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Fire History near Cranbrook, British Columbia

Historical reconstruction using tree-ring evidence

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Abstract

In this study, I used dendrochronology to create high-resolution annually-resolved fire chronologies for two sites (CRN2 and CRN4) located near Cranbrook, BC. The CRN2 site included eight fires over 252 years, with a mean fire interval of 34.1 years and a time since last fire of 56 years. The CRN4 site included 13 fires over 269 years, with a mean fire interval of 19.7 years and a time since last fire of 130 years. Low-severity fires have burned through both sites in 1718 and 1869, and fire intervals are consistent with other regional studies. Other fires identified in this study also burned in the Cranbrook area in 1665, 1718, 1751, 1802, 1831, 1869 and 1910. The 1910 fire is clear at CRN2, and appears as a stand replacing fire in CRN4. These chronologies reinforce the regional fire history knowledge and will be used to validate paleoecological work done in the neighbouring lakes. Combining dendrochronological and paleoecological data allows the creation of fire chronologies going back thousands of years. This study contributes to knowledge of historical fire regimes needed to understand the effects of climate change and fire suppression on the landscape, both important for future land management decisions.

Keywords: fire history, dendrochronology, paleoecology, fire chronology, fire management, western larch.

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Introduction

Fire plays an important role in changing the composition and structure of forest ecosystems in western North America (Gedalof et al. 2005), including British Columbia (Wong et al. 2004). In many forests, fire suppression over the last century has contributed to an important accumulation of fuels that can greatly influence both frequency and intensity of fires (Gedalof et al. 2005; Daniels et al. 2011; Cumming 2005). Moreover, climate change is expected to increase overall fire activity and to lengthen the fire season in temperate and boreal regions (Flannigan et al. 2009). Nevertheless, our understanding of even current forest disturbance regimes is elementary and disparate among disturbance types, making projections into the future under warmer climate extremely difficult (Haughian et al. 2012). Reconstructing past fire history is therefore needed to better understand natural disturbance patterns and the influence that both human actions and climate have and will have on our ecosystems. Acquiring this knowledge is essential to make educated decisions about future forest and fire management.

Two complementary techniques for reconstructing fire history over a range of time scales are dendrochronology and paleoecology. Dendrochronology is a method comparing the patterns of wide and narrow rings to establish the exact year in which each ring was formed (Fritts 1976). Crossdating, the most important principle of dendrochronology, is the procedure of matching ring patterns among trees and wood fragments in a given area (Fritts 1976). It allows the dating of trees by analyzing patterns of growth rings. Scars caused by fire, insects, and abrasion as well as periods of stress and release can also be identified and accurately dated. This technique has the advantage of being accurate at an annual level, and precise enough to identify the season in which events occurred. In British Columbia, dendrochronology has been used to construct fire history records of more than 400 years for several locations (Daniels et al. 2007; Da Silva 2009; Marcoux 2013). Although accurate, fire reconstructions using dendrochronology are limited by the lifespan and decay rates of trees.

Paleoecology uses charcoal and pollen found in lake sediments to recreate a timeline for both fire and plant species history, and allows analysis of links between historical disturbances and climate over millenia. Paleoecological timelines can be verified using tephrochronology, which uses layers of volcanic ash deposited during past fire events to create a coarse historical framework going back thousands of years. By carbon-dating charcoal from lake sediments, it is possible to add to the tephrochronologic data and reconstruct past forest fire activity at a fairly high resolution of decades as far back as 10,000 years (Courtney Mustaphi 2013a). Local fire events can be distinguished from regional ones as macroscopic charcoal is predominantly found close to fires (Courtney Mustaphi 2013a). This technique is particularly interesting for understanding historic fire regimes as the records can pre-date the influences of fire exclusion and other anthropogenic activities. These two techniques complement each other and can be effectively combined in order to create long-term fire chronologies. Dendrochronology provides very high resolution over the last few centuries, and can be used to calibrate fire dates inferred from lake sediments (Higuera et al. 2011); paleoecology gives a longer-term perspective. Dendrochronology informs us on stand dynamics and local climatic variability (Fritts 1976), and paleoecology allows the inference of long-term patterns; using a combination of these techniques thus helps us understand climate-fire interactions.

