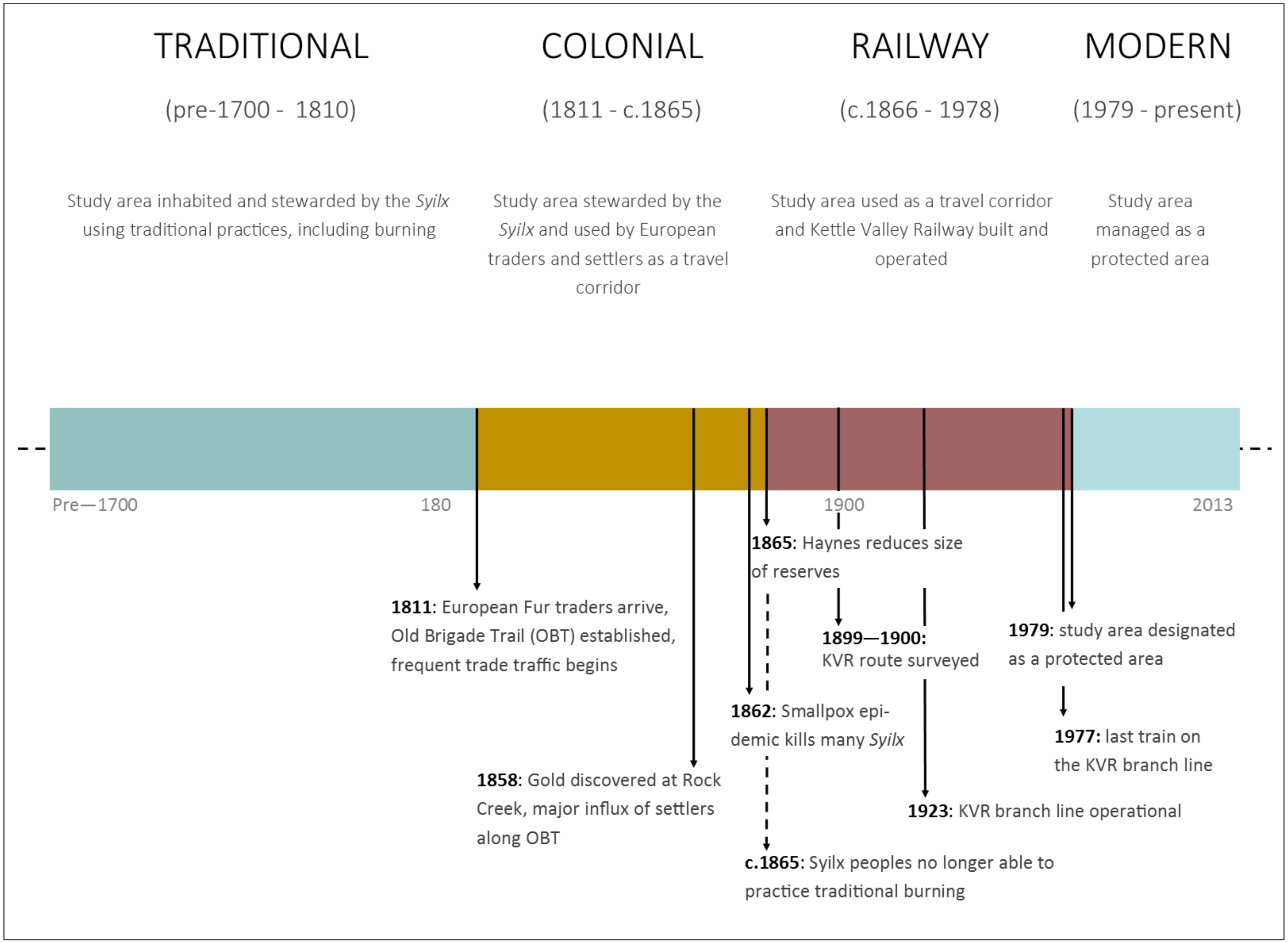

Figure 2.2: Timeline of the human history of the study area. The above eras were delineated to compare fire patterns and assess the role of land use in driving the historical fire regime.

included maintaining open forest conditions, improving wildlife habitat, and encouraging the growth of important plant species. Burns were also seen as a way to cleanse and give back to the land. The *Syilx* conducted fall burns every 2 -15 years, depending on fuels conditions, and these were typically extensive. Spring burns ("safe burns"), in contrast, were small and designed to be contained within discrete blocks. Okanagan Fire Keepers frequently walked the land to assess fuels conditions, and designed burns based on specific knowledge of forest fuels and ecological health.

Beginning in 1811, the Pacific Fur Company established a trading base at Fort Okanagan, and began exploring and trading with the *Syilx* people. Eventually the North West Company and Hudson Bay Company also began trading in the region, and frequently bartered with the *Syilx* for salmon, horses, and furs (Thomson 1978, Carstens 1991). The major travel route for the fur companies ran along what became known as the "Old Brigade Trail," and a portion of this ran along the west side of the Okanagan Valley through the study area along the shore of Vaseux Lake (Black 1835, Fraser 1967, Carstens 1991).

Fur trading was active in the region until 1847, and was quickly replaced by a gold rush beginning in 1859, when gold was discovered at Rock Creek. While members of trading companies were primarily interested in goods, the gold rush brought a large influx of Europeans interested in permanently settling in the area, and in ownership of land. This brought increased conflict with the *Syilx*, as they saw large tracts of their traditional territory allotted to settlers via land pre-emptions, beginning in 1859 (Carstens 1991).

Sometime during the late 1800s, the *Syilx* village in the study area was abandoned due to the combined effects of colonialism. I was unable to obtain an exact cause and date when this occurred, but based on research of the region's history, it seems likely this was c.1865. Several events transpired in this decade that forced the *Syilx* onto a markedly smaller portion of their traditional land base, and the study area was already in use as part of a major transportation corridor. In 1862, a province-wide smallpox epidemic reached the region, and killed a large percentage of the *Syilx* population (Thomson 1978, Union of British Columbia Indian Chiefs 2016). This epidemic came at the same time that conflict among European settlers and indigenous peoples was increasing, and European settlers were filing numerous land pre-emptions to claim acreage in traditional *Syilx* territory for agriculture, gold mining, transportation, and general settlement (Thomson 1978, 1994, Carstens 1991). In 1861, W.G. Cox, under the direction of the Governor of British Columbia, James Douglas, began outlining several reserves for the *Syilx*, based on the location of village, burial, and agricultural sites. Although these reserve boundaries were created with input from certain *Syilx* chiefs, they were limited in size to 10 acres per family, and granted the *Syilx* exclusive use of only a fraction of their former territory. In 1865, reserve boundaries were further truncated by John C. Haynes, Cox's successor, without permission from the *Syilx* (Thomson 1978, Carstens 1991). Modern reserve boundaries exclude the area between Skaha and Osoyoos Lakes, and given that the Old Brigade Trail passed through the study area, it is very unlikely that the study area was included in the outlined reserves, either in 1861 or 1865. Thus, for the purposes of this study, I assumed that the village was no longer inhabited in its traditional manner by the *Syilx* peoples after 1865.

Following the outlining of reserves and increased settlement in the region, the lands on the west side of Vaseux Lake were purchased and utilized by the Canadian Pacific Railway company (CPR) to build a spur of the Kettle Valley Railway (KVR) between Penticton and Osoyoos. Initial surveying for the route was undertaken by the Columbia and Western Railway company from 1899 – 1900, but permission to eventually build the line was granted to the CPR in the early 1900s. Construction of the portion between Okanagan Falls and Oliver (including the study area) began in 1921, and the line was operational by 1923. Eventually the line was deactivated due to reduced demand, and the last train ran the segment between Okanagan Falls and Oliver in 1977. The tracks were disassembled in 1979, and the route has since been converted to a right of way and bike trail (Sanford 2002).

The study area is currently managed by the Canadian Wildlife Service (CWS), and CWS is actively treating the study area to restore and maintain an open, dry forest and grassland ecosystem. A 22ha block was thinned to c. 200 trees per hectare and piled in 2003 and burned in 2004 (Cooper 2006), and another 48ha block made up of five treatment units was thinned to varying densities per unit and burned in 2013 (Mottishaw and Albert 2013). Treatments were designed to reduce forest density, encourage the growth of grassland plant communities, reduce wildfire risk to surrounding communities, and enhance wildlife habitat. Targets for thinning and burning were specifically developed to meet the habitat needs of the white-headed woodpecker (Cooper 2006, Mottishaw and Albert 2013). The long-term management plan for the area includes continued thinning and burning to further restore and maintain habitat for species at risk (Cooper et al. 2011).

Research Design

I used a systematic research design to ensure even coverage of the study area, and to facilitate spatial analysis (Figure 2.1). A 4000 x 1200 m grid superimposed on the study area was bounded by the property line to the north, west, and south, and Vaseux Lake to the east. The grid contained 96 cells, each 4ha in area (200m x 200m), and alternate grid cells were sampled (n = 43 cells; Figure 2.1).

Fire Scar Survey and Sampling

I located grid cell boundaries using a GPS, and surveyed the entire 4ha area of each cell for fire scars (Figure 2.1). The location, number of scars per tree, and condition of the potential sample (i.e. log, stump, snag, live tree) were recorded. I compiled and mapped survey results using a GIS, and visually assessed the location of surveyed fire-scarred trees. In cells with fire scars, I placed a 1 ha plot to include the greatest number of large, presumably old samples with multiple scars to record the longest and richest fire history information (Van Horne and Fule 2006), and I sampled up to five trees per plot. Fire-scar plots (Figure 2.1) were constrained to 1ha in size to be consistent and facilitate comparison with other fire history studies conducted in southern British Columbia (e.g. Cochrane 2007, Greene 2011, Heyerdahl et al. 2012), as fire intervals are dependent on the area over which they are calculated (Falk et al. 2007). Plots were either circular or rectangular in shape, and boundaries were established and mapped using the program ArcMap (ESRI 2016) (Figure 2.1). In order to minimize the impact on critical habitat structures on the study area, live trees and snags were sampled using the partial cross section method (Cochrane and Daniels 2008), and full cross sections were taken from logs and stumps during late autumn, when most at-risk wildlife species are hibernating and not using these structures. For each tree sampled, I recorded the location, species, diameter at breast height (dbh at 1.3m for live trees and snags), and distance and bearing from plot center.

Forest Demography Sampling

Stand composition and age structure were sampled at the center of fire scar plots or at the center of cells without fire scars (Figure 2.1; “stand age plots”). For the 13 plot centers located on a talus field, cliff, road, or natural gas pipeline, I moved the stand age plots to the closest location that could be safely and effectively sampled (mean distance = 19.6m). At each plot, I sampled the 10 live trees or snags (dbh ≥5cm) closest to plot center using an n-tree design (Lessard et al. 2002). Each tree was tagged and measured for distance and bearing from plot center, species, dbh, condition (live or dead) and cored to estimate age. Ten snags could not be cored due to decay, so I sampled the next closest tree. To calculate plot-level density, I tallied the number of sampled trees and snags, uncored snags, and cut stumps (generated by recent forest thinning), within the circle having a radius determined by the distance to the furthest sampled tree. I extracted cores with increment borers within 20cm of ground level whenever possible and made up to five attempts per tree to intersect the pith.

I assessed species composition and density using data obtained from n-tree plots (Lessard et al. 2002). Species composition was quantified by calculating the relative abundance and relative density of live trees of each species at the plot and study area level. I assessed forest density by calculating total density, live density, and the density of snags at the plot and study area level. Total density calculations included live trees, snags, and cut-stumps (generated by thinning treatments). I also assessed the total post-thinning density of the study area, reflective of the current aerial fuel load, by excluding cut stumps from calculations.

Sample Preparation and Cross-dating

All increment cores and fire-scarred sections were processed and analyzed according to established dendrochronological methods (Stokes and Smiley 1996). Samples were sanded until cell structures were visible with a binocular microscope, and then scanned to generate high-resolution images (2400 dpi) from which ring-widths were measured and crossdated using the programs CooRecorder and CDendro (Larsson and Larsson 2006). Increment cores were crossdated and used to establish species- and study area-specific chronologies, which were verified using existing reference chronologies for the region (Watson and Luckman 2001, 2004, L.D. Daniels, unpublished data). I used the crossdated outer-ring dates to estimate the year of death of snags and verify the outer-ring of live trees was 2014, the year of sampling. Inner-ring dates were used to estimate the year trees established. For 217 cores that did not intersect the pith, I applied a geometric correction to estimate the number of missing rings and year the tree established (Duncan 1989). Tree inner-ring dates were corrected for estimated age to coring height using growth curves constructed from seedlings collected from the study area (L.D. Daniels, unpublished data). The average total age correction (missing rings + age to coring height) for all cores was 6 ± 3 years, and 90% of cores had a correction of ≤ 8 years.

I assessed forest age structure by creating plot-level and study-area level histograms of tree establishment dates for both ponderosa pine and Douglas-fir. Trees were grouped into 10-year age classes, to account for estimated age corrections in the dataset and to facilitate graphical comparison with the fire record.

Fire-scar samples were crossdated using the study area-specific chronologies and verified when necessary using available local chronologies (Watson and Luckman 2001, 2004, L.D. Daniels, unpublished data). I analyzed fire scar samples for both the year, and whenever possible, the seasonality of the injury, based on intra-ring position (Swetnam and Baisan 1994; Grissino-Mayer and Romme 2004). I assigned dates to scars along the boundary of two rings (dormant-season scars) based on a method adapted from Heyerdahl et al. (2012). Dormant-season scars were assigned to the preceding year if late-earlywood or latewood scars for that year were recorded by other sampled trees in the study area. I assigned dormant-season scars to the following year if early- or mid-earlywood scars were recorded on other trees for that year. If all scars for a particular fire event were recorded as dormant-season scars, I assigned these to the preceding year, given that the majority of modern fires in the Okanagan region occur during mid- to late summer (BC Wildfire Service, unpublished data).

Fire History

I assessed fire frequency and severity using fire scars and forest age structure information. I compiled fire scar dates in the program FHAES (Grissino-Mayer 2001, Brewer et al. 2016) and used these to calculate minimum, maximum, and mean fire intervals at plot- and study area-scales. Scar years not recorded by at least 2 trees in the study area were excluded to account for the possibility of non-fire injury (n = 21) (as in Heyerdahl et al. 2012).

I used the establishment date of trees to identify fire-initiated cohorts as a proxy for fire effects of higher severity. Post-fire cohorts form when a fire kills overstory trees and liberates sufficient growing space for a group of seedlings to establish following a burn. Ponderosa pine and Douglas-fir germinate well on bare mineral soil, and conditions post-fire are often favorable for seedlings to establish and compete with grassland understory species (Burns and Honkala 1990, Agee 1993, Mast et al. 1998, Mast and Veblen 1999). Post-fire cohorts must be distinguished, however, from cohorts initiated by favorable climatic conditions and/or other disturbances (Oliver and Larson 1996, Heyerdahl et al. 2001, 2012, Brown and Wu 2005).

I identified cohorts and inferred whether they were fire-initiated using criteria modified from Brown and Wu (2005) and Heyerdahl et al (2012). A cohort was defined when 30% or more of the trees in a plot established within a 20-year period following a 30-year window of no establishment. Cohorts were assumed to be fire-initiated if they established within five years before or 10 years following the year of a nearby recorded fire scar. For cohorts that could not be assigned to a fire year based on the criteria above, I visually compared the establishment date of the cohort (the year the oldest tree in the cohort established) to a Palmer Drought Severity Index (PDSI) reconstruction (Cook et al. 2004) for the region. I also constructed a contingency table comparing 20-year moving-average PDSI values for post-fire and non-fire cohort years, to assess whether post-fire and non-fire cohorts were associated with significantly different climatic conditions. Hypothesis tests were performed using Pearson's chi-squared and $\alpha=0.05$.

Using fire-initiated cohort ages in combination with fire scar years, I assigned a fire-severity designation to each plot, reflecting the range of fire severities recorded at that location through time (adapted from Heyerdahl et al. 2012). Plots that contained fire scars but no fire-assigned cohorts were designated low-severity. Plots that contained fire scars from two or more fire years, and one or more fire-initiated cohorts were designated mixed-severity. Plots that contained no fire scars or fire scars for only one fire year, and one or more fire-initiated cohorts were designated high-severity.

Spatiotemporal Variability

I assessed spatiotemporal variability in the fire record using two parallel analyses: i) comparison of the fire record and the historical land-use timeline for the study area, and ii) statistical analysis of factors influencing fire occurrence using logistic regression.

Land-Use Timeline

To assess relationships between the fire record and historical land-use of the study area, I compiled historical information to create a timeline (Figure 2.2). I then used this timeline to delineate two broad and four specific eras, each representing important phases in the study area's history:

BROAD:

- **Indigenous fire use era** (1700 – 1865)
- **European settlement era** (1866 –2013)

SPECIFIC:

- **Traditional era** (1700 – 1810): *Syilx* traditional fire practices and land stewardship
- **Colonial era** (1811 – 1865): *Syilx* and European influence
- **Railway era** (1866 – 1978): European and industry influence
- **Modern era** (1979 – 2013): study area protected as a wildlife area

I compared fire frequency metrics (minimum, maximum, and mean fire intervals), fire scar seasonality, and fire synchrony among land use eras to assess whether the nature of the historical fires changed through time, and whether these changes corresponded with the timing of land-use transitions.

Factors Influencing Fire Occurrence

I also conducted a statistical analysis of factors influencing the spatiotemporal variation in fires using logistic regression. In this analysis, I was interested in two potential local controls of variability in the fire regime: topography and human history of the study area. I modelled the likelihood of fire occurrence as a function of slope steepness and aspect (both in degrees), elevation (m.a.s.l.), and human land-use eras. Slope aspect, ranging from 1° to 360°, was converted to a linear scale, ranging from 0 (corresponding to 45°) to 180 (corresponding to 225°) to represent warmer and cooler aspects (as in Greene 2011). The last of these variables, eras, was represented as a class variable, in two different formats in parallel analyses. The first analysis tested the four specific eras (Traditional, Colonial, Railway, and Modern) identified above, while the second analysis tested the two broader eras corresponding to presence or absence of *Syilx* traditional burning.

I generated models and estimated coefficients using the statistical package SAS® 9.4 (The SAS Institute 2014). The relationship between fire and topographic variables at the plot level was modeled using the PROC GENMOD procedure (link= logit, distribution= binomial), incorporating a General Estimating Equation (GEE) (SAS "Repeated" statement, type=ar(1)) to account for the first-order temporal autocorrelation inherent in the dataset (plots measured repeatedly for the occurrence of fire through time). The relationship between fire occurrence and land-use eras was modelled by creating separate study-area level models using the PROC GLIMMIX procedure (dist=binomial; link=logit; REPEATED statement). The structure of plot-level analyses was such that parameter estimates associated with land-use eras were likely to be affected by the sample depth of fire scars for each fire event, and thus interpretations were more meaningful when applied at the study-area level.

To determine which variables to include, I first created a model containing all variables of interest, and then refined the model by removing the variable with the highest p-value, and proceeding iteratively until all variables in the model were significant. I also created models testing each independent variable individually, to ensure that only significant variables were interpreted and included in final analyses.

I tested the significance of variables using generalized score statistics based on a chi-squared distribution for models created using PROC GENMOD (Boos 1992), and Type III tests for fixed effects based on the F distribution for models generated using PROC GLIMMIX. All significance testing used an alpha level of 0.5.

RESULTS

Forest Composition and Structure

Estimated relative abundance of live trees across the study area was 31% ponderosa pine and 69% Douglas-fir (see Appendix A for a summary of plot-level data). The majority (77%) of plots contained trees of both species. Of the remaining plots, 10% contained only pines and 23% contained only firs. Total plot-level densities (pre-thinning) varied considerably across the study area, ranging from 10 – 2727 trees per hectare (tph), and average total density was 359 ± 588 tph. Post-thinning density ranged from 9 – 2727 at the plot level, and averaged 293 ± 539 tph across the study-area (Figure 2.3a). Density also varied between species: ponderosa pine had a mean density at the plot-level of 86 ± 103 tph (range= 0 – 389), less than half that of Douglas-fir (mean= 192 ± 529, range= 0 – 2479). I found a relatively low density of snags within the study area (mean = 14 ± 43 tph, range = 0 – 248).