This project is part of a larger study on the historic climate-fire-vegetation interactions of the Kootenay Region of British Columbia, conducted by collaborators at the University of British Columbia, Carleton University, and Brock University. The goal is to better understand the implications of climate change and fire suppression on dry forests. My objective was the construction of annually-resolved historic fire chronologies for two lakes located south of Cranbrook, British Columbia. Using dendrochronology, the fire history of the last c. 350 years was reconstructed from cambial scars embedded in long-lived western larch trees. A detailed description of this dendrochronological analysis is reported in this essay.

Ultimately, the resulting fire chronologies will be used to calibrate the paleoecological records from the lake sediments currently taking place.

Study Area

The two study sites (CRN4 and CRN2) are located south of the city of Cranbrook, BC, near the sites in the Joseph and Gold Creek watersheds where fire history was studied by Da Silva (2009) and Marcoux (2013; Marcoux et al. 2013) (Fig. 1, Table 1). Each site is a forested surrounding a shallow lake with little inflow and outflow. The lake sediments contain only macroscopic charcoal from fires that burned in the immediate surroundings (Courtney Mustaphi 2013a).

The sites are situated in the low to mid-elevations of the Rocky Mountain Trench, where annual precipitation averages 398.6 mm with 69% as rainfall (Environment Canada 2014). In July and August, temperatures range from 9.5 to 25.9^{o}C, and precipitation is as low as 36.6 and 26.1 mm, respectively (Environment Canada 2014). The two sites are located approximately 16 km apart.

CRN4 is a dry site dominated by Douglas-fir (*Pseudotsuga menziesii*) with minor components of western larch (*Larix occidentalis*). It is located in the Dry Mild Interior Douglas-fir (IDFdm) Biogeoclimatic (BEC) subzone (Hope et al. 1991A). It is close to the city of Cranbrook, and local historical records show that a steam-powered sawmill was located close to the lake in the early 20th century (Courtney Mustaphi 2013b). CRN2 is a mesic site dominated by lodgepole pine (*Pinus contorta*) with minor components of western larch. It is located in the Dry Cool Montane Spruce (MSdk) BEC subzone (Hope et al. 1991B).

Table 1. Description of location, topography, BEC zone and plot size and shape for CRN2 and CRN4 plots. Elevation was measured as meters above sea level (m.a.s.l.).

	CRN2	CRN4
Latitude	49^{o} 22’ 40.28” N	49^{o} 28’ 14.43” N
Longitude	115^{o} 35’ 52.17” W	115^{o} 46’ 23.40” W
Elevation (m.a.s.l.)	1246	1082
Slope angle (^{o})	12	20
Slope aspect	11	157
Land topography	Valley Bottom	Lower Slope

BEC zone	Montane spruce	Interior Douglas-fir
Plot size and shape	56.4 m radius	200 m x 50 m