Fire History

Surveys located 518 fire-scarred trees, snags, stumps, and logs (hereafter "trees") in 39 of 43 grid cells surveyed, and averaged 2.3 visible scars per tree (range 1-19) (Figure 2.3b). Six plots had no fire-scarred trees, 10 included only one, and 27 plots included trees with multiple fire scars. I obtained samples from 160 trees, of which 148 were crossdated, yielding 409 scars in 55 scar years, 34 of which were recorded by ≥2 trees and inferred to be spreading fires.

From 1714 - 2013, fires burned frequently in the study area, and fire evidence varied spatially (Table 2.1, Figure 2.3 b, c, Figure 2.4). Fire intervals ranged from 3–145 years, with plot-level means from 15.3–64.7 years and a grand a mean of 31.2 years. At the study area level, fires burned at a mean interval of 7.8 years, and Intervals ranged from 3-31 years. The 43-year interval following the last recorded fire on the study area (1970) exceeded any prior interval.

I detected 43 even-aged cohorts in 40 of 43 plots, of which 35 cohorts were determined to be fire-initiated. Thirty-seven plots had a single cohort, and three plots contained two cohorts. Cohort start dates ranged from 1798–1979, and 65% of cohorts were initiated in the 20th century (see Figure 2.4). The eight cohorts not assigned to a fire year established between 1880 and 1891, which corresponded to a period of cooler and wetter climate, as indicated by positive average PDSI values, and an absence of recorded surface fires. These cohorts were inferred to have been initiated by a combination of suitable climate and a lack of surface fires, and not by localized high-severity fires not documented by cambial scars. Hypothesis tests of contingency tables using Pearson's chi-squared showed there was not a significant difference in the climatic conditions associated with non-fire vs. post-fire cohorts (p= 0.315).

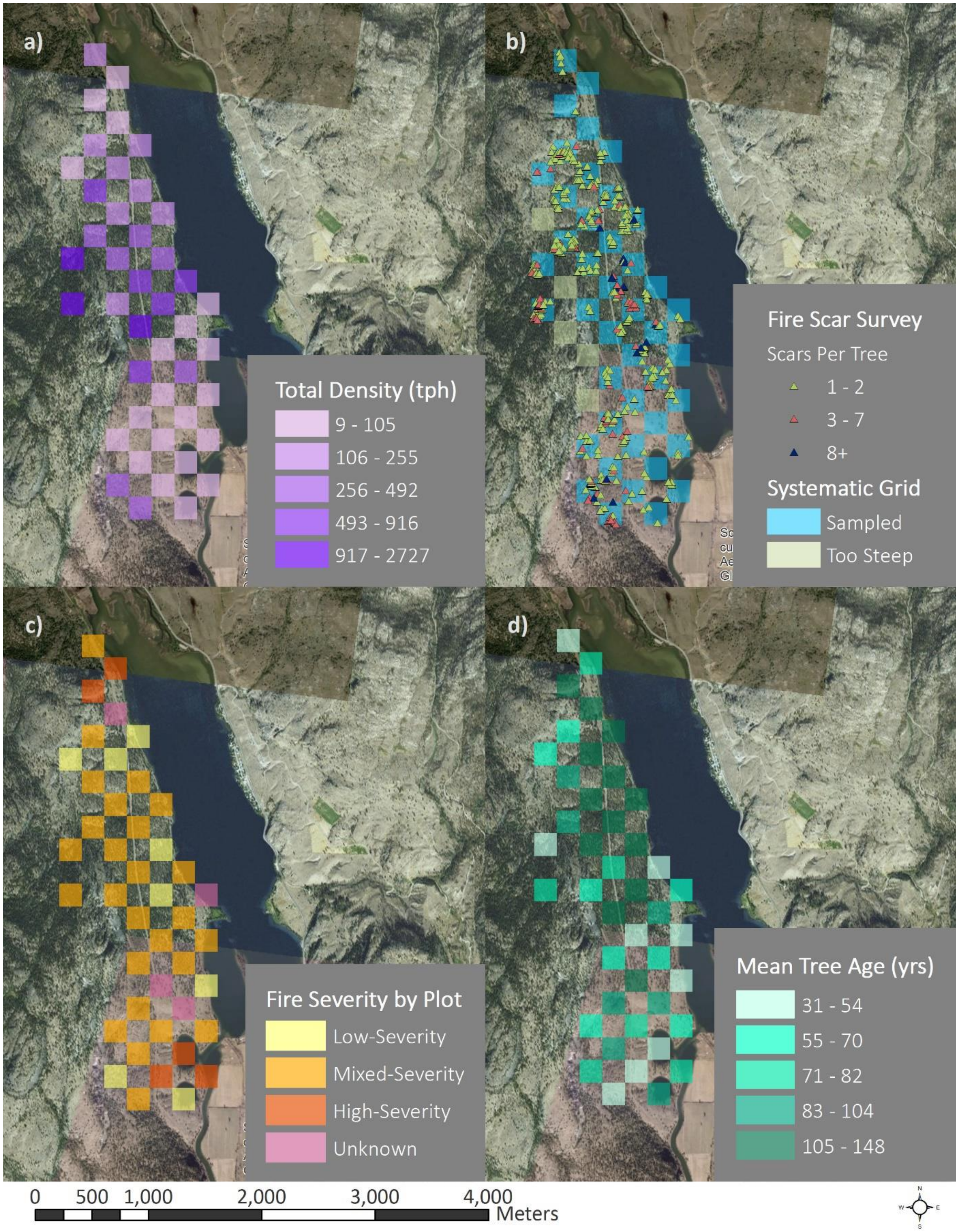

Figure 2.3: Variation in a) density, b) fire scar distribution, c) fire severity, d) tree age by plot. Total density incorporated live trees, snags, and stumps generated by recent thinning. Fire severity was designated based on the range of fire evidence (scars and cohorts) recorded at each plot through time.

PLOT INFORMATION				FIRE HISTORY							
							Fire Intervals				
Plot	Density (tph)	% Live Pine	% Live Fir	No. Samples	Record Length	No. of Fires	Mean (yrs)	Range	Time Since Last Fire	No. of Post-Fire Cohorts	Severity Through Time
2	379	60.0%	40.0%	5	1664 - 1999	9	29.44	11 - 68	68	1	Mixed
4	59	45.5%	54.5%	2	1876 - 2013	1	–	–	68	0	Low
6	389	100.0%	0.0%	5	1574 -2013	9	24.33	6 - 47	43	1	Mixed
8	37	100.0%	0.0%	1	1902 - 2008	1	–	–	68	1	High
10	91	100.0%	0.0%	4	1787 - 2013	1	–	–	68	1	High
12	31	100.0%	0.0%	5	1771 -2013	10	22.5	5 - 50	43	1	Mixed
14	88	100.0%	0.0%	2	1819 - 2013	1	–	–	68	1	High
16	43	84.6%	15.4%	4	1779 - 2013	4	45.8	25 - 90	43	1	Mixed
18	37	91.7%	8.3%	5	1867 - 2013	3	31.0	25 - 43	43	1	Mixed
20	28	100.0%	0.0%	1	1682 - 2013	2	–	–	68	1	Mixed
22	41	66.7%	33.3%	5	1760 - 2013	3	31.0	25 - 43	43	1	Mixed
24	9	23.1%	76.9%	0	–	–	–	–	U	0	Unknown
28	15	63.6%	36.4%	0	–	–	–	–	U	0	Unknown
30	105	16.7%	83.3%	3	1899 - 2013	2	–	–	68	0	Low
32	569	10.0%	90.0%	3	1792 - 2013	5	35.8	8 - 56	43	1	Mixed
34	292	90.9%	9.1%	5	1732 - 2013	6	31.5	14 - 68	68	1	Mixed
38	105	18.2%	81.8%	5	1679 - 2013	16	18.7	4 - 68	68	1	Mixed
40	64	50.0%	50.0%	1	1760 - 2013	4	61.3	15 - 145	68	1	Mixed
44	1990	0.0%	100.0%	4	1779 - 2011	4	37.3	8 - 68	68	1	Mixed
46	88	54.5%	45.5%	5	1611 - 2000	14	18.9	5 - 53	53	1	Mixed
48	2727	0.0%	100.0%	5	1806 - 2010	9	22.0	6 - 50	43	1	Mixed
50	159	81.8%	18.2%	1	1762 - 1969	1	–	–	43	1	Mixed
52	916	16.7%	83.3%	5	1892 - 2005	3	31.0	8 - 53	53	0	Low
54	75	58.8%	41.2%	0	–	–	–	–	U	0	Unknown
58	702	70.0%	30.0%	5	1894 - 2005	3	31.0	8 - 53	53	1	Mixed
60	639	0.0%	100.0%	5	1782 - 2012	3	64.7	8 - 101	43	1	Mixed
61	2212	0.0%	100.0%	5	1710 - 2013	7	33.9	10 - 90	43	1	Mixed
63	389	100.0%	0.0%	5	1758 - 2013	7	30.9	9 - 101	43	2	Mixed
65	426	90.0%	10.0%	5	1758 - 2004	14	17.5	4 - 85	85	0	Low
67	492	83.3%	16.7%	5	1743 - 2009	6	42.3	11 - 79	43	1	Mixed
69	366	63.6%	36.4%	5	1893 - 2004	2	–	–	85	1	Mixed
73	255	92.3%	7.7%	5	1703 - 2013	16	15.3	4 - 68	68	1	Mixed
75	190	70.0%	30.0%	5	1687 - 2013	14	21.4	3 - 96	48	1	Mixed
77	587	100.0%	0.0%	5	1896 - 2000	2	–	–	43	1	Mixed
79	169	81.8%	18.2%	5	1813 - 2013	5	18.6	3 - 53	53	1	Mixed
81	52	100.0%	0.0%	3	1806 - 2013	7	27.7	6 - 50	43	0	Low
83	193	63.6%	36.4%	4	1892 - 2001	1	–	–	93	0	Low
86	138	50.0%	50.0%	4	1657 - 1995	7	27.0	7 - 56	43	1	Mixed
88	123	100.0%	0.0%	2	1819 - 2013	3	35.3	5 - 58	43	0	Low
90	35	70.0%	30.0%	0	–	–	–	–	U	0	High
91	17	30.0%	70.0%	0	–	–	–	–	183	1	High
94	18	90.0%	10.0%	0	–	–	–	–	111	1	High
95	115	70.0%	30.0%	4	1867 - 2013	3	37.3	30 - 43	43	2	Mixed
PLOT-LEVEL SUMMARY	359	64.1%	35.9%	148	1574 - 2013	208	31.2	3 - 145	43	34	–
SITE-LEVEL COMPOSITE	**359**	**30.9%**	**69.1%**	**148**	**1574**	**33**	**7.8**	**3 - 31**	**43**	**35**	**Mixed**

Table 2.1: Forest structure and fire record summary by plot.

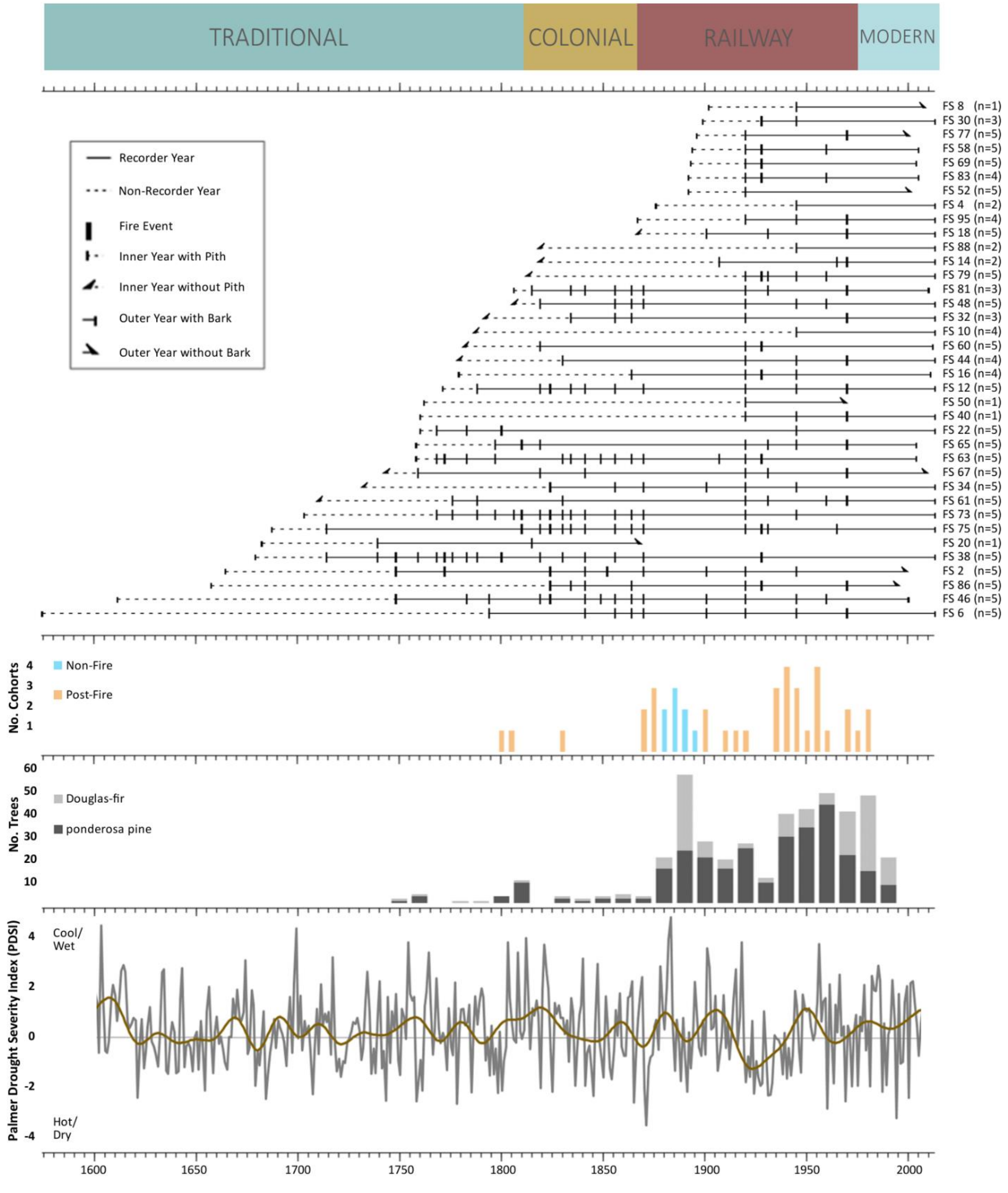

Figure 2.4: (top to bottom) Historical land-use eras, fire scar evidence by plot, identified cohorts and inferred cause, forest age-structure, and regional summer-season PDSI (Cook et al. 2004) smoothed using 20yr cubic splines.

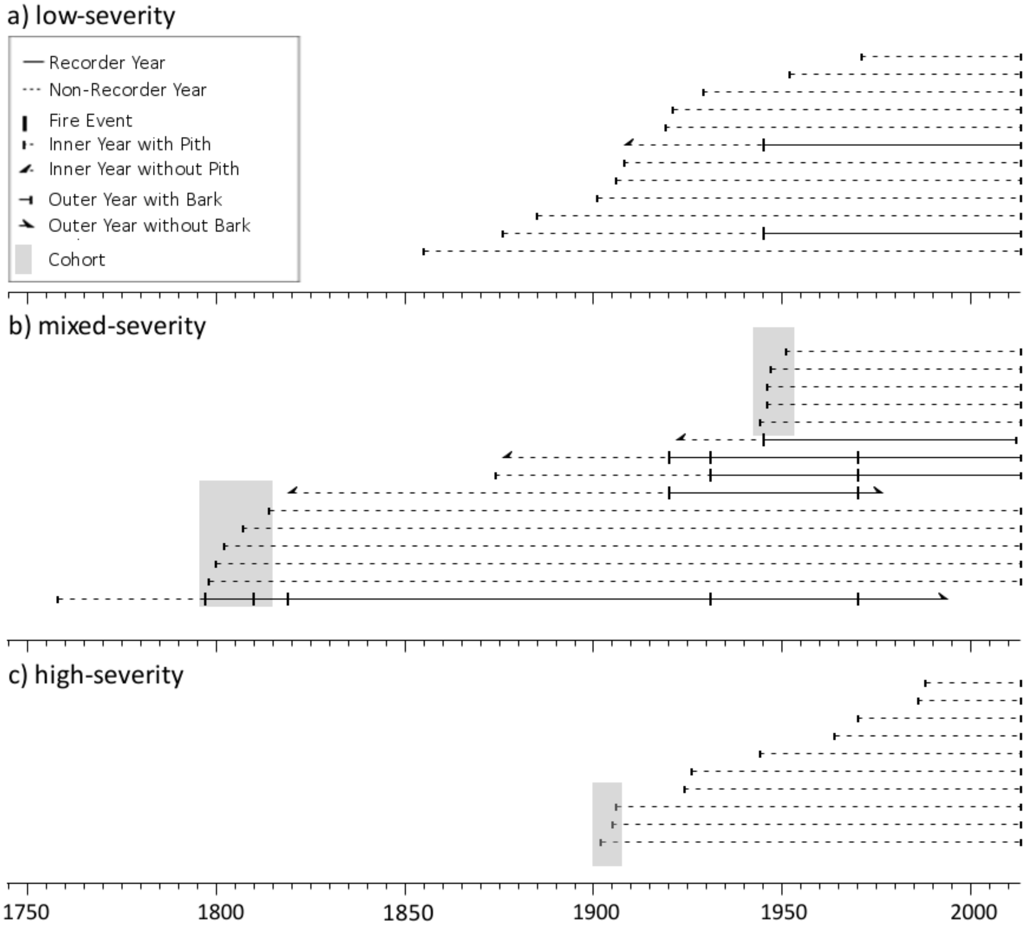

Figure 2.5: Example plot-fire-severity diagrams. Rows show fire scar and stand age samples for 3 representative plots (4, 63, and 94), designated as having a low-, mixed-, and high-severity fire history, respectively.

All non-fire cohorts and 31 of 35 post-fire cohorts established during cool/wet conditions.

Fire severity designations varied among plots, and the majority were classified as mixed-severity through time (63%) (Table 1, Figures 2.3c, 2.5). Of the remaining plots, 16% were classified as low-severity, 14% as high-severity, and 7% had an uncertain fire history. Overall, data suggest that the study area historically experienced a mixed-severity fire regime, and that surface fires made up a large component of historical fires.

Forest Age Structure

Based on tree establishment dates, the forest in the study area was relatively young, with older veteran trees scattered throughout. Mean age was 86.5 years and 70% of sampled trees established after 1900. Tree ages ranged from 22 to c. 265 years for both Douglas-fir and ponderosa pine, and age distributions varied spatially across the study area (Figure 2.3d). Plots surrounding the former *Syilx* village were composed of relatively young trees (age ≤ 167 years), while tree ages generally increased in plots to the north and west of the twin bays.

At the study area-level (Figure 2.4), the oldest trees established in the mid-18th century, with few trees establishing and surviving per decade through much of the 19th century. Tree establishment and survival increased beginning c. 1875 and continued at high rates through c. 1925. Following a decade in which few trees established and survived, high rates resumed in approximately 1935, and remained stable thereafter. No sampled trees (dbh ≥ 5cm) established after 1992, although the oldest regeneration (dbh <5cm) established in 1981 (L.D. Daniels, unpublished data). The age structure patterns for ponderosa pine and Douglas-fir were similar; however, the lower rates of establishment and survival c. 1930 were more pronounced, began earlier, and ended more gradually in Douglas-fir than ponderosa pine (Figure 2.4).