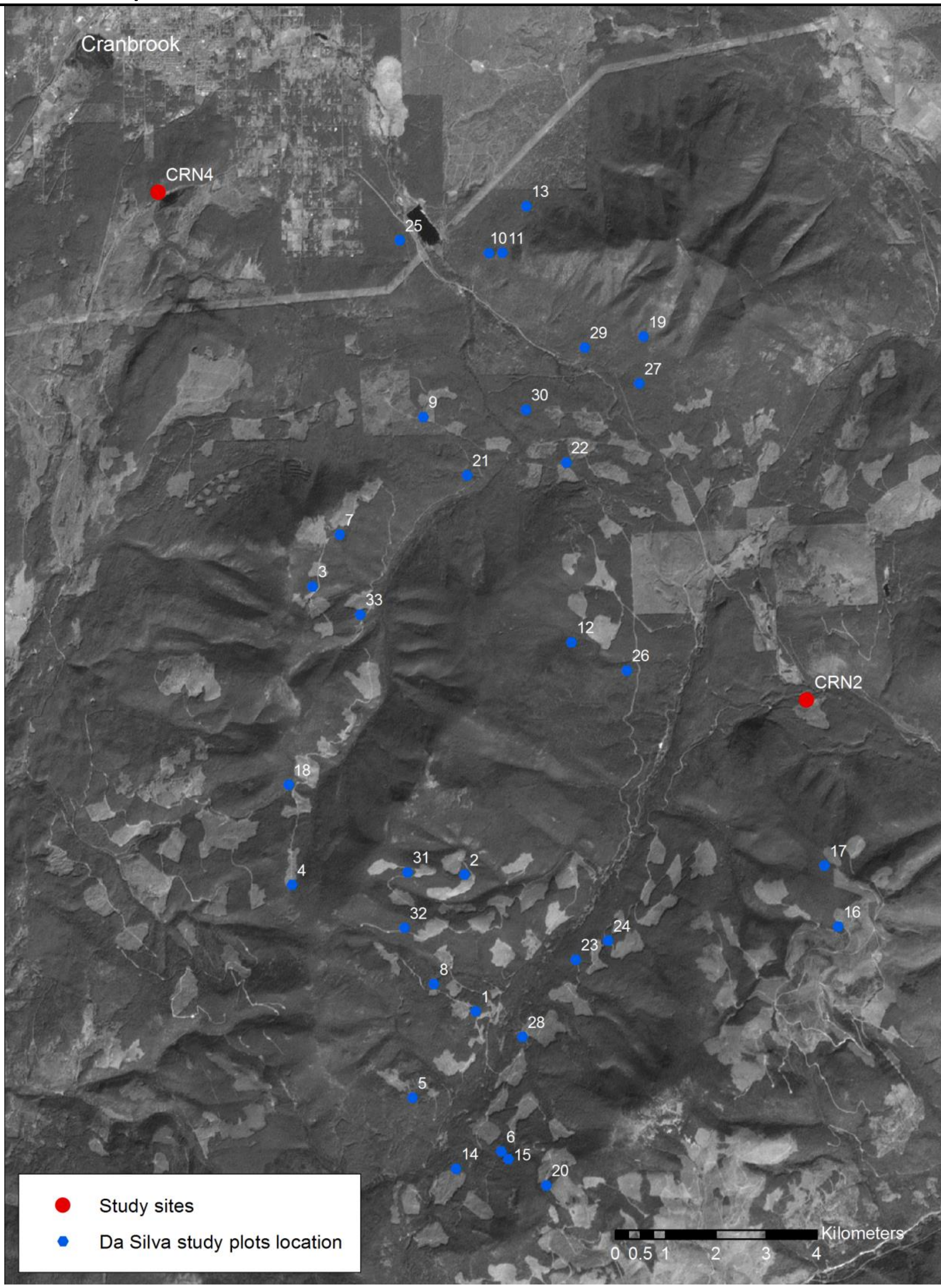

Figure 1. Location of CRN study sites relative to Cranbrook and the Da Silva (2009) study plots in the Joseph and Gold Creek watersheds.

Methods

The forests surrounding the two lakes were searched to locate all trees, snags, logs or cut stumps with fire scars (hereafter "fire-scarred trees"). Fire scars were distinguished from scars caused by other disturbances using scar morphology and the presence of charcoal. Areas with high fire-scarred tree density were selected, and one hectare plots were established. The plots were either circular (CRN2) or rectangular (CRN4) to ensure ten fire-scarred trees were sampled (Fig. 2 and 3). Ten fire-scarred western larch trees were sampled on each site by cutting a partial or full cross-sectional disk from each fire-scarred tree. The CRN2 site contained five snags, four stumps and one log and CRN4 only contained stumps. As well, 20 dominant trees were cored within a 56.4m radius (1 ha) circular plot. The analysis of the cores was completed by collaborators at Carleton University to determine stand age.

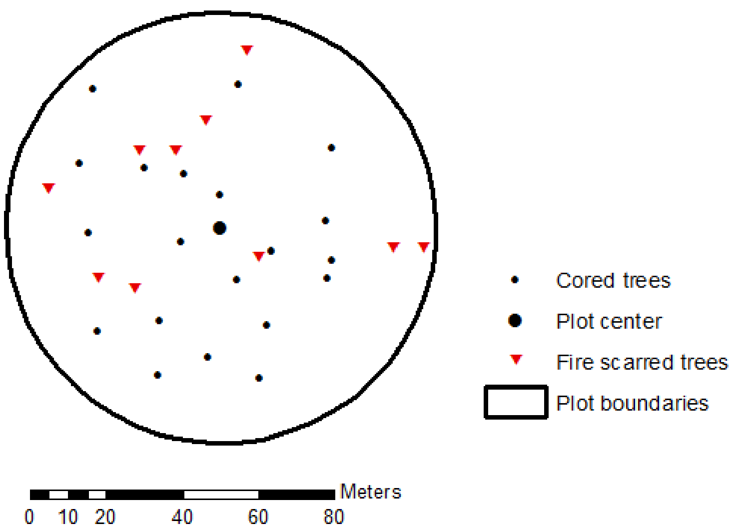

Figure 2. Layout of circular plot at site CRN2 and location of 10 fire-scarred trees and 20 canopy-dominant trees relative to plot centre.

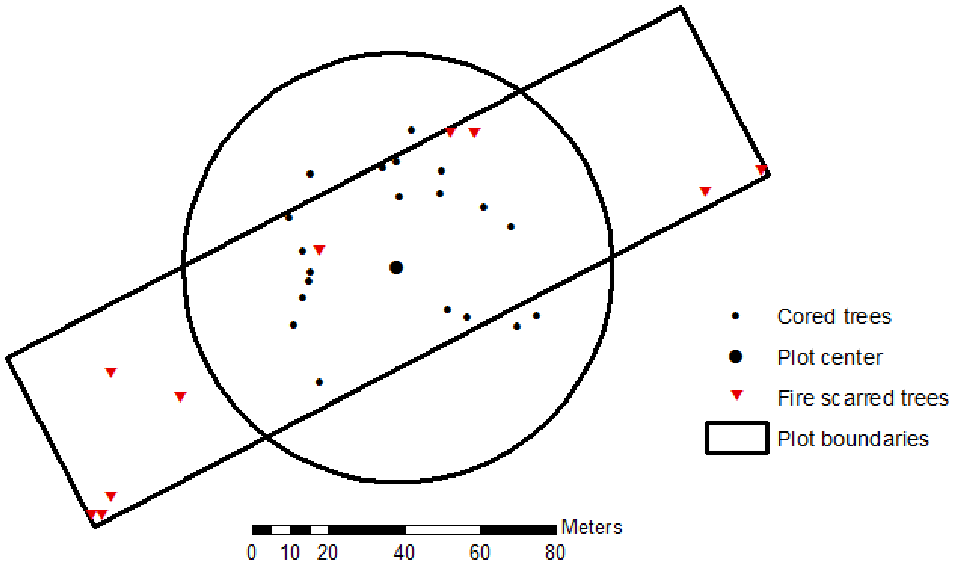

Figure 3. Layout of circular and rectangular plots at site CRN2 and location of ten fire-scarred trees and 20 canopy-dominant trees relative to plot centre. A rectangular plot was used for the fire-scarred trees in order to capture ten trees within one hectare, which was not possible with a round plot. A circular plot with the same plot centre was used for the canopy-dominant trees, allowing easier comparison with other plots.

A total of 24 fire-scarred cross-sections were collected from 20 different trees in the two study sites. Eleven fire-scarred samples were taken from the CRN2 plot and 13 from the CRN4 plot. All samples came from dead western larch stumps, many of which were severely degraded (Fig. 4). Samples were dried and then glued to reinforce their structural integrity. Samples were then prepared for analysis using a belt sander with successively finer sand paper (80 grit to 600 grit) to ensure all rings were visible. A large-format scanner was then used to generate high-resolution (1200 dots per inches) digital images of each sample. Images included outer and inner rings, all fire-scar lobes, and all fire-scar tips. Yearly radial growth was measured using CooRecorder software (Larsson 2011b). On sound samples, ring widths were measured along a single straight-line radius from bark to pith. On highly decayed samples, ring widths were measured in segments, using the sections where the wood was sound. Each ring-width series was statistically crossdated against an existing western larch radial growth chronology from the East Kootenay region (Daniels et al. 2007) using CDendro software (Larsson 2011a). Visual and statistical crossdating allowed me to determine the calendar year of the outer-most ring and the estimated year of death of each fire-scarred tree, identify false and missing rings, and assign a precise calendar year to each growth ring and fire scar. For fire scars located on the boundary between two annual rings, the associated calendar year was set as the earlier of the two rings, as late summer and early fall fires are more likely to occur at that time of year according to modern fire records (BC Wildfire Management Branch 2010).