Comparison of the Fire Record and Historical Land-Use Timeline

Fire frequency, seasonality, and synchrony varied noticeably during the period of study (1700 – 2013), and these changes aligned closely with the timing of phases in the anthropogenic history of the study area. Four major shifts in fire pattern coincided with the displacement of the *Syilx* from the study area (Figure 2.4, Table 2.2):

1. A 48-year gap in fires occurred between 1871 - 1919 in all but seven plots, in which the gap was 29 years
2. Fires became less frequent after 1865
3. Fires tended to burn later in the season after 1865
4. Fires were more synchronous after 1865

Composited mean fire interval (CMFI) and fire seasonality varied considerably among eras (Table 2.2). Fires burned more frequently and a greater proportion of fires were recorded as earlywood scars when the *Syilx* were conducting traditional burns in the study area. Fire intervals more than doubled and the proportion of fires recorded as earlywood scars was noticeably reduced after the *Syilx* were displaced. Fires were most frequent when both the *Syilx* and Europeans were present in the study area. No fires were recorded after the Kettle Valley railway was decommissioned in 1978. Two lightning

Land-Use Era	TRADITIONAL (1700 - 1810)	COLONIAL (1811 - 1865)	RAILWAY (1866 - 1978)	MODERN (1979 - 2013)	1700 - 1865	1866 - 2013
Nature of Land Use	Syilx traditional land stewardship	Syilx land stewardship + European settlers camping and travelling	Settlers camping and travelling + Kettle Valley Railway	Protected area; occasional recreational users trespassing	Syilx traditional stewardship present	Syilx traditional stewardship absent
Fire Intervals (n)	13	9	9	–	23	10
CMFI (yrs)	7.4	5.4	11.1	–	6.5	14.3
Min. Interval (yrs)	3	3	3	–	3	3
Max. Interval (yrs)	25	8	31	–	25	43
Earlywood Scars (%)	21.6	15.5	4.3	–	17.4	4.3
Latewood + Dormant Season Scars (%)	78.4	84.5	95.7	–	82.6	95.7

Table 2.2: Comparing fire frequency and seasonality by land-use era.

ignitions occurred in the study area after 1978, but both were suppressed before they exceeded 1ha in size (BC Wildfire Service, unpublished data).

Factors Influencing Fire Occurrence

Models created using logistic regression indicated that land-use history strongly influenced the historical fire regime, while topographic factors did not. Parameter estimates for land-use eras at the study-area scale indicated that fires were twice as likely annually (odds ratio = 2.12, p=0.017) during the indigenous fire use era.

The topographic variables of slope steepness, aspect, and elevation were not significant predictors of fire occurrence (p=0.527, 0.707, 0.060 respectively). Estimated coefficients indicated that fires were generally more likely at higher elevations, on gentler slopes, and on drier and warmer aspects.

DISCUSSION

Fire scar and forest demography evidence suggest that the study area was historically shaped by frequent mixed-severity fires, and that changes in land use had a profound effect on the historical fire regime. Tree establishment dates also revealed that the forest in the study area was relatively young. Taken with the fact that many portions of the study area still support a relatively low density of trees and a rich variety of antelope brush and bunchgrass-dominated plant communities, these data suggest that the study area may have formerly been a parkland with sparse trees and isolated areas of greater tree cover, and that changes to the fire regime over the last century have greatly affected forest structure.

Impacts of Land-Use Changes on the Historical Fire Regime

Patterns in the fire record concurrent with historical land-use changes suggest that *Syilx* traditional burning drove the historical fire regime prior to 1865. Fires were more frequent and tended to burn earlier in the season when the *Syilx* were stewarding the study area in a traditional manner, and were less synchronous across the landscape. These findings are consistent with traditional burning practices described by *Syilx* Fire Keepers, who have indicated they were highly adept at timing ignitions to promote control and desired vegetative effects, and often conducted small burns in the spring to take advantage of milder weather conditions (Allison and Michel 2004). Phenological data for ponderosa pine and Douglas-fir was not available for the study area, and thus I could not infer specific seasonal timing of individual fire events. While I cannot conclusively say that earlywood scars recorded in the study area indicate spring or early summer burning, the location of a scar tip in this portion of the growth ring indicates that the fire occurred early in the growing season, before summer moisture stress slowed radial growth. In the southern interior of BC, the growing season for ponderosa pine and Douglas-fir is generally associated with spring and early summer, though phenology of these species may differ slightly (Heyerdahl et al. 2007). The proportion of early vs. latewood scars can also be compared to illuminate relative timing among historical eras. I found that earlywood scars made up a much greater percentage of scars during the time when the *Syilx* were managing the study area traditionally, suggesting a greater proportion of fires occurred early in the season during that period. Ignitions occurring after the *Syilx* were displaced, in contrast, would have likely been caused by sparks from the railway and other unintentional ignitions related to the study area's use as a travel corridor, or by lightning (Agee 1993, Johnson and Miyanishi 2001, van Wagtendonk and Cayan 2008). These would be expected to occur mostly during the height of the fire season in the summer and early fall, when weather is hottest and driest, and the probability of sustained ignition is maximized (Agee 1993, Johnson and Miyanishi 2001, Macias Fauria et al. 2011).

The argument that the historical fire regime was largely anthropogenic is also supported by the presence of a large gap in surface fires observed after 1871 (Figure 2.4). This date corresponds very closely with the time when the *Syilx* were displaced from their traditional lands (Thomson 1978, 1994, Carstens 1991, Union of British Columbia Indian Chiefs 2016). Following this gap, fires resumed when the Kettle Valley Railway was being surveyed, installed, and began operating (Sanford 2002), and may have thereby introduced a novel anthropogenic ignition source. Although lightning ignitions are common in the southern Okanagan, the topographic position of the study area in the valley bottom is such that lightning ignitions in the study area are infrequent (BC Wildfire Service, unpublished data). It therefore follows that for the study area to have sustained a historically frequent-fire regime, many of the ignitions would have needed to be anthropogenic. The coincident timing of changes in the fire record and the historical timeline of the study area support this conclusion.

Another line of evidence supporting that many fires were likely anthropogenic is that land-use eras were found to be significant predictors of fire occurrence, while topographic controls were not. Fires were over twice as likely annually when the *Syilx* were stewarding the study area, while fires were equally likely on all aspects, slope angles, and elevations. In a scenario where fires were being lit with land-stewardship goals in mind and encouraged to burn during cooler and wetter conditions, fires would not necessarily be more likely on the aspects and slopes where they would burn most intensely or spread most rapidly. Although warmer aspects and steeper slopes are more conducive to sustaining fire and promoting fire spread (Agee 1993, Johnson and Miyanishi 2001), these would only have been the site of traditional fires if these areas also happened to be those where the *Syilx* were seeking to manage for values, or if fires lit elsewhere were able to spread to these locations. The data suggest that the impact of anthropogenic ignitions superseded that of topography in controlling spatial variability in fire likelihood within the study area.

An alternative explanation for the result that topographic factors were not strong controls could be that conditions across the study area were suitable for burning in most years, such that ignitions were usually sustained, regardless of topographic position. Given the arid climate in the study area, the fuels may have been dry enough on all aspects, slope angles, and elevations to ignite and sustain fire spread during the average fire season. This study area is also much smaller than those of Greene (2011) and Cochrane (2007), similar studies conducted in southern British Columbia, in which topographic factors were found to be significant controls of the historical fire regime. Those study areas encompassed opposing sides of steeply incised valleys and a wider range of elevations, in which temperature and humidity differed strongly among plots. In contrast, the study area is limited to the western side of the Okanagan River Valley. While minor slopes of all aspects are present, the climatic conditions across the study area would not be expected to vary as widely as if sites across the valley or at significantly higher elevations were included in analyses. Thus, differing topographic features among plots would be less likely to cause fire likelihood to vary spatially across the study area to the same degree as in other studies conducted over larger areas.

Fire and Forest Dynamics

The fire record preserved in fire scars and post-fire cohorts revealed that historical fires in the study area were of mixed severity, with a large component of low-severity surface fires. A fire regime of this nature would have acted as an important control of recruitment and mortality through time (Brown et al. 1999, Veblen et al. 2000, Taylor and Skinner 2003, Hessburg et al. 2005, Perry et al. 2011, Heyerdahl et al. 2012, Marcoux et al. 2013). Frequent fires of predominantly low-severity could have promoted an open forest structure by killing seedlings and saplings not yet large enough to be resistant, and enhancing the competitive advantage of grassland understory species that are highly fire-adapted (Swetnam and Baisan 1996, Mast et al. 1998, Brown et al. 1999, Heyerdahl et al. 2001, 2006, Brown and Wu 2005, Hessburg et al. 2005, Scholl and Taylor 2010). In addition to promoting an open forest structure and a high diversity of grassland species, a mixed-severity fire regime dominated by frequent surface fires would have imparted a high degree of complexity both at the stand and landscape level (Agee 2005, Halofsky et al. 2011, Perry et al. 2011, Marcoux et al. 2015). Demography data revealed considerable variability among plots in age and density (Figure 2.3a, d), and these structures were likely generated in large part by the historical fire regime. If fires were to continue to be absent from the study area, this complexity and habitat could be lost, as illustrated for Jasper National Park (Chavardes and Daniels 2016).

An alternative explanation for the relatively young age structure at Vaseux is that the study area was formerly forested, but a widespread high severity fire occurred in the late 19th century, killing most canopy trees and liberating growing space to initiate the observed pulse in establishment and non-fire cohorts (Oliver and Larson 1996, Williams and Baker 2012). It is possible that the 8 non-fire cohorts identified were initiated by a high-severity fire event not also recorded by fire scars. However, two additional lines of evidence considered do not support this conclusion: 1) the absence of large volumes of coarse woody debris within the study area (Daniels et al. 2014) and 2) average PDSI values for the period when these cohorts established were relatively high, indicating cooler and wetter conditions.

If the study area was formerly forested at similar densities to the present prior to the late 1800s, and was subject to a stand-replacing fire event, you would expect to find debris within the study area from trees killed during the fire. I found very few logs and stumps during surveying, except in the small area in the northeastern portion of the study area where trees were thinned by CWS in the last decade. Of the already limited quantity of coarse woody debris, 0% of the remnant wood I sampled (n=137) was found to have died between 1880 – 1900, indicating these trees were not killed by a stand-replacing fire during that period. Considering this sample of 137 pieces of remnant wood, taken in relatively even distribution from across the study area, it follows that at least a major proportion of the already limited woody debris found in the study area (Daniels et al. 2014) was not created by a high-severity fire in the late 1800s. Evidence points instead to the 8 non-fire cohorts having been initiated by the gap in surface fires following the 1870 fire event, combined with moist and cool climatic conditions favorable for new establishment and growth.

In dry forests, periods of favorable climate augment growing space, such that new seedlings have sufficient resources to initiate, resulting in pulses of establishment (White 1985, Mast et al. 1998, Mast and Veblen 1999, Brown and Wu 2005, Brown 2006, Heyerdahl et al. 2012). Combined with a pause in surface fires, this allows seedlings and saplings sufficient time to grow to a fire-resilient size class, increasing their likelihood of surviving subsequent fire events (Arno and Gruell 1983, Agee 1993, Brown and Wu 2005, Heyerdahl et al. 2012). The fire record for the study area (Figure 2.4) shows a large gap in recorded surface fires between 1870 and 1901, coincident with a period of slightly wetter and cooler climate. As identified in Brown and Wu (2005) and Heyerdahl et al (2012), these kinds of conditions can create cohorts in dry forests that are not associated with a stand-replacing disturbance. High-severity fire events are also typically associated with periods of drought and/or extreme weather conditions (Agee 1993, Johnson and Miyanishi 2001, Turner et al. 2003, Schoennagel et al. 2004), meaning the 8 non-fire cohorts identified established during conditions not typically associated with stand-replacing fire events.

The importance of surface fire frequency in controlling establishment is also underscored by the observation that multiple moist/cool periods occurred earlier in the study area's history, but sampling did not detect large pulses in establishment at those times. While many seedlings may have initiated during those windows of favorable climate, they did not survive to the present to be sampled in large numbers, likely due to the frequent surface fires that occurred in the study area prior to 1870. While surface fires were recorded throughout the 20th century until 1970, these were at intervals over twice the length of those in the 18th and early 19th century, which provided trees a longer window in which to grow to a fire-resilient size (Arno and Gruell 1983, Agee 1993, Brown and Wu 2005, Heyerdahl et al. 2006, 2012).

Although establishment in the study area appears to have been closely linked to disturbance, the reduced number of trees that established and survived in the 1930s suggest that strongly unfavorable climate was also capable of limiting establishment. Summer PDSI reconstructions revealed that the most significant drought of the period of study occurred from approximately 1915 – 1940, and the age structures of both ponderosa pine and Douglas-fir showed a noticeable decrease in individuals in these age classes (Figure 2.4). Several fires also occurred during this period, in 1920, 1928, and 1931, which could have acted to limit establishment, in concert with climatic conditions. However, fires occurred at a similar interval between 1940 and 1970, yet trees continued to establish in higher numbers than during the drought period, supporting my interpretation that the low number of trees that established in the early 1900s was influenced by climate.

After the more severe drought of the early 1900s, trees continued to establish until the time of sampling at a relatively even rate, likely facilitated by fewer fires in the 20th century. The summer PDSI reconstruction (Cook et al. 2004) also revealed a general trend of cooler and moister conditions in the latter half of the 20th century, although very hot and dry years still occurred during that timeframe. Thus, it appears the study area experienced multiple “safe periods” (Brown and Wu 2005) in the 20th century when fire was absent and climate was suitable--particularly the 43-year fire-free period following the last recorded fire in 1970. In the continued absence of fire, if climatic conditions remain adequate to support additional establishment and growth, I expect that infilling by ponderosa pine and Douglas-fir will continue.

In some forests, researchers have found that infilling is predominantly occurring by shade-tolerant species. In many cases these species are also less fire-adapted than those historically dominating the sites, shifting stands to a less-fire resilient state as composition changes (e.g. Covington and Moore 1994, Swetnam and Baisan 1996, Hessburg et al. 2000, 2005, Taylor and Skinner 2003, Beaty and Taylor 2007, Scholl and Taylor 2010, Taylor et al. 2014, Harris and Taylor 2015). In my study area, however, all age classes present were occupied by both shade-intolerant ponderosa pine and more shade-tolerant Douglas-fir. This indicates that Douglas-fir has been colonizing the study area even during time periods when fires were frequent, and that the presence of this species within the study area is not necessarily a product of fire exclusion. Both species are also well-adapted to survive surface fires, given their thick insulating bark (Arno and Gruell 1983, Burns and Honkala 1990, Agee 1993).

Although infilling does not appear to have shifted the species composition of the study area, structural changes caused by infilling could have significant implications. Given the inference that the study area was formerly a parkland with more limited forest cover, the current condition of the study area represents a much larger aerial fuel load than would have been present previously. Tree crowns in many stands may be closer together, contain more ladder fuels in the form of seedlings and saplings, and stands may contain more trees in smaller size classes with lower canopy-base heights and thinner bark. These kinds of structural changes make stands more likely to carry fire into tree crowns, and could thus cause future fires to burn with a greater intensity than historical fires (Agee 1993, Hessburg et al. 2000, Taylor and Skinner 2003, Brown et al. 2004, Agee and Skinner 2005, Taylor et al. 2014). Fires could also be more widespread given the increased potential for long-range spotting and more vigorous burning—complicating fire suppression efforts and posing a greater threat to values at stake in the study area and in surrounding communities (Agee 1993, Johnson and Miyanishi 2001, Agee and Skinner 2005, Collins et al. 2011, Taylor et al. 2014, Harris and Taylor 2015). As tree cover increases, the proportion and diversity of rare fire-adapted grass and shrub species could also decline, with corresponding implications for wildlife habitat, invasive species issues, indigenous cultural values, and the study area's ability to recover from fires (Agee 1993, Hessburg et al. 2005, Heyerdahl et al. 2006, Perry et al. 2011, Harris and Taylor 2015). Overall, continued infilling could shift the fire regime of the study area towards one dominated by a much greater proportion of high-severity fire effects, pushing it outside the historical range of variability inferred from the fire record.

Management Implications

Much debate has surrounded how managers should interpret and apply information about historical fire regimes to promote values of interest and landscape resilience (Covington and Moore 1994, Moore et al. 1999, Schoennagel et al. 2004, Brown et al. 2004, Drever et al. 2006, Klenner et al. 2008, Williams and Baker 2012, Fulé et al. 2014, Odion et al. 2014, 2016, Stevens et al. 2016). A great deal of this discussion has surrounded whether fires were frequent enough historically that the period of modern fire exclusion has exceeded the historical range of variability in different forest types. If multiple fire intervals have been "skipped" in forests that were historically fire-maintained, then changes to forest structure can be expected, and restoration may be needed to preserve biodiversity and prevent fire hazard from escalating as a result of increasing fuel loads (Schoennagel et al. 2004, Brown et al. 2004). If, however, fire intervals were historically long, and dense even-aged stands are a natural component of an area's forest dynamics, then restoration may not be required to the same degree (e.g. Sherriff and Veblen 2007, Schoennagel et al. 2011). The prevailing conclusion to arise from many studies is that managers need to determine which forests require restoration and what form that restoration should take based on specific information about each area's historical fire regime and the factors driving forest dynamics there (Heyerdahl et al. 2001, Schoennagel et al. 2004, 2011, Brown et al. 2004, Hessburg et al. 2005, Halofsky et al. 2011, Korb et al. 2013, Marcoux et al. 2013).

In my study area, I found that fires are less frequent today than they were prior to 1865, and that fire exclusion has altered forest structure. The interval between the last recorded fire and the time of sampling exceeds any previously recorded interval at the study-area level. Unless fire is restored to the landscape at the appropriate severity and frequency, increased fire hazard, habitat loss, and changes in biodiversity are possible. The results of this study support the Canadian Wildlife Service's current management plan (Cooper et al. 2011), which is based on implementing a program of prescribed burning and mechanical thinning to promote fire-generated habitat and promote an open forest/grassland mosaic.

The results of this study conflict, however, with interpretations raised by Klenner et al (2008), who conclude that surface fires did not play a major role in the forest dynamics of the Okanagan region of British Columbia. They argue that restoration is not likely needed in most areas and should be based on a mixed-severity fire regime model, with a significant component of higher-severity fire. Although I found that the fire regime in the study area was mixed-severity in nature, I found that low-severity surface fires did play a meaningful role in the fire regime, and by extension forest dynamics. This finding is similar to that of Heyerdahl et al. (2007, 2012), who found that surface fires made up a large proportion of fire events in the history of forests in the Stein River Valley of southern British Columbia, 250 kilometers northwest of my study area.

The conflicting interpretations between Klenner et al (2008) and this study may owe in part to the differing data sources and methods of these studies. Klenner et al (2008) based their conclusions on information yielded from historical forest survey data, and on modern lightning and weather data associated with the subset of fires exceeding 40ha. While these are highly valuable sources of information, I argue that they may fail to offer a complete picture of factors at play in historical fire dynamics in the Okanagan—particularly indigenous traditional land stewardship.

Klenner et al (2008) contend that because lightning densities in many parts of the Okanagan, particularly at lower elevations and in valley bottoms, are relatively low, a regime dominated by frequent surface fires could not have existed. While I agree that lightning density in the region is not likely to produce a frequent-fire regime, the *Syilx* report they have been igniting fires in the Okanagan for thousands of years (Allison and Michel 2004), and this would have been an important driver of historical fire dynamics. Valley bottom and low-elevation regions where lightning is less frequent are the areas where the *Syilx* peoples lived and interacted with the landscape the most, and where their stewardship could have driven a frequent-fire regime. If forests developed since the last glacial maxima in the presence of indigenous peoples, then forest structures and biodiversity as we know them are inextricably linked to traditional practices. The fire regime that would have existed without humans becomes irrelevant if managers wish to preserve landscape values that were generated in part by human land stewardship over millennia. Although Klenner et al (2008) pose a valid point that lightning densities are highly variable across the Okanagan, to conclude that surface fires were not an important component of forest dynamics historically is to ignore the greater picture of the landscape's history. If managers wish to preserve the biodiversity and unique habitat structures currently present in the study area, then modern lightning intervals will not be a sufficient baseline from which to set treatment intervals.

Management Suggestions

I recommend that CWS continue with their current management trajectory, which is based on frequent prescribed burns and mechanical thinning to maintain open forest structure and fire-generated habitat features (Cooper et al. 2011). The fire record reconstructed in this study not only supports their current management direction, but can also provide a baseline from which to gauge treatment intervals, intensity, and variability. Fire regimes are currently classified in British Columbia using the Natural Disturbance Type system, which is a broad classification, and one prone to misrepresenting mixed-severity fire regimes (Marcoux et al. 2013). CWS's current management plan is based on the NDT class identified for the Okanagan region as a whole (NDT IV) (Cooper et al. 2011), and thus the results of this study can provide a more study area-specific platform from which to build a burning and thinning program designed to emulate historical fire dynamics.

It may be particularly important that CWS design a treatment program with a great deal of variability built in, as I found that fire interval and severity varied spatially and temporally in the study area's history. This kind of variability in fire regimes has been found to be an essential mechanism for generating complexity and enhancing overall landscape resilience to future disturbances (Turner et al. 1994, Turner 2010, Halofsky et al. 2011, Perry et al. 2011). Prior to displacement of the *Syilx*, fire intervals ranged from 3 – 25 years, and fires burned at an average interval of 7 years. I recommend CWS use this is a template for timing their treatment program, if they wish to emulate the historical fire regime. I also recommend that CWS aim to vary the severity of prescribed burns and thinnings both spatially within treatments and among treatments, to enhance landscape complexity and emulate the variability I observed in historical fires.

CONCLUSIONS

I found a great deal of evidence to suggest that indigenous burning practices had a profound effect on the fire regime at Vaseux Lake. The results of this study underscore that indigenous peoples have a tremendous amount of knowledge surrounding forest dynamics and fire use to contribute to modern management. The fire record and forest demography data at Vaseux show that this study area as we know it today is inextricably linked to the way the *Syilx* people stewarded it historically. I hope this study can contribute to the discussion about the salience of traditional ecological knowledge, and provide support for members of the Okanagan Nation Alliance who are seeking greater agency in fire management of the region, and to cooperate with provincial fire managers to incorporate traditional knowledge into the modern fire management paradigms.

This study sought to provide fire history and forest dynamics information for a lesser-studied region of North America, and one in which many ecological, cultural, and economic values are at stake. The Okanagan region of British Columbia hosts a dry-forest and grassland mosaic unique within Canada, and one in which managers and researchers have debated the role of surface fires in shaping forest dynamics (Heyerdahl et al. 2007, 2012, Klenner et al. 2008). I found that the historical fire regime of the Westside Unit of the Vaseux-Bighorn NWA was of mixed-severity, as has been found in other studies of this type in Southern British Columbia (Cochrane 2007, Greene 2011, Heyerdahl et al. 2012, Marcoux et al. 2013, Chavardes and Daniels 2016). Surface fires played a substantial role in historical fire patterns, and by extension, historical forest dynamics.

The forest at Vaseux Lake was young, and historical establishment patterns were predominantly controlled by the length of fire-free intervals. Suitable climate in the form of moister and cooler conditions helped to facilitate tree establishment when fires were absent, allowing seedlings take advantage of reduced competition and exposed mineral soil following fire events. The young age of this forest, combined with the rich contingent of grassland species and generally open forest structure (despite fire exclusion in the late 20th century) suggest that the study area may have formerly been a parkland with far less tree cover than observed today. The historical mean fire interval at Vaseux was frequent enough that the area has likely “skipped” many fire events that would have occurred had the *Syilx* peoples not been displaced from the study area.

Other valley-bottom areas within the Okanagan region may have experienced a similar fire history, yet have been subject to a provincial fire suppression policy since the early 20th century. There is reason to believe that many areas of the Okanagan may have experienced fires more frequently in the past than they do today, and may be more densely forested now than they were historically due to fire exclusion. This has tremendous implications for fire hazard, fire risk, and forest health—particularly given that most of the population of the Okanagan resides in valley-bottom areas.

It is important to note, however, that this study investigated the fire history of a relatively small study area at low elevations that had a rich human history. While the results I found may reflect the fire history and forest dynamics of many other sites in the region with similar features and human history, they are by no means representative of the entire Okanagan. Future studies of this nature in additional sites in southern British Columbia, designed to answer a range of questions about spatiotemporal variability in fire patterns, would provide valuable information to managers seeking information specific to the forests in which they work. Additional studies could also contribute to the broader fire-scar network, and thereby enable more powerful inferences and predictive tools for managing fire into an uncertain future.

CHAPTER THREE:
HISTORICAL FIRE-CLIMATE RELATIONSHIPS

INTRODUCTION

Climate is an important top-down driver of fire regimes (Agee 1993, Heyerdahl et al. 2001, Falk et al. 2011). Variation in local, regional, and global climate can have major impacts to fire behavior, extent, and spatial patterns over time (Swetnam and Betancourt 1990, Agee 1993, Heyerdahl et al. 2002, 2008a, Westerling et al. 2006). Although complete and high-quality instrumental climate records are available for the 20th century for many locations in North America (e.g. Vincent et al. 2002, Mekis and Vincent 2011), fire history studies can assess historical climate-fire relationships using paleoclimatic reconstructions from tree rings. These studies can identify associations between locally- and regionally-synchronous "fire years" and regional and global patterns in temperature, precipitation, and global climate oscillations (e.g. Kitzberger et al. 2007, Heyerdahl et al. 2008b, Falk et al. 2011). Knowledge of historical climate-fire dynamics can also serve as a valuable line of evidence for fire managers seeking to anticipate local and regional changes to fire hazard associated with a changing global climate (Hessl et al. 2004, Kitzberger et al. 2007). Although fire regimes may be altered by global climate change in novel and unpredictable ways, information about past relationships between top-down controls and fire regimes may be one of the most relevant and informative tools available to anticipate future changes (Swetnam et al. 1999, Kitzberger et al. 2007, Turner 2010).

In forests of the inland Pacific Northwest (PNW), multiple fire history studies have investigated fire-climate relationships and found compelling evidence for a link between annual- and decadal-scale climate and the incidence of fire years (e.g. Heyerdahl et al. 2002, 2008a, Hessl et al. 2004, Wright and Agee 2004, Kitzberger et al. 2007). Fires tended to burn during years with warm springs and summers (Heyerdahl et al. 2008a) or dry summers (Heyerdahl et al. 2002, 2008a, Hessl et al. 2004), which commonly occur during El Niño phases of the El Niño-Southern Oscillation (ENSO) (Heyerdahl et al. 2002, 2008a, Wright and Agee 2004) and positive (warm) phases of the Pacific Decadal Oscillation (PDO) (Hessl et al. 2004, Heyerdahl et al. 2008a).

ENSO and PDO may be relevant to fire occurrence in that they are linked to winter snowpack depth and subsequent growing-season drought at the regional level (Redmond and Koch 1991, Cayan 1996, Hoerling et al. 1997, Mantua et al. 1997, Gershunov and Barnett 1998, Mccabe and Dettinger

1999, McCabe et al. 2012, Rasmusson and Wallace 2013). ENSO is a phenomenon in which coupled changes in surface air pressure and sea-surface temperature in the tropical Pacific Ocean affect global circulation patterns (Kiladis and Diaz 1989, Rasmusson and Wallace 2013). In the PNW and Northern Rockies in the United States, El Niño (La Niña) phases are associated with warm/dry (cool/wet) winter and spring conditions and anomalously shallow (deep) snowpacks (Redmond and Koch 1991, Cayan 1996, Gershunov and Barnett 1998, Mccabe and Dettinger 1999). This pattern is the reverse of that observed in the Southwest and Southern Rockies, owing to the way ENSO impacts the northern and southern jet streams, causing a prominent dipole in precipitation across North America (Cayan 1996, Mccabe and Dettinger 1999, McCabe et al. 2012). ENSO is thought to impact fire occurrence in the PNW by affecting the amount of winter precipitation and the timing of spring snowmelt. Earlier snowmelt associated with shallow snowpack during El Niño events is thought to allow fuels to dry to critical levels earlier in the spring and generally reduce fuel moistures, thereby increasing the likelihood of sustained ignition and lengthening the fire season (Heyerdahl et al. 2002, Hessl et al. 2004, Wright and Agee 2004). Deep snowpack and cool spring temperatures associated with La Niña events, in contrast, are thought to delay fuel drying and generally result in higher fuel moistures, thereby shortening the fire season. The relative impact of El Niño and La Niña events in the PNW is not equal however: Hoerling et al (1997) found that El Niño events had a stronger effect on PNW surface-level climate than La Niña events.

The PDO is a similar phenomenon to ENSO but centers over the Northern Pacific ocean, and operates on a much longer (20-40 yr) time scale (Mantua et al. 1997, D'Arrigo et al. 2001, Gedalof and Smith 2001). PDO is thought to influence fire occurrence both by impacting winter and spring temperature and precipitation, which affect winter snowpack depth and fire-season onset, and by altering the strength of ENSO events (Gershunov and Barnett 1998, Hessl et al. 2004, Kitzberger et al. 2007, Heyerdahl et al. 2008a, 2008b). In the PNW, positive (warm) phases of the PDO tend to amplify the strength of El Niño events, and dampen those of La Niña events. Conversely, negative phases of the PDO tend to dampen El Niño events and enhance La Niña events (Redmond and Koch 1991, Gershunov and Barnett 1998, Mccabe and Dettinger 1999). While Hessl et al (2004) found a significant link between positive phases of PDO and regionally-extensive fire years, the results of Heyerdahl et al (2008a) and Kitzberger et al (2007) suggest that ENSO-PDO teleconnections may be a stronger control of regional fire synchrony than either ENSO or PDO alone.

Few studies have examined fire-climate relationships in the dry Okanagan region of British Columbia (BC), Canada. Although home to dry forests of similar composition and structure as those elsewhere in the PNW and the rest of North America, there is controversy as to whether fire regimes in southern BC were subject to similar controls and exhibited similar patterns in fire frequency and severity (Heyerdahl et al. 2007, 2012, Klenner et al. 2008). Little is known about the degree to which inter-annual and decadal-scale climatic teleconnections act as a top-down control to historical fire regimes in the Okanagan region in particular.

A potential confounding factor of fire-climate relationships in the Okanagan and other regions of British Columbia is that indigenous traditional burning may have been an important driver of historical fire patterns in many areas. Indigenous peoples of BC have expressed that they used fire as an integral component of their traditional land stewardship[**], and that they have been lighting fires intentionally for thousands of years (Johnson Gottesfeld 1994, Turner 1999, Allison and Michel 2004, Lepofsky and Lertzman 2008, Simmons 2012). The *Syilx* people[††] of the southern Okanagan, now known as the Okanagan Nation Alliance (Okanagan Nation Alliance 2010a), burned frequently in the past (every 2 – 15 years), both in the fall and spring, to enhance wildlife habitat, encourage the growth of culturally important plant species, and to reduce fuel loads on the forest floor (Allison and Michel 2004, Simmons 2012). Later, European settlement brought new potential ignition sources, changes to forest fuels through clearing and grazing, and eventually fire suppression to the region (Fraser 1967, Thomson 1969, Sanford 2002). If indigenous traditional land stewardship drove historical fire regimes in portions of the Okanagan region, then managers will need to consider this when interpreting historical fire-climate relationships and applying predictive models to anticipate future fires.

OBJECTIVES

I sought to investigate climate as a top-down driver of the fire regime at the Westside Unit of the Vaseux-Bighorn National Wildlife Area, near Oliver, BC. I was interested in the relationship between the incidence of fires and climate at inter-annual and decadal scales—particularly whether fires were more likely during hot/dry summers, during the El Niño phase of ENSO, and positive (warm) phases of PDO, as has been found in other studies in the region. I was also interested in testing whether changes

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[**] The term "stewardship" is used in this chapter to represent the way indigenous people cared for, cultivated, and gave back to the land traditionally. I acknowledge that this term is inadequate to fully express the complex and multi-faceted relationship that indigenous people had and continue to have with their traditional lands.

[††] The name *Syilx* is commonly used to refer to the indigenous people of the Okanagan region, based on the name of their shared language. I have used this name throughout this chapter; however, I acknowledge that not all peoples indigenous to the Okanagan identify with this name, and that a single nomenclature for all people of the region is a European construct.

in fire-climate relationships coincided with events in the human history of the study area, to examine the relative importance of local land use and climate as controls of the historical fire regime. If indigenous traditional burning drove historical fire dynamics prior to the mid-19th century, then the timing of traditional burning practices may have superseded climate in controlling historical fire occurrence.

METHODS

Study Area

The Westside Unit of the Vaseux-Bighorn National Wildlife Area (49°17’ N 119°33’ W) measures approximately 400ha and is bounded by steep cliffs and slopes to the west, north, and south, and Vaseux Lake to the east (Figure 3.1). The study area (hereafter “West Vaseux”) lies within the northern extent of the Great Basin Desert, extending into southern Canada from the northwestern United States as a contiguous mosaic of grassland ecosystems. It resides on a local boundary between the Bunchgrass and Ponderosa Pine Zones, according to biogeoclimatic ecosystem classification (Meidinger and Pojar 1991), and three variants of these zones are classified within the study area: BGxh1 (bunchgrass very dry hot Okanagan), PPxh1 (ponderosa Pine very dry hot Okanagan), and PPxh1a (grassland phase of the ponderosa pine very dry hot Okanagan) (MacKenzie 2012). Numerous rare and threatened grassland plant species, including bluebunch wheatgrass (*Pseudoroegneria spicata* (Pursh) Á.Löve), antelope brush (*Purshia tridentata* (Pursh) DC.), and arrowleaf balsamroot (*Balsamorhiza sagittata* (Pursh) Nutt.) grow in the understory. Trees present are ponderosa pine (*Pinus ponderosa* Douglas ex. C. Lawson), and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco*)* in varying densities (Cooper et al. 2011). West Vaseux also supports habitat for 39 at-risk wildlife species that are dependent on grassland plant communities. These include bighorn sheep (*Ovis Canadensis* Shaw, 1804), the Behr’s Hairstreak butterfly (*Satyrium behrii* (W.H. Edwards, 1870), Lewis’s and white-headed woodpeckers (*Melanerpes lewis* (Gray, 1849)) (*Picoides albolarvatus* (Cassin, 1850)), the blue racer snake (*Coluber constrictor foxii* (Baird & Girard, 1853)), and the Pacific rattlesnake *(Crotalus oreganus* (Holbrook, 1840)*)* (Cooper et al. 2011).

West Vaseux features gentle undulating topography along the lake, with milder slopes giving way to a network of rock steps and prominent cliffs to the west. Elevations within the study area range from 326 – 675m above sea level (a.s.l.). Slope steepness at plot locations varied from 0-50 degrees, and east-facing vertical rock faces of varying heights are common on the westernmost third of the property.

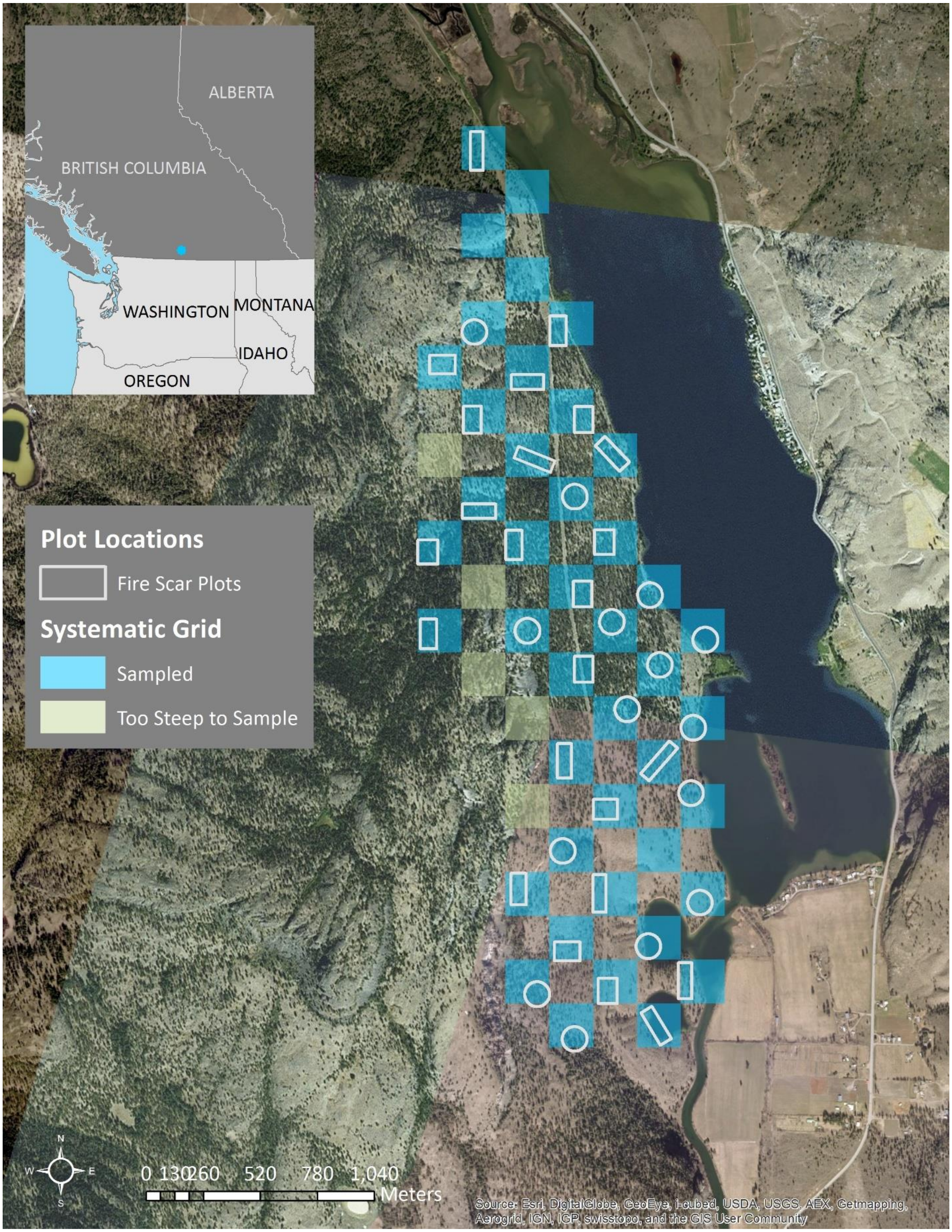

Figure 3.1: Regional location of the study area, systematic sampling grid, and plot layout. Alternate grid cells were surveyed, and 1ha fire scar plots were sampled from cells containing fire scars.

Elevation generally increases moving west from the shores of Vaseux Lake, and moving towards the center from the north and south. Most slopes on the study area are east facing, though varied terrain provides for minor slopes of all aspects.

Regional climate is dry and classified as a mid-latitude step (BSk) in the Köppen system (Köppen 1936), with a mean annual precipitation of 310 mm, mean annual temperature of 9.5°C, and average summer maximum temperature of 27°C (1981-2010; Wang et al. 2012). The Penticton Fire Zone typically experiences an active wildfire season from late spring through early fall, with an average of 41 lightning ignitions per year over 929,944 ha. Between 1950 and 2012, 74% of lightning ignitions occurred during July and August, when weather tends to be hottest and driest (BC Wildfire Service, unpublished data).

Human History

The study area lies within the traditional territory of the *Syilx* people (Armstrong et al. 1994, Okanagan Nation Alliance 2010b), and archeological and oral history records indicate that a long-standing village was located in the southern portion of the study area (Cooper et al. 2011).

European traders and settlers arrived in the region in the early 19th century, and a heavily-utilized travel route known as the “Old Brigade Trail” passed through the east edge of the study area (Black 1835, Fraser 1967, Thomson 1978, Carstens 1991). The *Syilx* were faced with growing impacts to their traditional way of life as colonialism progressed, including land claims by settlers within their traditional territories, and diseases such as smallpox, which decimated indigenous populations across BC, including in the Okanagan (Thomson 1978, 1994, Carstens 1991, Union of British Columbia Indian Chiefs 2016). In 1861, the Governor of British Columbia also began outlining reserves, with limited input from *Syilx* Chiefs. In 1865, these boundaries were further truncated without permission from the *Syilx* (Thomson 1978, Carstens 1991), forcing them onto only a fraction of their former territory. Based on the above events, I assumed for the purposes of this study that the *Syilx* were unable to practice traditional burning in the study area after 1865.

As Europeans continued to settle and develop the region, the study area was purchased by the Canadian Pacific Railway Company to build a spur of the Kettle Valley Railway between Penticton and Osoyoos, which operated from 1923 – 1977 (Sanford 2002). The tracks were later decommissioned in 1979, and the study area was converted to a protected area, now managed by the Canadian Wildlife Service to conserve rare grassland plant communities and wildlife (Cooper et al. 2011).

Research Design

I used a systematic research design to ensure even coverage of the study area (Figure 3.1). A 4000 x 1200 m grid was bounded by the property line to the north, west, and south, and Vaseux Lake to the east. The grid contained 96 cells, each 4ha in area (200m x 200m), and alternate grid cells were sampled (n = 43 cells; Figure 3.1).

I surveyed each grid cell for fire scars and mapped results using a GIS. In cells with fire scars, I placed a 1 ha plot to include the greatest number of large, presumably old samples with multiple scars to record the longest and richest fire history information (Van Horne and Fule 2006), and I sampled up to 5 fire-scarred trees per plot. In order to minimize the impact on critical habitat structures in the study area, live trees and snags were sampled using the partial cross section method (Cochrane and Daniels 2008), and full cross sections were taken from logs and stumps during late autumn, when most at-risk wildlife species are hibernating and not using these structures.

Sample Preparation and Crossdating

Fire-scarred sections were processed and analyzed according to established dendrochronological methods (Stokes and Smiley 1996). Samples were sanded until cell structures were visible with a binocular microscope, and then scanned to generate high-resolution images (2400 dpi) from which ring-widths were measured and crossdated using the programs CooRecorder and CDendro (Larsson and Larsson 2006). Samples were crossdated using the study area-specific chronologies created in Chapter Two and verified when necessary using Watson and Luckman's (2001, 2004) and L.D. Daniels (unpublished data) chronologies. I analyzed fire scar samples for both the year, and whenever possible, the seasonality of the injury, based on intra-ring position (Swetnam and Baisan 1994; Grissino-Mayer and Romme 2004).

I assigned dates to scars along the boundary of two rings (dormant-season scars) based on a method adapted from Heyerdahl et al (2012). Dormant-season scars were assigned to the preceding year if late-earlywood or latewood scars for that year were recorded by other sampled trees in the study area. I assigned dormant-season scars to the following year if early- or mid-earlywood scars were recorded on other trees for that year. If all scars for a fire event were recorded as dormant-season scars, I assigned these to the preceding year. These criteria were chosen given that most modern fires in the Okanagan region occur during mid- to late summer (BC Wildfire Service, unpublished data). *Syilx* traditional burns were also often conducted in the fall and these were typically more extensive, intense burns (Allison and Michel 2004) and were, thus, more likely to scar trees than spring burns.

Temporal Comparisons

To assess whether fire occurrence and extent varied with climate, I conducted parallel analyses on all fire years (≥ 2 trees scarred within the study area) and on large fire years. “Large fire years” were identified as those in which 20% or more of recording plots in the study area recorded a fire event, after conducting a sensitivity analysis on a range of thresholds. Studies have varied in the proportion of the study area that must burn to be considered a “large” fire, but 20% of plots is a proportion found in several studies in the Pacific Northwest and Rocky Mountain regions (e.g. Heyerdahl, Morgan, et al. 2008; Heyerdahl et al. 2002).

I constrained analyses to the period between 1768 – 1970. I chose 1768 as the lower bound of analyses to offset the influence of low sample depth for years early in the fire record. After the year 1768, ≥ 20% of plots were recording fire, limiting analyses to the period in which the fire record was most robust. I chose 1970 as the upper bound as this was the year of the last recorded fire in the study area.

To assess whether fire-climate relationships were influenced by the study area’s human history, I also defined two land-use eras, each lasting approximately a century. These were delineated based on the estimated date that the *Syilx* were displaced from the study area and no longer able to steward the study area traditionally:

I. **Indigenous fire use era**: 1768 – 1865
II. **European settlement era**: 1866 – 1970

Climate Data

I assessed historical fire-climate relationships, and differences between land-use eras, using three climate parameters: Palmer Drought Severity Index (PDSI), the El Nino Southern Oscillation (ENSO), and the Pacific Decadal Oscillation (PDO), which have all been shown to influence fire regimes in western North America (Kitzberger et al. 2007), including sites in British Columbia (Heyerdahl et al. 2007). PDSI is a commonly used annual measure of combined temperature and precipitation indices (Palmer 1965). PDSI may be relevant to the occurrence of wildfire given the importance of fuel moisture and summer temperature and precipitation in governing the likelihood and behavior of fires (Agee 1993, Johnson and Miyanishi 2001, Macias Fauria et al. 2011).

As instrumental records are not long enough to cover the period of interest for this study, I used paleo-reconstructions of climatic variables derived from tree ring series. For PDSI, I used a gridded summer-season reconstruction (Grid 42) by Cook et al (2004). For ENSO I used the Niño3 reconstruction (D'Arrigo et al. 2005). For the Niño3 reconstruction, positive values correspond to warm phases of ENSO (El Niño years), and negative values correspond to cool phases (La Niña years). This is the reverse of the also widely used Southern Oscillation Index (Stahle et al. 1998). For PDO, I used a reconstruction by Gedalof and Smith (2001) for both continuous data and multi-decadal scale phases, as this dataset was constructed from trees in southern British Columbia, and may best represent PDO as it applies to the study area.

Fire-Climate Analyses

I used superposed epoch analysis (SEA) (Grissino-Mayer and Swetnam 2000) to determine whether annual indices of PDSI and ENSO differed significantly between non-fire years and fire years/large fire years. SEA was performed using the program FHAES (Brewer et al. 2016) and confidence intervals (α= 0.05) were calculated by bootstrapping using 1000 model simulations. I investigated differences between the 3 years preceding and 1 year following the fire year to assess short-term lagged relationships, as have been observed in several other dry forest systems (e.g. Swetnam and Baisan 1996, Veblen et al. 2000, Grissino-Mayer and Romme 2004, Brown et al. 2008, Margolis and Balmat 2009, Kitchen 2016). In dry areas where fuel continuity limits the incidence and spread of fires, researchers have found that fires were associated with cooler and wetter conditions in the years prior to fire events, as this allowed fuels to accumulate to a sufficient level to sustain fire spread by the time of ignition. In the Southwest and Southern Rockies of the USA, where the effects of ENSO are opposite to those of the PNW, studies found that large fire events often occurred during dry years following El Niño events (cool/moist conditions), which may have enhanced fuel continuity leading up to the year of ignition (Swetnam and Betancourt 1990, Veblen et al. 2000). In the PNW, however, several fire-climate studies have found no significant relationships between antecedent temperature, precipitation, or ENSO conditions and the incidence of local or regionally-extensive fire years, suggesting that fuels in many PNW forests may be sufficiently continuous to sustain fire during the average fire season (Heyerdahl et al. 2002, 2008a, Hessl et al. 2004, Wright and Agee 2004, Kitzberger et al. 2007).

In a second set of analyses, I used logistic regression to model the relationship between inter-annual and decadal scale climate and the incidence of fire in the study area. Logistic regression was used to assess (a) annual indices of PDSI, ENSO, and PDO to corroborate SEA analyses, (b) assess multi-decadal variation in PDO as the frequency of PDO phase-shifts exceeds the window of SEA analysis (Hessl et al. 2004), and (c) to assess the three climate variables, PDSI, ENSO, PDO, and land-use eras simultaneously. I used the statistical package SAS® 9.4 (The SAS Institute 2014), and the PROC GLIMMIX procedure (link= logit, distribution= binomial; REPEATED statement) to generate the model and estimated coefficients. I first created a model containing all variables of interest, and removed the variable with the highest p-value, proceeding iteratively, until all remaining variables were significant. I also created models testing each variable individually, to ensure only significant variables were included in final analyses. I tested the significance of modelled variables using Type III tests of fixed-effects solutions based on the F-distribution ($\alpha=0.05$).

RESULTS

Fire Record

Sampling and crossdating yielded 406 fire scars. When composited at the study area level, fire scars recorded 34 distinct fire events, and fires burned in the study area at an average interval of 7.8 years (range 3-31 years). During the indigenous fire use era, 19 fires burned with a mean interval of 7 years (range = 3 - 25 years), and 4 fires scarred ≥20% of recording plots. During the European settlement era, 10 fires burned with a mean interval of 14 years (range = 3 – 31 years), and 5 fires scarred ≥20% of recording plots.

During the Indigenous fire use era, fire events and large fire events occurred during a variety of climatic conditions, and were not more likely during warm/dry conditions (Figure 3.2). Of the 15 local fire events and 4 large fire events recorded during the indigenous fire use era, 5 local fires (33%) and 2 large fires (50%) occurred when PDSI was negative (warm/dry conditions), 7 local fires (46%) and 1 large fire (25%) occurred when Niño-3 was positive (El Niño conditions), and 9 local fires (60%) and 1 large fire (25%) occurred when PDO was positive (warm/dry conditions). Multiple combinations of PDSI, ENSO, and PDO were observed.

During the European settlement era, in contrast, fires were more likely during warm/dry conditions, El Niño conditions, and positive phases of the PDO. Of the 5 local fires and 5 large fires recorded during the European settlement era, 3 local fires and 3 large fires (60%) occurred when PDSI was negative, 4 local fires and 4 large fires (80%) occurred when Niño-3 was positive, and 4 fires (80%) and 3 large fires (60%) occurred when PDO was positive. As with the indigenous fire use era, combinations of all three climatic variables occurred in relatively equal proportion. However, 60% of local fire years occurred when positive ENSO and positive PDO coincided, and 60% of large fire years occurred when negative PDSI and positive ENSO coincided.

Fire-Climate Relationships

SEA results showed that fire-climate relationships differed between the indigenous fire use and European settlement eras (Figures 3.3,3.4). During the indigenous fire use era, fires were not significantly related to PDSI, and conditions in the years prior to fire years and large fire years were

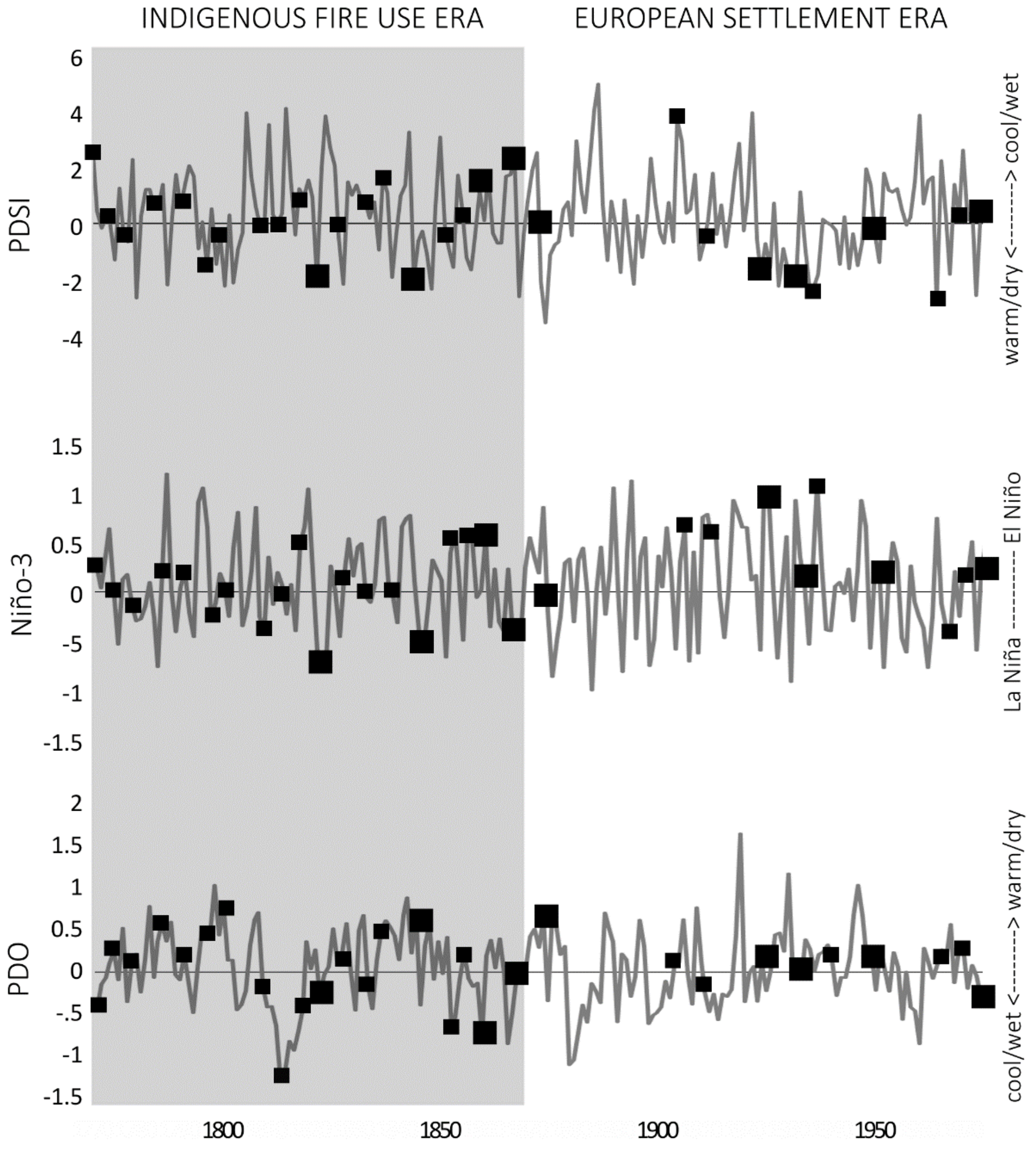

Figure 3.2: Incidence of fire years and large fire years with respect to climate time-series. Grey lines show annual values in PDSI (Cook et al. 2008), Niño-3 (D'Arrigo et al. 2005), and PDO (Gedalof and Smith 2001). Small squares indicate local fire events, and large squares indicate fire events that scarred trees in ≥ 20% of recording plots ("large fires").

generally cool and wet. Average conditions during both fire years and large fire years were mild, indicating fires either occurred during a variety of conditions, or that fires tended to occur during mild years. Fire years during this era were weakly associated with El Niño (warm/dry) conditions, while large fire years were weakly associated with La Niña (cool/moist) conditions, though none of these relationships was statistically significant.

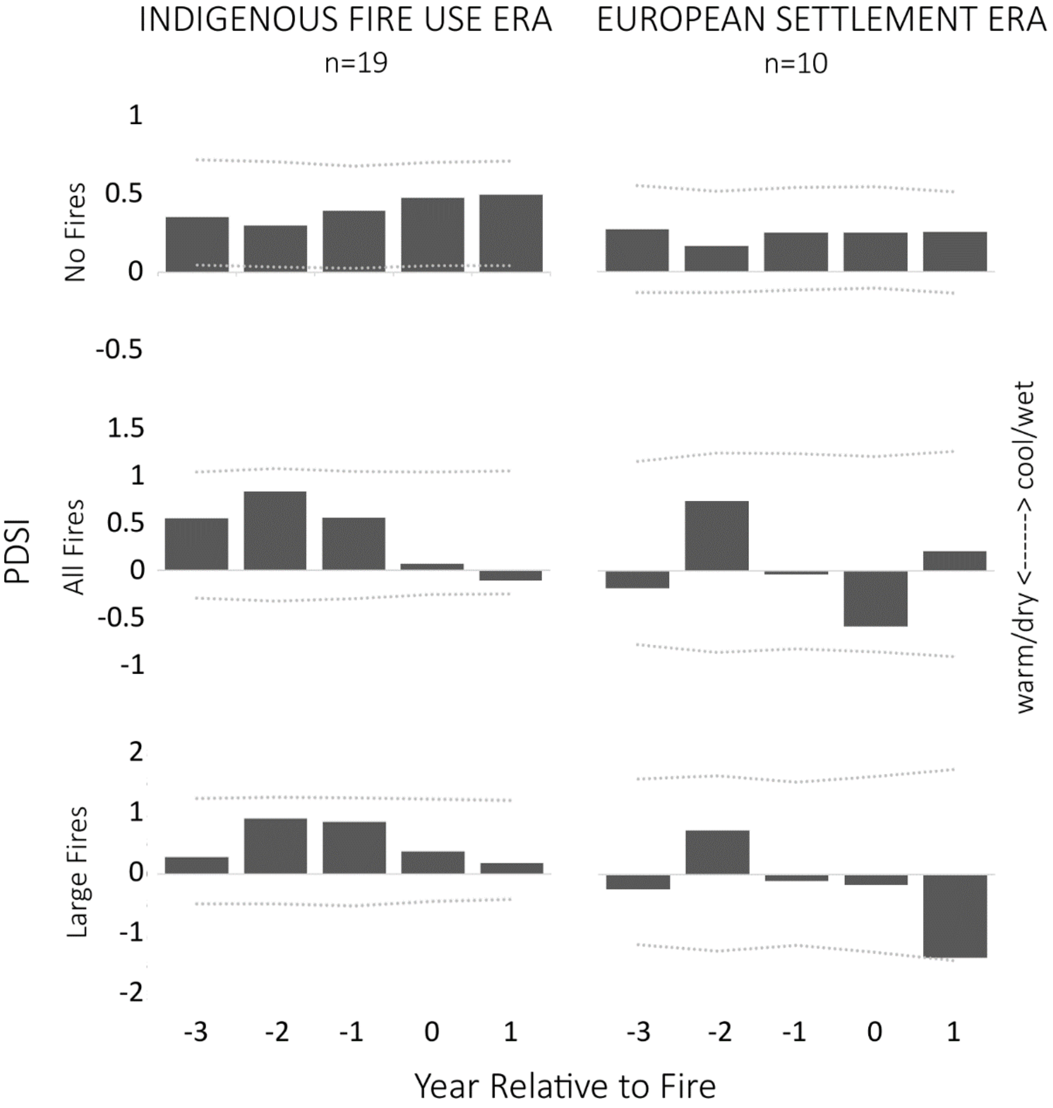

Figure 3.3: Relationship between Palmer Drought Severity Index (PDSI) (Cook et al 2004) and years without fire, all fire years, and large fire years, by land-use era. Light grey bars indicate significant results (α=0.05). Dotted lines indicate 95% confidence intervals.

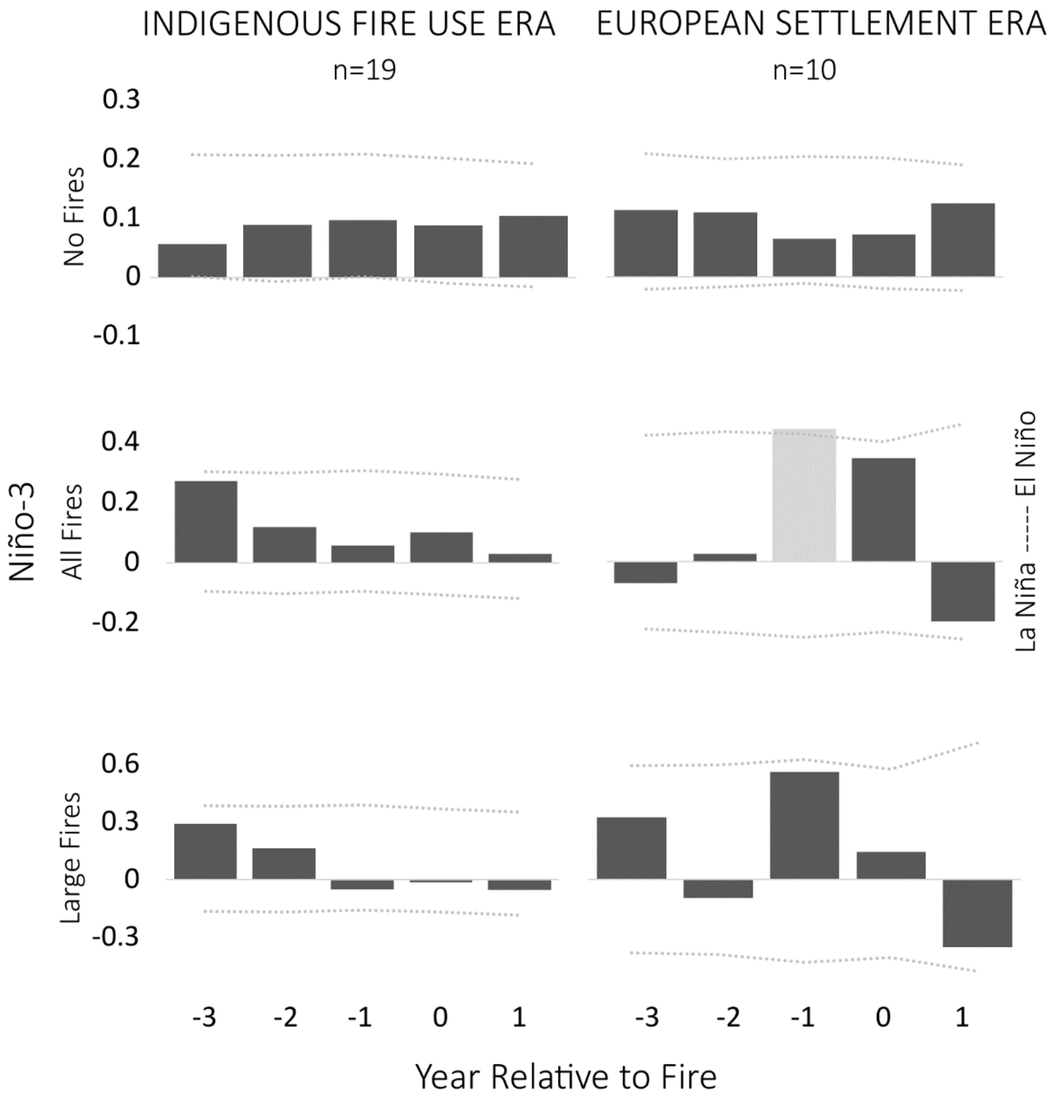

Figure 3.4: Relationship between the El Niño-Southern Oscillation (ENSO) (Niño 3 Index; (Cook et al. 2003) and years without fire, all fire years, and large fire years, by land-use era. Light grey bars indicate significant results (α=0.05). Dotted lines indicate 95% confidence intervals.

Fires in the European settlement era were generally associated with drought conditions and overall patterns differed from those of the indigenous fire use era. Fires during the European settlement era tended to occur during warm/dry years, though this result was not statistically significant. Fires and the year preceding fires during this era tended to be El Niño years, and the relationship for the year prior to fire events was statistically significant. Large fire years showed a similar, though not significant, pattern.

Logistic regression corroborated the differing patterns observed between land use eras, though fire-climate relationships were not significant during either era when tested using this method. During the indigenous fire use era, fires were more likely during cool and wet conditions (positive values of PDSI), El Niño years, and during cool phases of the PDO. During the European settlement era, in contrast, fires were generally more likely during warm and dry conditions (negative values of PDSI), El Niño years, and warm phases of the PDO. The only variable whose coefficient was statistically significant was land use era. Fires were more than twice as likely during the indigenous fire use era (odds ratio= 2.1; $p<0.001$).

DISCUSSION

The differences in fire-climate relationships between the indigenous fire use and European settlement eras supports the conclusion that the primary source of anthropogenic ignitions changed in the mid-1860s concurrent with documented land use. Fires during the indigenous fire use era were associated with a variety of climatic conditions (Figures 3.2, 3.3 and 3.4), while fires during the European settlement era were associated with warm/dry conditions and significantly associated with El Niño conditions. If many fires during the indigenous fire use era were being lit purposely by the *Syilx* people, these fires would not necessarily have occurred during inter-annual or decadal-scale droughts. Rather, fires lit for traditional purposes were more closely linked with resource needs, fuels assessments, and seasonal weather patterns (Turner 1999, Allison and Michel 2004). Knowledge shared by *Syilx* traditional Fire Keeper, Annie Kruger, indicates the *Syilx* burned with a goal of enhancing wildlife habitat and forest structural diversity, encouraging the growth of certain plant species, and to reduce fuel loads on the forest floor (Allison and Michel 2004). Kruger also shared that the *Syilx* timed their burns based on seasonal weather conditions and periodic fuels assessments, and preferred to burn in the spring and fall, to produce desired fire effects and to maximize fire control. Thus, my result that fires were not associated with inter-annual- and decadal-scale droughts agrees with *Syilx* oral history of traditional burning practices, and supports the inference that traditional land stewardship was a dominant force driving historical fire dynamics at West Vaseux until the mid-19th century.

Alternatively, weak fire-climate relations result when weather is sufficiently warm and dry during any given fire season that fire likelihood does not vary much inter-annually. If this were the case, fire occurrence might be more closely tied to daily and monthly weather at the time of ignition (Agee 1993, Johnson and Miyanishi 2001) rather than seasonal or annual climatic indices. The Vaseux study area is very dry, and receives most precipitation in the winter. The area also experiences average summer temperatures around 20°C, and average summer maximum temperatures near 30°C (Wang et al. 2012). Thus, the fuels may have been dry and weather warm enough during the average season that ignitions were typically sustained and generated enough heat to scar trees. This scenario implies ignitions-limited fire occurrence and supports the interpretation that human ignitions were the dominant control on the fire regime. Modern lightning ignitions around the study area are infrequent due to its topographic position, and only one lightning-ignited fire in the documentary record burned into the study area boundary from surrounding lands (BC Wildfire Service, unpublished data). Thus, human-ignitions are necessary to explain the frequent-fire regime observed in the fire record and explain changes in fire occurrence between land-use eras.

Settlement in the region by Europeans resulted in devastating diseases, removed indigenous people from their lands, and banned their traditional use of fire. Thus, ignitions during the European settlement era reflect a shift in anthropogenic use of the study area and likely resulted from accidental starts related to travelers passing through the study area, the Kettle Valley Railway, and lightning (Agee 1993, Thomson 1994, Sanford 2002). While the timing of European settlement era ignitions would have been related to settlers' travel patterns, railway schedules, and thunderstorm tracks, the likelihood of these ignitions resulting in a sustained and spreading fire would have been maximized when temperatures were high, relative humidities were low, and fuels were dry (Agee 1993, Nash and Johnson 1996, Johnson and Miyanishi 2001, Macias Fauria et al. 2011). It follows that these ignition sources would have been most likely to cause a sustained fire during times when PDSI values were negative and during El Niño conditions. These conditions correspond to warmer and drier conditions in regional climate, and have been linked to fire occurrence by other studies in the PNW (Heyerdahl et al. 2002, 2008a, Hessl et al. 2004, Wright and Agee 2004, Kitzberger et al. 2007).

The finding that prior-year El Niño conditions were associated with fire events could have several explanations. Firstly, this could imply that fires occurred after cumulative drying over the previous fire season, facilitated by warm/dry conditions and an earlier onset of the previous season's snowmelt (Heyerdahl et al. 2002). However, given the nature of fuels at Vaseux—grassland plant communities in the understory and open stands of ponderosa pine and Douglas-fir in the overstory—combined with the dry and hot summer climate in the region (Wang et al. 2012), I suggest that it is unlikely that fuels in this system would require drying over the course of multiple seasons in order to be primed for burning (Agee 1993, Johnson and Miyanishi 2001, Schoennagel et al. 2004). Conditions the year of fires were also associated with El Niño conditions, although relationships were not statistically significant. This lagged relationship may be an artifact of fires occurring in the latter part of a multi-year

El Niño event. A third potential explanation relates to temporal lags between the sea surface temperatures in the tropical Pacific that indicate ENSO events and delayed effects on climate during the fire season in the study area located at 49°17’ N latitude in southern BC. Redmond and Koch (1991) found that tropical ENSO conditions may precede surface climate conditions in the PNW by up to six months. Thus, the ENSO conditions in one year may have an impact on spring precipitation and temperature in the following year, particularly during multi-year events. In their study area in central and eastern Washington, Hessl (2004) found that current year El Niño events were significantly negatively correlated to current year and following year spring precipitation. Given the close proximity of their study location to West Vaseux and similar regional climate, the relationship between fires at Vaseux and previous-year El Niño conditions may be partially explained by this effect. Modern fire occurrence and area burned have been linked to dry springs because these accelerate the drying of fuels and create conditions conducive to ignition earlier in the fire season (Westerling et al. 2006).

The finding that climate variables were not a significant predictor of large fire years during either era may have several alternate explanations. 1) Climate was not a strong control of large fire years. 2) The *Syilx* lit small and large fires under similar conditions at annual and decadal scales and timed their ignitions based on factors other than weather, as described above. 3) The small sample size for large fire events may have been biased by single fire events that burned during anomalous climatic conditions. Considering all lines of evidence, I suggest that large fires were not significantly associated with specific climatic conditions due to the anthropogenic nature of the fire regime and the small sample size. Future studies conducted in the southern Okanagan would help to elucidate fire-climate relationships during years of extensive fires.

The finding that conditions were cool and moist two years preceding fire years and large fire years during both land-use eras and the full period of study, though not statistically significant, may suggest that favorable conditions were necessary for fuels to build up and become continuous, as observed in other dry forest systems in Arizona and New Mexico (Swetnam and Baisan 1996, Margolis and Balmat 2009), Colorado (Veblen et al. 2000, Grissino-Mayer and Romme 2004), and the US Great Basin (Brown et al. 2008, Kitchen 2016). Although located at a much more northerly latitude, the study area is very dry (Wang et al. 2012), and lies within the northern extent of the Great Basin Desert ecosystem (Cooper et al. 2011). Thus, similar fuels dynamics may be in play in this system as in other dry, ponderosa pine- and Douglas-fir-dominated forests elsewhere. However, this interpretation cannot be made with confidence and requires further investigation as these relationships were not statistically significant. Several fire-climate studies in the PNW also found no statistically-significant lagged relationships between fire occurrence and prior cool/moist years, suggesting that fuels in many parts of the PNW may be sufficiently continuous to sustain fire spread, independent of antecedent climate (Heyerdahl et al. 2002, 2008a, Hessl et al. 2004, Wright and Agee 2004).

Logistic regression did not indicate PDO was a significant driver of the historical fire regime at Vaseux during either land-use era. However, 80% of local fires and 60% of large fires in the European settlement era occurred when PDO values were positive, suggesting that European settlement era fires were influenced by warm/dry conditions associated with positive phases of the PDO. The relative influence of different combinations of PDSI, ENSO, and PDO was also inconclusive, as different combinations were nearly equally represented in both the indigenous fire use and European settlement eras. However, 60% of local fires occurred when both Niño-3 and PDO were positive, suggesting that ENSO-PDO teleconnections may be important to fire occurrence in the study area. Kitzberger et al (2007) and Heyerdahl et al (2008) found that combined warm ENSO and PDO conditions were linked to regionally-synchronous fire years across the PNW. Additional studies in southern British Columbia could help shed light on the influence of global-climate teleconnections in governing fire occurrence in this more northerly portion of the PNW region.

CONCLUSIONS

Local-scale human land-use superseded the effects of inter-annual and decadal-scale climatic variation in driving the historical fire regime at West Vaseux, particularly prior to European settlement. Multiple lines of evidence indicated that the historical fire regime was more sensitive to ignitions than other limiting factors. Since ignitions by indigenous people met multiple objectives and were unlikely during significant droughts when fire would be difficult to control (Allison and Michel 2004), effects of annual droughts and multi-year global teleconnections were weak. The change in fire-climate relations during the European settlement era is consistent with lightning and accidental human ignitions along transportation corridors that were most likely to spread and scar trees during dry El Niño conditions. These findings, in combination with the high frequency of fires in this 400ha study area bounded by a lake and steep rocky cliffs, provide strong evidence that the historical fire regime at Vaseux was largely due to human ignitions. Similarly, Fry and Stephens (2006), also found no significant associations between fire years and inter-annual climate in their study area and inferred a largely anthropogenic fire history.

Other studies in the Pacific Northwest have found inter-annual and multi-decadal climatic variation to be significant drivers of fire occurrence and to synchronize fires across broad regions

(Heyerdahl et al. 2002, 2008b, Hessl et al. 2004, Kitzberger et al. 2007). Understanding such fire-climate relationships provides important insights into future fire regimes altered by global climate change. However, the strong influence of traditional indigenous burning confounded the fire-climate signal so that West Vaseux is not an appropriate location for assessing potential future fire regimes for the Okanagan region. If other valley-bottom sites in the Okanagan had a similar land-use history, then the fire-climate relations at West Vaseux may be broadly representative of the Okanagan, but they are not indicative of future relations. Further research is needed to evaluate both historical and modern fire-climate relationships in additional locations in the Okanagan, to better understand human impacts and improve forecasting of fire regimes in a changing environment.

CHAPTER FOUR: CONCLUSIONS AND FURTHER RESEARCH

Multiple lines of evidence suggest that burning by indigenous peoples was the dominant driver of the historical fire regime at West Vaseux. That historical fire dynamics were largely anthropogenic has tremendous implications for management of the study area. If the Canadian Wildlife Service wishes to preserve forest structures, wildlife habitat, and plant communities that were generated in the study area by historical fire patterns, then the influence of traditional land stewardship cannot be ignored. Given oral histories and shared knowledge indicating many indigenous peoples in western Canada utilized fire (Boyd 1999, Turner 1999, Allison and Michel 2004, Lepofsky and Lertzman 2008, Simmons 2012), it is likely that fire regimes in many other parts of this region were also driven in part by indigenous burning. Indigenous peoples have inhabited western Canada for thousands of years, and thus the development of these forests may be inextricably linked to their traditional practices. The results of this study underscore that indigenous peoples have a wealth of knowledge in fire-use and ecological stewardship, and have much to contribute to modern fire and fuels management.

Disrupting *Syilx* traditional stewardship not only altered the fire regime, but also impacted forest structure in the study area, by lengthening the interval between fires and allowing a greater proportion of seedlings to survive to fire-resilient size classes (Agee 1993, 2005, Mast and Veblen 1999, Schoennagel et al. 2004, Agee and Skinner 2005, Brown 2006, Perry et al. 2011). Demography data indicate that the study area is denser than it would have been historically, and that current forest structure is more conducive to higher intensity crown fires, given changes to fuel loading, continuity, and vertical arrangement (Agee 1993, Johnson and Miyanishi 2001, Brown et al. 2004, Agee and Skinner 2005, Daniels et al. 2014). The fire regime of the study area may have already shifted towards a much greater component of high-severity fire, with corresponding implications for wildlife, plant community diversity, and fire hazard to surrounding communities.

Today the opportunities for human-caused fires in the study area are more limited (Cooper et al. 2011), and the density of modern lightning ignitions in the immediate area is low (BC Wildfire Service, unpublished data). If the historical fire regime at Vaseux was largely anthropogenic, then we can expect future fires to occur relatively infrequently without proactive management. The Canadian Wildlife Service has already recognized that critical habitat structures on the site were fire-generated, and that preserving wildlife and biodiversity dictates a program of prescribed burning, mechanical thinning, and managed wildfire to restore and maintain the landscape. This study can help to provide context for decisions about how frequently to treat in the future, and what form these treatments should take.

I found that historical fires varied considerably in their interval, seasonality, synchrony, and extent, even within land-use eras. While the majority of historical fires were inferred to be low-severity surface fires, several events burned with high enough severity to cause tree mortality and initiate cohorts, and the intervals between both low- and higher-severity fire events were not uniform across any period in the site's history. This variability was likely responsible for imparting a great deal of complexity onto the landscape at West Vaseux, which was supported by demography data revealing a heterogeneous age structure and spatial variability in tree age, size, and density. Complexity is an essential component of ecological resilience (Drever et al. 2006, Long 2009, Turner 2010, Perry et al. 2011), and mixed-severity fire regimes are particularly effective at generating a variety of forest structures and overall complexity at multiple scales (Agee 2005, Halofsky et al. 2011, Perry et al. 2011, Marcoux et al. 2013). Maintaining resilience at West Vaseux and in similar sites across the Okanagan where fire has been excluded in the 20th and 21st centuries may require thoughtful planning and implementing a restoration program with great deals of variability built in. I recommend that CWS not only vary the interval and severity between treatments, but also vary severity *within* treatments, to generate heterogeneity and complexity, and emulate the variability I observed in historical fire dynamics.

Fire regimes are often discussed in terms of being predominantly climate *OR* fuels-limited (Schoennagel et al. 2004). I would propose that the historical fire regime at Vaseux was neither. There were no statistically significant relationships between the climate variables tested and the incidence of fire years, suggesting that long-term drought was not necessary to dry fuels sufficiently for an ignition to be sustained. I also did not find any statistically significant lagged relationships, as has been found in other dry forests (e.g. Swetnam and Baisan 1996, Veblen et al. 2000, Grissino-Mayer and Romme 2004, Brown et al. 2008, Margolis and Balmat 2009, Kitchen 2016) to suggest that wetter years were required to generate continuous fuel beds. Although graphs of SEA results showed what appeared to be a weak lagged relationship, where conditions were wetter and cooler two years prior to a fire event, this cannot be used to confidently infer that the fire regime was fuels-limited.

The historical timing of fires instead appears to have been most closely linked to whether humans were present on the landscape and lighting fires—either intentionally or accidentally. I would thus propose that the historical fire regime at Vaseux Lake was predominantly *ignitions-limited*. Conditions were suitable for burning in most years, and fires occurred when an ignition was available.

Although fuel continuity, climate, and daily fire weather undoubtedly influenced fire patterns, my results suggest that the fire record was more closely aligned with human land-use than any other factor investigated.

There is also ongoing debate as to whether surface fires were an important component of historical fire regimes in the Okanagan (Heyerdahl et al. 2007, 2012, Klenner et al. 2008), and the results of this study can contribute to this conversation. Not only did I find abundant evidence of surface fire at West Vaseux Lake, but I found that surface fires were the dominant form of fire historically. This is not to suggest, however, that higher-severity effects were not an ecologically meaningful component of the historical regime. To the contrary—I would argue that the variability I observed in the severity and interval between fires at West Vaseux was a critical mechanism for generating local and landscape-scale complexity, and by extension, forest resilience. That studies in southern British Columbia have found historical mixed-severity fire regimes with differing proportions of low vs. moderate vs. high-severity effects only underscores that variability and complexity are essential and intrinsic qualities of forest systems, even in dry regions (Heyerdahl et al. 2007, 2012, Greene 2011, Marcoux et al. 2013, 2015, Chavardes and Daniels 2016).

Future studies conducted at additional locations in the Okanagan and other regions of southern British Columbia could be valuable to managers looking to understand fire history, fire ecology, and fire-climate relationships at a local resolution. When combined into fire-scar networks, and incorporated into landscape-scale mapping, fire history studies can also provide powerful interpretive tools for researchers and land managers looking to plan for the future at broad scales (Morgan et al. 2001, 2008, Drever et al. 2006, Heyerdahl et al. 2008b, Keane et al. 2009, Perry et al. 2011, Falk et al. 2011, Hessburg et al. 2013). While information about past forest structure can be helpful in planning and implementing restoration and fuels management plans (e.g. Fulé et al. 1997, Moore et al. 1999, Maxwell et al. 2014), understanding how fire functioned historically as a disturbance process may be the cornerstone of building ecological resilience in the face of global climate change (Turner et al. 1994, Drever et al. 2006, Long 2009, Turner 2010, Perry et al. 2011, Hessburg et al. 2016). In the context of our changing climate and the surprises likely to come, we must manage our forests with a mind towards the processes that have shaped them historically, rather than a by a rigid image of the past.

REFERENCES

Agee, J. 1993. Fire ecology of Pacific Northwest forests. Island Press, Washington, D.C.

Agee, J. 1998. The landscape ecology of western forest fire regimes. Northwest Sci. **72**: 24–34.

Agee, J. 2005. The complex nature of mixed severity fire regimes. *In* Mixed severity fire regimes: ecology and management. *Edited by* L. Lagene, J. Zelnik, S. Cadwallader, and B. Hughes. Washington State University Coop Extension Service/ The Association for Fire Ecology. pp. 1–10.

Agee, J.K., and Skinner, C.N. 2005. Basic principles of forest fuel reduction treatments. For. Ecol. Manage. **211**: 83–96. doi:10.1016/j.foreco.2005.01.034.

Aldrich, S.R., Lafon, C.W., Grissino-Mayer, H.D., and DeWeese, G.G. 2014. Fire history and its relations with land use and climate over three centuries in the central Appalachian Mountains, USA. J. Biogeogr. **41**: 2093–2104. doi:10.1111/jbi.12373.

Allison, T., and Michel, H. 2004. Helping Our Land Heal: A Cultural Perspective on Fire and Forest Restoration. BC Grasslands **Oct**: 7.

Armstrong, Derickson, Maracle, and Young-Ing (*Editors*). 1994. We Get Our Living Like Milk From the Land. Theytus Books, Ltd, Penticton, BC, Canada.

Arno, S.F., and Gruell, G. 1983. Fire History at the Forest-Grassland Ecotone in Southwestern Montana. J. Range Manag. **36**(3): 332–336.

Baker, W.L., and Ehle, D. 2001. Uncertainty in surface-fire history: the case of ponderosa pine forests in the western United States. Can. J. For. Res. **31**(7): 1205–1226. doi:10.1139/cjfr-31-7-1205.

Barrett, S.W., and Arno, S.F. 1982. Indian fires as an ecological influence in the northern Rockies. J. For. **Oct**: 647–651.

Beaty, R.M., and Taylor, A.H.A.H. 2007. Fire disturbance and forest structure in old-growth mixed conifer forests in the northern Sierra Nevada, California. J. Veg. Sci. **18**(6): 879. doi:10.1658/1100-9233(2007)18[879:FDAFSI]2.0.CO;2.

Black, S. 1835. Map of Thompson's River District. Historic Map. Captions by RC Harris. Available from ojs.library.ubc.ca/index.php/bcstudies/article/viewFile/1310/1353 [accessed 1 March 2016].

Boos, D. 1992. On Generalized Score Tests. Am. Stat. **46**: 327–333.

Bowman, D.M.J.S., Balch, J.K., Artaxo, P., Bond, W.J., Carlson, J.M., Cochrane, M. a, D'Antonio, C.M., Defries, R.S., Doyle, J.C., Harrison, S.P., Johnston, F.H., Keeley, J.E., Krawchuk, M. a, Kull, C. a, Marston, J.B., Moritz, M. a, Prentice, I.C., Roos, C.I., Scott, A.C., Swetnam, T.W., van der Werf, G.R., and Pyne, S.J. 2009. Fire in the Earth system. Science (80-.). **324**(5926): 481–4.

doi:10.1126/science.1163886.

Boyd, R. (*Editor*). 1999. Indians, Fire, and the Land in the Pacific Northwest. Oregon State University Press, Corvallis, OR.

Brewer, P., Velasquez, M., Sutherland, E., and Falk, D. 2016. Fire History Analysis and Exploration Software (FHAES) 2.0.2. www.fhaes.org. doi:10.5281/zenodo.34124.

Brown, P., Heyerdahl, E., Kitchen, S., and Weber, M. 2008. Climate effects on historical fires (1630–1900) in Utah. Int. J. Wildl. Fire **17**(1): 28–39. doi:10.1071/WF07023.

Brown, P., Kaufmann, M., and Shepperd, W. 1999. Long-term, landscape patterns of past fire events in a montane ponderosa pine forest of central Colorado. Landsc. Ecol. **14**: 513–532. doi:10.1023/a:1008137005355.

Brown, P.M. 2006. Climate effects on fire regimes and tree recruitment in Black Hills ponderosa pine forests. Ecology **87**(10): 2500–2510. doi:10.1890/0012-9658(2006)87[2500:CEOFRA]2.0.CO;2.

Brown, P.M., and Wu, R. 2005. CLIMATE AND DISTURBANCE FORCING OF EPISODIC TREE RECRUITMENT IN A SOUTHWESTERN PONDEROSA PINE LANDSCAPE. Ecology **86**: 3030–3038. doi:10.1890/05-0034.

Brown, R.T., Agee, J.K., and Franklin, J.F. 2004. Forest Restoration and Fire: Principles in the Context of Place. Conserv. Biol. **18**(4): 903–912. doi:10.1111/j.1523-1739.2004.521_1.x.

Burns, R.M., and Honkala, B.H. (*Editors*). 1990. Silvics of North America 1: Conifers. USDA Forest Service, Washington, D.C.

Carstens, P. 1991. The Queen’s people: a study of hegemony, coercion, and accomodation among the Okanagan of Canada. University of Toronto Press, Toronto.

Cayan, D.R. 1996. Interannual climate variability and snowpack in the western United States. J. Clim. **9**(5): 928–948. doi:10.1175/1520-0442(1996)009<0928:ICVASI>2.0.CO;2.

Chavardes, R., and Daniels, L. 2016. Altered mixed-severity fire regime has homogenised montane forests of Jasper National Park. Int. J. Wildl. Fire **http://dx.** doi:10.1071/WF15048.

Cochrane, J.. 2007. Characteristics of historical forest fires in complex mixed-conifer forests of southeastern British Columbia. MSc Thesis. Department of Geography, The University of British Columbia.

Cochrane, J., and Daniels, L. 2008. Striking a balance : Safe sampling of partial stem cross-sections in British Columbia. BC J. Ecosyst. Manag. **9**(1): 38–46.

Collins, B.M., Everett, R.G., and Stephens, S.L. 2011. Impacts of fire exclusion and recent managed fire on forest structure in old growth Sierra Nevada mixed-conifer forests. Ecosphere **2**(4): Article 51: 1-

14. doi:10.1890/ES11-00026.1.

Cook, E., Meko, D., Stahle, D., Cleaveland, M., Woodhouse, C., and Eakin, C. 2008. North America Summer PDSI Reconstructions, Version 2a. NOAA/NGDC Paleoclimatology Progam, Boulder, CO. Available from https://www.ncdc.noaa.gov/paleo/pdsi.html [accessed 1 February 2016].

Cook, E., Woodhouse, C., Eakin, C., Meko, D., and Stahle, D. 2004. Long-term aridity changes in the western United States. Science (80-.). **306**(5698): 1015–1018.

Cooper, M. 2006. Draft Management Plan for Vaseux-Bighorn National Wildlife Area. Environment Canada. Canadian Wildlife Service, Delta, BC, Canada.

Cooper, M., Sarell, M., Bryan, A., and Chapman, K. 2011. Vaseux – Bighorn National Wildlife Area Management Plan. Environment Canada. Canadian Wildlife Service, Delta, BC, Canada.

Covington, W.W., and Moore, M.M. 1994. Southwestern Ponderosa Forest Structure: Changes since Euro-American Settlement. J. For. (January): 39–47.

D'Arrigo, R., Villalba, R., and Wiles, G. 2001. Tree-ring estimates of Pacific decadal climate variability. Clim. Dyn. **18**: 219–224.

D'Arrigo, R.D., Cook, E., Wilson, R., Allan, R., and Mann, M. 2005. On the variability of ENSO over the past six centuries. Geophys. Res. Lett. **32**: L03711: 1-4.

Dale, V.H., Joyce, L. a., Mcnulty, S., Neilson, R.P., Ayres, M.P., Flannigan, M.D., Hanson, P.J., Irland, L.C., Lugo, A.E., Peterson, C.J., Simberloff, D., Swanson, F.J., Stocks, B.J., and Michael Wotton, B. 2001. Climate Change and Forest Disturbances. Bioscience **51**(9): 723–734. doi:10.1641/0006-3568(2001)051[0723:CCAFD]2.0.CO;2.

Daniels, L.D., Erasmus, H., Forge, B., Greene, G., and Lavallee, S. 2014. Monitoring Fire Intensity and Severity: 2013 Prescribed Burn at the Westside Unit, Vaseux-Bighorn National Wildlife Area. Report to the Canadian Wildlife Service.

Drever, C.R., Peterson, G., Messier, C., Bergeron, Y., and Flannigan, M. 2006. Can forest management based on natural disturbances maintain ecological resilience ? Can. J. For. Res. **36**: 2285–2299. doi:10.1139/X06-132.

Duncan, R. 1989. An evaluation of errors in tree age estimates based on increment cores in Kahikatea (Dacrycarpus dacrydioides). New Zeal. Nat. Sci. **Jan**: 31–37.

ESRI. 2016. ArcGIS Desktop 10.3.1. Environmental Research Systems Institute, Redlands, CA.

Falk, D. a., Miller, C., McKenzie, D., and Black, A.E. 2007. Cross-Scale Analysis of Fire Regimes. Ecosystems **10**(5): 809–823. doi:10.1007/s10021-007-9070-7.

Falk, D., Heyerdahl, E., Brown, P., Farris, C., Fulé, P., McKenzie, D., Swetnam, T., Taylor, A., and Van

Horne, M. 2011. Multi-scale controls of historical forest-fire regimes: new insights from fire-scar networks. Front. Ecol. Environ. **9**(8): 446–454. doi:10.1890/100052.

Franklin, J.F., Spies, T. a, Pelt, R. Van, Carey, A.B., Thornburgh, D. a, Berg, D.R., Lindenmayer, D.B., Harmon, M.E., Keeton, W.S., Shaw, D.C., Bible, K., and Chen, J. 2002. Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. For. Ecol. Manage. **155**(1–3): 399–423. doi:10.1016/S0378-1127(01)00575-8.

Fraser, D. 1967. A Short History and Description of Osoyoos. Historical Account, The Osoyoos Museum and Archives, Osoyoos, BC, Canada. Available from http://www.osoyoosmuseum.ca/index.php/about-us/history-of-osoyoos.html [accessed 11 December 2015].

Fry, D.L., and Stephens, S.L. 2006. Influence of humans and climate on the fire history of a ponderosa pine-mixed conifer forest in the southeastern Klamath Mountains, California. For. Ecol. Manage. **223**(1–3): 428–438. doi:10.1016/j.foreco.2005.12.021.

Fulé, P., Covington, W., and Moore, M. 1997. Determining reference conditions for ecosystem management of southwestern ponderosa pine forests. Ecol. Appl. **7**(3): 895–908.

Fulé, P.Z., Swetnam, T.W., Brown, P.M., Falk, D.A., Peterson, D.L., Allen, C.D., Aplet, G.H., Battaglia, M.A., Binkley, D., Farris, C., Keane, R.E., Margolis, E.Q., Grissino-Mayer, H., Miller, C., Sieg, C.H., Skinner, C., Stephens, S.L., and Taylor, A. 2014. Unsupported inferences of high-severity fire in historical dry forests of the western United States: Response to Williams and Baker. Glob. Ecol. Biogeogr. **23**(7): 825–830. doi:10.1111/geb.12136.

Gedalof, Z., and Smith, D.J. 2001. Interdecadal climate variability and regime-scale shifts in Pacific North America Pre-Instrumental North Pacific Climate. Geophys. Res. Lett. **28**(8): 1515–1518. doi:10.1029/2000GL011779.

Gershunov, A., and Barnett, T. 1998. Interdecadal modultion of ENSO teleconnections. Bull. Am. Meteorol. Soc. **79**: 2715–2726. doi:10.1175/1520-0477(1998)079<2715:imoet>2.0.co;2.

Greene, G. 2011. Historical Fire Regime of the Darkwoods: Quantifying the Past to Plan for the Future. MSc Thesis, Faculty of Forestry, The University of British Columbia.

Grissino-Mayer, H., and Romme, W. 2004. Climatic and human influences on fire regimes of the southern San Juan Mountains, Colorado, USA. Ecology **85**(6): 1708–1724.

Grissino-Mayer, H.D., and Swetnam, T.W. 2000. Century-scale climate forcing of fire regimes in the American Southwest. The Holocene **10**(2): 213–220. doi:10.1191/095968300668451235.

Halofsky, J.E., Donato, D.C., Hibbs, D.E., Campbell, J.L., Cannon, M.D., Fontaine, J.B., Thompson, J.R., Anthony, R.G., Bormann, B.T., Kayes, L.J., Law, B.E., Peterson, D.L., and Spies, T.A. 2011. Mixed-severity fire regimes: lessons and hypotheses from the Klamath-Siskiyou Ecoregion. Ecosphere **2**(4): Article 40: 1-19. doi:10.1890/ES10-00184.1.

Harris, L., and Taylor, A.H. 2015. Topography, Fuels, and Fire Exclusion Drive Fire Severity of the Rim Fire in an Old-Growth Mixed-Conifer Forest, Yosemite National Park, USA. Ecosystems **18**(7): 1192–1208. Springer US. doi:10.1007/s10021-015-9890-9.

Hessburg, P., Reynolds, K., Salter, R., Dickinson, J., Gaines, W., and Harrod, R. 2013. Landscape Evaluation for Restoration Planning on the Okanogan-Wenatchee National Forest, USA. Sustainability **5**(3): 805–840. doi:10.3390/su5030805.

Hessburg, P.F., Agee, J.K., and Franklin, J.F. 2005. Dry forests and wildland fires of the inland Northwest USA: Contrasting the landscape ecology of the pre-settlement and modern eras. For. Ecol. Manage. **211**(1–2): 117–139. doi:10.1016/j.foreco.2005.02.016.

Hessburg, P.F., Salter, R.B., and James, K.M. 2007. Re-examining fire severity relations in pre-management era mixed conifer forests: inferences from landscape patterns of forest structure. Landsc. Ecol. **22**(S1): 5–24. doi:10.1007/s10980-007-9098-2.

Hessburg, P.F., Smith, B.G., and Salter, R.B. 2000. Recent changes (1930s–1990s) in spatial patterns of interior northwest forests, USA. For. Ecol. Manage. **136**(1–3): 53–83. doi:10.1016/S0378-1127(99)00263-7.

Hessburg, P.F., Spies, T.A., Perry, D.A., Skinner, C.N., Taylor, A.H., Brown, P.M., Stephens, S.L., Larson, A.J., Churchill, D.J., Povak, N.A., Singleton, P.H., McComb, B., Zielinski, W.J., Collins, B.M., Salter, R.B., Keane, J.J., Franklin, J.F., and Riegel, G. 2016. Tamm Review: Management of mixed-severity fire regime forests in Oregon, Washington, and Northern California. For. Ecol. Manage. **366**: 221–250. Elsevier B.V. doi:10.1016/j.foreco.2016.01.034.

Hessl, A., McKenzie, D., and Schellhaas, R. 2004. Drought and Pacific Decadal Oscillation linked to fire occurrence in the inland Pacific Northwest. Ecol. Appl. **14**(2): 425–442.

Heyerdahl, E., Brubaker, L., and Agee, J. 2002. Annual and decadal climate forcing of historical fire regimes in the interior Pacific Northwest, USA. The Holocene **5**: 597–604.

Heyerdahl, E., Lertzman, K., Karpuk, S., and Wong, C.M. 2007. Local-scale controls of a low-severity fire regime (1750-1950), southern British Columbia. Ecoscience **14**(1): 40–47. doi:10.2980/1195-6860(2007)14[40:LCOALF]2.0.CO;2.

Heyerdahl, E., McKenzie, D., Daniels, L., Hessl, A., Littell, J., and Mantua, N. 2008a. Climate drivers of regionally synchronous fires in the inland Northwest (1651–1900). Int. J. Wildl. Fire **17**(1): 40–49.

doi:10.1071/WF07024.

Heyerdahl, E., Morgan, P., and Riser, J. 2008b. Multi-season climate synchronized historical fires in dry forests (1650-1900), northern Rockies, U.S.A. Ecology **89**(3): 705–16.

Heyerdahl, E.E.K., Brubaker, L.L.B., and Agee, J.J.K. 2001. SPATIAL CONTROLS OF HISTORICAL FIRE REGIMES: A MULTISCALE EXAMPLE FROM THE INTERIOR WEST, USA. Ecology **82**(3): 660–678. doi:10.1890/0012-9658(2001)082[0660:SCOHFR]2.0.CO;2.

Heyerdahl, E.K., Lertzman, K., and Wong, C.M. 2012. Mixed-severity fire regimes in dry forests of southern interior British Columbia, Canada. Can. J. For. Res. **42**: 88–98. doi:10.1139/x11-160.

Heyerdahl, E.K., Miller, R.F., and Parsons, R.A. 2006. History of fire and Douglas-fir establishment in a savanna and sagebrush-grassland mosaic, southwestern Montana, USA. For. Ecol. Manage. **230**(1–3): 107–118. doi:10.1016/j.foreco.2006.04.024.

Hoerling, M., Kumar, A., and Zhong, M. 1997. El Nino, La Nina, and the nonlinearity of their teleconnections. J. Clim. **10**: 1769–1786.

Van Horne, M.L., and Fule, P.Z. 2006. Comparing methods of reconstructing fire history using fire scars in a southerwestern United States ponderosa pine forest. Can. J. For. Res. **36**(4): 855–867.

Johnson, E.A., Miyanishi, K., and Bridge, S.R.J. 2001. Wildfire regime in the boreal forest and the idea of suppression and fuel buildup. Conserv. Biol. **15**(6): 1554–1557. doi:10.1046/j.1523-1739.2001.01005.x.

Johnson, E., and Miyanishi, K. (*Editors*). 2001. Forest Fires: Behavior and Ecological Effects. Academic Press, San Diego, CA.

Johnson Gottesfeld, L. 1994. Aboriginal Burning for Vegetation Management in Northwest British Columbia. Hum. Ecol. **22**(2): 171–188.

Keane, R.E., Hessburg, P.F., Landres, P.B., and Swanson, F.J. 2009. The use of historical range and variability (HRV) in landscape management. For. Ecol. Manage. **258**(7): 1025–1037. doi:10.1016/j.foreco.2009.05.035.

Keeley, J. 2002. Native American impacts on fire regimes of the California coastal ranges. J. Biogeogr. **29**: 303–320.

Kiladis, G., and Diaz, H. 1989. Global Climate Anomalies Associated With Extremes of Southern Oscillation. J. Clim. **2**: 1069–1090.

Kitchen, S.G. 2016. Climate and human influences on historical fire regimes (AD 1400-1900) in the eastern Great Basin (USA). The Holocene **26**(3): 397–407. doi:10.1177/0959683615609751.

Kitzberger, T., Brown, P.M., Heyerdahl, E.K., Swetnam, T.W., and Veblen, T.T. 2007. Contingent Pacific-

Atlantic Ocean influence on multicentury wildfire synchrony over western North America. Proc. Natl. Acad. Sci. U. S. A. **104**(2): 543–548. doi:10.1073/pnas.0606078104.

Klenner, W., Walton, R., Arsenault, A., and Kremsater, L. 2008. Dry forests in the Southern Interior of British Columbia: Historic disturbances and implications for restoration and management. For. Ecol. Manage. **256**(10): 1711–1722. doi:10.1016/j.foreco.2008.02.047.

Köppen, W. 1936. Das geographische System der Klimate. Handb. der Klimatologie (c): 7–30. doi:10.3354/cr01204.

Korb, J.E., Fulé, P.Z., and Wu, R. 2013. Forest Ecology and Management Variability of warm / dry mixed conifer forests in southwestern Colorado , USA : Implications for ecological restoration. For. Ecol. Manage. **304**: 182–191. Elsevier B.V. doi:10.1016/j.foreco.2013.04.028.

Landres, P., Morgan, P., and Swanson, F. 1999. Overview of the use of natural variability concepts in managing ecological systems. Ecol. Appl. **9**(November): 1179–1188.

Larsson, L.-Å., and Larsson, P.O. 2006. Cybis 78. Cybis Elektronik & Data AB, Saltsjöbaden, Sweden.

Lepofsky, D., and Lertzman, K. 2008. Documenting ancient plant management in the northwest of North America. Botany **86**: 129–145. doi:10.1139/B07-094.

Lertzman, K., Fall, J., and Dorner, B. 1998. Three kinds of heterogeneity in fire regimes: at the crossroads of fire history and landscape ecology. Northwest Sci. **72**: 4–23.

Lessard, V.C., Drummer, T.D., and Reed, D.D. 2002. Precision of density estimates from fixed-radius plots compared to n-tree distance sampling. For. Sci. **48**(1): 1–6.

Long, J.N. 2009. Emulating natural disturbance regimes as a basis for forest management: A North American view. For. Ecol. Manage. **257**(9): 1868–1873. doi:10.1016/j.foreco.2008.12.019.

Macias Fauria, M., Michaletz, S.T., and Johnson, E. a. 2011. Predicting climate change effects on wildfires requires linking processes across scales. Wiley Interdiscip. Rev. Clim. Chang. **2**(1): 99–112. doi:10.1002/wcc.92.

MacKenzie, W. 2012. Biogeoclimatic Ecosystem Classification Program of British Columbia. B.C. Min. For., Lands, and Nat. Res. Ops, Smithers, BC. Available from www.for.gov.bc.ca/hre/becweb/resources/codes-standards/standards-becdb.html [accessed 3 March 2016].

Mantua, N.J., Hare, S.R., Zhang, Y., Wallace, J.M., and Francis, R.C. 1997. A Pacific Interdecadal Climate Oscillation with Impacts on Salmon Production. Bull. Am. Meteorol. Soc. **78**(6): 1069–1079.

Marcoux, H.H.M., Gergel, S.E., and Daniels, L.D. 2013. Mixed-severity fire regimes: How well are they represented by existing fire-regime classification systems? Can. J. For. Res. **668**(November 2012):

658–668. doi:10.1139/cjfr-2012-0449.

Marcoux, H.M., Daniels, L.D., Gergel, S.E., Da Silva, E., Gedalof, Z., and Hessburg, P.F. 2015. Differentiating mixed- and high-severity fire regimes in mixed-conifer forests of the Canadian Cordillera. For. Ecol. Manage. **341**: 45–58. Elsevier B.V. doi:10.1016/j.foreco.2014.12.027.

Margolis, E.Q., and Balmat, J. 2009. Fire history and fire–climate relationships along a fire regime gradient in the Santa Fe Municipal Watershed, NM, USA. For. Ecol. Manage. **258**(11): 2416–2430. doi:10.1016/j.foreco.2009.08.019.

Mast, J.N., and Veblen, T.T. 1999. Tree spatial patterns and stand development along the pine-grassland ecotone in the Colorado Front Range. Can. J. For. Res. **29**(5): 575–584. doi:10.1139/cjfr-29-5-575.

Mast, J.N., Veblen, T.T., and Linhart, Y.B. 1998. Disturbance and climatic influences on age structure of ponderosa pine at the pine/grassland ecotone, Colorado Front Range. J. Biogeogr. **25**: 743–755. doi:10.1046/j.1365-2699.1998.2540743.x.

Maxwell, R., Taylor, A., Skinner, C., Safford, H., Isaacs, R., Airey, C., and Young, A. 2014. Landscape-scale modeling of reference period forest conditions and fire behavior on heavily logged lands. Ecosphere **5**(3): Article 32: 1–28. doi:10.1890/ES13-00294.1.

McCabe, G.J., Ault, T.R., Cook, B.I., Betancourt, J.L., and Schwartz, M.D. 2012. Influences of the El Niño Southern Oscillation and the Pacific Decadal Oscillation on the timing of the North American spring. Int. J. Climatol. **32**(15): 2301–2310. doi:10.1002/joc.3400.

Mccabe, G.J., and Dettinger, M.D. 1999. Decadal Variations in the Strength of Enso Teleconnections With Precipitation in the Western United States. Int. J. Climatol. **19**: 1399–1410.

Meidinger, D. V, and Pojar, J. 1991. Special Report Series 6: Ecosystems of British Columbia. BC Ministry of Forests, Victoria, BC, Canada.

Mekis, É., and Vincent, L. 2011. An overview of the second generation adjusted daily precipitation dataset for trend analysis in Canada. Atmosphere-Ocean **49**: 163–177.

Millar, C.I., Stephenson, N.L., and Stephens, S.L. 2007. Climate change and forests of the future: managing in the face of uncertainty. Ecol. Appl. **17**(8): 2145–51.

Moore, M.M., Covington, W.W., and Fule, P.Z. 1999. Reference Conditions and Ecological Restoration : A Southwestern Ponderosa Pine Perspective. Ecol. Appl. **9**(4): 1266–1277.

Morgan, P., Heyerdahl, E., and Gibson, C. 2008. Multi-season climate synchronized forest fires throughout the 20th century, northern Rockies, U.S.A. Ecology **89**(3): 717–28.

Morgan, P., Swetnam, T.W.T., Hardy, C.C., Rollins, M.G., and Long, D.G. 2001. Mapping fire regimes across time and space: Understanding coarse and fine-scale fire patterns. Int. J. Wildl. Fire **10**: 329–

342. doi:10.1071/wf01032.

Mottishaw, J., and Albert, C. 2013. West Vaseux 2013 Prescribed Fire Burn Plan. BC Wildfire Service. Penticton Fire Zone, Penticton, BC, Canada.

Nash, C.H., and Johnson, E.A. 1996. Synoptic climatology of lightning-caused forest fires in subalpine and boreal forests. Can. J. For. Res. **26**: 1859–1874. doi:10.1139/x26-211.

Odion, D.C., Hanson, C.T., Arsenault, A., Baker, W.L., DellaSala, D.A., Hutto, R.L., Klenner, W., Moritz, M.A., Sherriff, R.L., Veblen, T.T., and Williams, M.A. 2014. Examining historical and current mixed-severity fire regimes in ponderosa pine and mixed-conifer forests of western North America. PLoS One **9**(2): e87852: 1-14. doi:10.1371/journal.pone.0087852.

Odion, D.C., Hanson, C.T., Baker, W.L., DellaSala, D.A., and Williams, M.A. 2016. Areas of agreement and disagreement regarding ponderosa pine and mixed conifer forest fire regimes: A dialogue with stevens et al. PLoS One **11**(5): 1–6. doi:10.1371/journal.pone.0154579.

Okanagan Nation Alliance. 2010a. The Syilx People. Available from http://www.syilx.org/who-we-are/the-syilx-people/ [accessed 11 December 2015].

Okanagan Nation Alliance. 2010b. Okanagan Nation Traditional Territory. Available from http://www.syilx.org/who-we-are/organization-information/okanagan-nation-territory/ [accessed 11 December 2015].

Oliver, C.D., and Larson, B.C. 1996. Stand Dynamics. *In* Update Edi. John Wiley and Sons, Inc, New York, NY.

Palmer, W. 1965. Research Paper No. 45: Meteorological Drought. US Dept. of Commerce Weather Bureau, Washington, D.C.

Perry, D.A., Riegel, G., McComb, B., Spies, T.A., Hessburg, P.F., Stephens, S.L., Taylor, A.H., Franklin, J.F., and Skinner, C.N. 2011. The ecology of mixed severity fire regimes in Washington, Oregon, and Northern California. For. Ecol. Manage. **262**(5): 703–717. Elsevier B.V. doi:10.1016/j.foreco.2011.05.004.

Rasmusson, M., and Wallace, J. 2013. Meterological Aspects of the El Niño / Southern Oscillation. Science (80-.). **222**(4629): 1195–1202.

Redmond, K.T., and Koch, R.W. 1991. Surface Climate and Streamflow Variability in the Western United States and Their Relationship to Large-Scale Circulation Indices. Water Resour. Res. **27**(9): 2381–2399. doi:10.1029/91WR00690.

Sanford, B. 2002. McCulloch’s Wonder: The Story of the Kettle Valley Railway. *In* 25th Anniv. Whitecap Books, North Vancouver, BC.

Schoennagel, T., Sherriff, R.L., and Veblen, T.T. 2011. Fire history and tree recruitment in the Colorado Front Range upper montane zone: implications for forest restoration. Ecol. Appl. **21**(6): 2210–22.

Schoennagel, T., Veblen, T.T., and Romme, W.H. 2004. The Interaction of Fire, Fuels, and Climate across Rocky Mountain Forests. Bioscience **54**(7): 661. doi:10.1641/0006-3568(2004)054[0661:TIOFFA]2.0.CO;2.

Scholl, A.E., and Taylor, A.H. 2010. Fire regimes, forest change, and self-organization in an old-growth mixed-conifer forest, Yosemite National Park, USA. Ecol. Appl. **20**(2): 362–380. doi:10.1890/08-2324.1.

Sherriff, R.L., and Veblen, T.T. 2007. A Spatially-Explicit Reconstruction of Historical Fire Occurrence in the Ponderosa Pine Zone of the Colorado Front Range. Ecosystems **10**(2): 311–323. doi:10.1007/s10021-007-9022-2.

Sibold, J.S., Veblen, T.T., and Gonzalez, M.E. 2006. Spatial and temporal variation in historic fire regimes in subalpine forests across the Colorado Front Range in Rocky Mountain National Park, Colorado, USA. J. Biogeogr. **33**(4): 631–647. doi:10.1111/j.1365-2699.2005.01404.x.

Simmons, E. 2012. British Columbia's Indigenous People: The Burning Issue. J. Ecosyst. Manag. **13**(2): 1–2.

Stahle, D.W., Cleaveland, M.K., Therrell, M.D., Gay, D. a., D'Arrigo, R.D., Krusic, P.J., Cook, E.R., Allan, R.J., Cole, J.E., Dunbar, R.B., Moore, M.D., Stokes, M. a., Burns, B.T., Villanueva-Diaz, J., and Thompson, L.G. 1998. Experimental Dendroclimatic Reconstruction of the Southern Oscillation. Bull. Am. Meteorol. Soc. **79**(10): 2137–2152. doi:10.1175/1520-0477(1998)079<2137:EDROTS>2.0.CO;2.

Stevens, J.T., Safford, H.D., North, M.P., Fried, J.S., Gray, A.N., Brown, P.M., Dolanc, C.R., Dobrowski, S.Z., Falk, D.A., Farris, C.A., Franklin, J.F., Fulé, P.Z., Keala Hagmann, R., Knapp, E.E., Miller, J.D., Smith, D.F., Swetnam, T.W., and Taylor, A.H. 2016. Average stand age from forest inventory plots does not describe historical fire regimes in ponderosa pine and mixed-conifer forests of western North America. PLoS One **11**(5): e0147688: 1-20. doi:10.1371/journal.pone.0147688.

Stokes, M., and Smiley, T. 1996. An introduction to tree-ring dating. University of Arizona Press, Chicago, IL.

Swetnam, T., Allen, C., and Betancourt, J. 1999. Applied historical ecology: using the past to manage for the future. Ecol. Appl. **9**(November): 1189–1206.

Swetnam, T., and Baisan, C. 1996. Historical fire regime patterns in the southwestern United States since AD 1700. *In* Fire Effects in Southwestern Forests: Proceedings of the 2nd La Mesa Fire Symposium.

Edited by C. Allen. USDA Forest Service, Rocky Mountain Research Station, General Technical Report RM-GTR-286. pp. 11–32.

Swetnam, T., and Betancourt, J. 1990. Fire-southern oscillation relations in the southwestern United States. Science (80-.). **249**(4972): 1017–1020.

Swetnam, T., Falk, D., Hessl, A., and Farris, C. 2011. Reconstructing Landscape Pattern of Historical Fires and Fire Regimes. *In* The Landscape Ecology of Fire. *Edited by* D. McKenzie, C. Miller, and D. Falk. Springer, New York, NY. pp. 165–192.

Taylor, A., and Skinner, C. 2003. Spatial patterns and controls on historical fire regimes and forest structure in the Klamath Mountains. Ecol. Appl. **13**(3): 704–719.

Taylor, A.H. 2010. Fire disturbance and forest structure in an old-growth Pinus ponderosa forest, southern Cascades, USA. J. Veg. Sci. **21**(3): 561–572. doi:10.1111/j.1654-1103.2009.01164.x.

Taylor, A.H., Vandervlugt, A.M., Maxwell, R.S., Beaty, R.M., Airey, C., and Skinner, C.N. 2014. Changes in forest structure, fuels and potential fire behaviour since 1873 in the Lake Tahoe Basin, USA. Appl. Veg. Sci. **17**(1): 17–31. doi:10.1111/avsc.12049.

The SAS Institute. 2014. SAS 9.4. The SAS Institute, Cary, NC.

Thomson, D. 1978. Opportunity Lost: A History of Okanagan Indian Reserves in the Colonial Period. *In* Forty-Second Annual Report of the Okanagan Historical Society1. *Edited by* D. Thomson. Wayside Press LTD, Vernon, BC. pp. 43–52.

Thomson, D. 1994. The Response of the Okanagan Indians to European Settlement. B. C. Stud. **101**(Spring): 96–108.

Thomson, D.D. 1969. A History of the Okanagan: Indians and Whites in the Settlement Era, 1860-1920. PhD Dissertation. Department of History, The University of British Columbia.

Turner, M. 2010. Disturbance and landscape dynamics in a changing world. Ecology **91**(March): 2833–2849. doi:doi:10.1890/10-0097.1.

Turner, M., Hargrove, W., Gardner, R., and Romme, W. 1994. Effects of Fire on Landscape Heterogeneity in Yellowstone National Park , Wyoming. J. Veg. Sci. **5**(5): 731–742.

Turner, M., Romme, W., and Tinker, D. 2003. Surprises and lessons from the 1988 Yellowstone fires. Front. Ecol. Environ. **1**(7): 351–358.

Turner, N.J. 1999. Time to burn: Traditional use of fire to enhance resource production by aboriginal peoples in British Columbia. *In* Indians, fire and the land in the Pacific Northwest. *Edited by* R. Boyd. Oregon State University Press, Corvallis, OR. pp. 185–218.

Union of British Columbia Indian Chiefs. 2016. Historical Timeline: From 1700s to the Present. Available from http://www.ubcic.bc.ca/timeline [accessed 11 December 2015].

Veblen, T., Kitzberger, T., and Donnegan, J. 2000. Climatic and human influences on fire regimes in ponderosa pine forests in the Colorado Front Range. Ecol. Appl. **10**(4): 1178–1195.

Vincent, L., Zhang, X., Bonasal, B., and Hogg, W. 2002. Homogenization of daily temperatures over Canada. J. Clim. **15**: 1322–1334.

van Wagtendonk, J.W., and Cayan, D. 2008. Temporal and Spatial Distribution of Lightning Strikes in California in Relation to Large-Scale Weather Patterns. Fire Ecol. **4**(1): 34–55.

Wang, T., Hamann, A., Spittlehouse, D.L., and Murdock, T. 2012. ClimateBC - High-Resolution Spatial Climate Data for Western North America. J. Appl. Meteorol. Climatol. **51**: 16–29.

Watson, E., and Luckman, B. 2001. The development of a moisture-stressed tree-ring chronology network for the southern Canadian Cordillera. Tree-Ring Res. **57**(2): 149–168.

Watson, E., and Luckman, B. 2004. Tree-ring based reconstructions of precipitation for the southern Canadian Cordillera. Clim. Change **65**: 209–241.

Westerling, a L., Hidalgo, H.G., Cayan, D.R., and Swetnam, T.W. 2006. Warming and earlier spring increase western U.S. forest wildfire activity. Science (80-.). **313**(5789): 940–3. doi:10.1126/science.1128834.

White, A. 1985. Presettlement regeneration patterns in a southwestern ponderosa pine stand. Ecology **66**(2): 589–594.

Williams, M., and Baker, W. 2012. Spatially extensive reconstructions show variable severity fire and heterogeneous structure in historical western United States dry forests. Glob. Ecol. Biogeogr. **21**: 1042–1052. doi:10.1111/j.1466-8238.2011.00750.x.

Wright, C., and Agee, J. 2004. Fire and vegetation history in the eastern Cascade Mountains, Washington. Ecol. Appl. **14**(2): 443–459.

APPENDIX A: FOREST STRUCTURE SUMMARY

Plot No.	RELATIVE ABUNDANCE (%)		DENSITY (tph)					DBH (cm)	Age (yrs)
	Pine	**Fir**	**Pre-Thinning**	**Post-Thinning**	**Live Pine**	**Live Fir**	**Snags**		
2	60.0%	40.0%	379	379	227	151	0	11.5 ± 5.7	52 ± 9
4	45.5%	54.5%	59	59	27	32	0	48.1 ± 22.2	99 ± 33
6	100.0%	0.0%	389	389	389	0	0	16.3 ± 8.8	72 ± 23
8	100.0%	0.0%	37	37	37	0	0	25.5 ± 11.3	54 ± 25
10	100.0%	0.0%	91	83	83	0	0	25.0 ± 12.6	82 ± 38
12	100.0%	0.0%	31	31	29	0	2	35.6 ± 14.7	98 ± 58
14	100.0%	0.0%	88	88	88	0	0	18.9 ± 7.3	50 ± 8
16	84.6%	15.4%	43	43	36	7	0	21.1 ± 10.7	70 ± 65
18	91.7%	8.3%	37	37	32	3	3	22.3 ± 13.3	82 ± 44
20	100.0%	0.0%	28	28	28	0	0	28.3 ± 16.2	64 ± 27
22	66.7%	33.3%	41	41	25	13	3	23.7 ± 14.0	96 ± 88
24	23.1%	76.9%	9	9	2	7	0	48.3 ± 16.7	96 ± 33
28	63.6%	36.4%	15	15	9	5	0	55.4 ± 14.9	128 ± 59
30	16.7%	83.3%	105	105	17	87	0	12.8 ± 9.8	37 ± 12
32	10.0%	90.0%	569	569	57	512	0	16.1 ± 13.5	59 ± 46
34	90.9%	9.1%	292	292	265	27	0	15.8 ± 9.6	67 ± 13
38	18.2%	81.8%	105	105	19	86	0	21.3 ± 9.6	50 ± 11
40	50.0%	50.0%	64	64	29	29	6	16.9 ± 8.4	42 ± 14
44	0.0%	100.0%	1990	1368	0	1244	124	23.8 ± 6.1	128 ± 7
46	54.5%	45.5%	88	88	48	40	0	38.0 ± 17.7	104 ± 72
48	0.0%	100.0%	2727	2727	0	2479	248	14.6 ± 4.3	75 ± 2
50	81.8%	18.2%	159	159	130	29	0	16.9 ± 17.1	57 ± 55
52	16.7%	83.3%	916	259	40	199	20	25.0 ± 4.9	124 ± 3
54	58.8%	41.2%	75	75	42	29	4	27.5 ± 19.0	69 ± 42
58	70.0%	30.0%	702	338	182	78	78	20.2 ± 7.4	80 ± 24
60	0.0%	100.0%	639	639	0	639	0	12.1 ± 6.3	31 ± 4
61	0.0%	100.0%	2212	2212	0	2212	0	10.3 ± 2.9	40 ± 2
63	100.0%	0.0%	389	389	354	0	35	26.6 ± 20.0	138 ± 75
65	90.0%	10.0%	426	213	192	21	0	31.4 ± 11.1	117 ± 27
67	83.3%	16.7%	492	492	379	76	38	23.0 ± 14.7	94 ± 27
69	63.6%	36.4%	366	144	92	52	0	29.2 ± 9.0	113 ± 19
73	92.3%	7.7%	255	166	153	13	0	28.4 ± 10.8	128 ± 21
75	70.0%	30.0%	190	134	78	34	22	36.2 ± 5.4	148 ± 41
77	100.0%	0.0%	587	196	196	0	0	30.6 ± 10.1	91 ± 8
79	81.8%	18.2%	169	93	76	17	0	32.2 ± 8.5	129 ± 8
81	100.0%	0.0%	52	47	43	0	4	24.4 ± 9.6	70 ± 13
83	63.6%	36.4%	193	93	50	29	14	35.2 ± 12.1	118 ± 10
86	50.0%	50.0%	138	138	69	69	0	18.6 ± 13.7	62 ± 52
88	100.0%	0.0%	123	59	59	0	0	44.0 ± 10.6	116 ± 39
90	70.0%	30.0%	35	35	24	10	0	40.5 ± 15.5	131 ± 45
91	30.0%	70.0%	17	15	5	11	0	48.5 ± 26.1	131 ± 64
94	90.0%	10.0%	18	18	16	2	0	32.6 ± 20.2	73 ± 34
95	70.0%	30.0%	115	115	80	34	0	20.4 ± 16.0	54 ± 39
COMPOSITE	**30.9%**	**69.1%**	**359**	**293**	**86**	**192**	**14**	**26.8 ± 16.5**	**86 ± 48**

Appendix A: Forest structure summary by plot. Pre-thinning density incorporated live trees, snags, and stumps generated by recent thinning in portions of the study area. Diameter at breast height (DBH) taken at 1.3m.