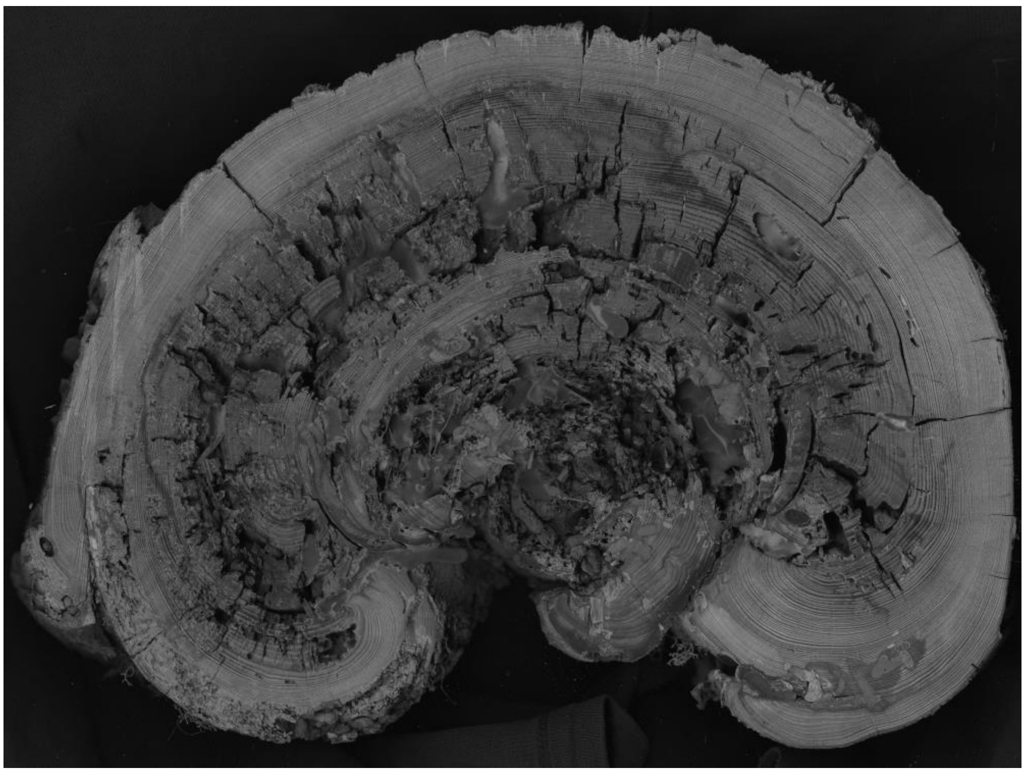

Figure 4. Sample 5977B, Tree #7, CN4 plot, showing the important decay present in many samples

A composite fire record was derived by combining all fire dates for each plot. Combining the results from individual trees is needed as a single tree will not necessarily record every fire burning at its base (Swetnam et al. 1999). The composite record is intended to represent all the fires in the vicinity of the small lakes that could have resulted in a pulse of macroscopic charcoal. From these records, I calculated the number of fires, fire-to-fire intervals, and minimum, maximum, and mean fire interval for each site, as well as the time since last fire, measured as the time between the date of the last identified fire and the year when the sample was gathered (2013 for CRN2 and CRN4 sites).

Results

Twenty-one of 24 samples were successfully crossdated (Appendix A). Correlations with the existing chronology ranged from 0.26 to 0.57. Low correlation for some trees reflected the influence of fire on growth. The trees used to build the regional chronology were specifically chosen for the absence of disturbance signs, which allowed the chronology to reflect regional climatic trends rather than site-specific disturbances. In contrast, fire-stressed trees can be extremely suppressed and experience a significant release after the disturbance, which decreases the correlation between their ring widths and the regional chronologies.

Overall, the inner ring dates for individual trees ranged from 1532 to 1869; outer-ring dates ranged from 1896 to 1970. Individual trees had one to eight fire scars. While most scars were caused by fire, some were likely caused by other agents such as insects or abrasion. Most of these “scarlets” do not align with fire scar dates (Appendix A), consistent with our interpretation of their morphology suggesting they were unlikely caused by fire.

Of the 11 samples that were taken from 10 different trees on the CRN2 plot, nine were crossdated successfully. The two samples that could not be crossdated were taken from the same tree, so only nine of the 10 trees could be analyzed. Eight fire scars were identified on these samples between 1718 and 1970 (Fig. 5). Fires that occurred in 1734, 1805, 1930, 1950, and 1957 were only recorded by one tree. The 1718 fire was recorded by two trees, and the 1869 and 1910 fires were recorded by five and seven trees, respectively. Fire intervals ranged from 7 to 71 years, and had an average of 34.1 years (Table 2). Time since last fire was 56 years and exceeded both the mean and median fire return intervals, but did not exceed the maximum interval.

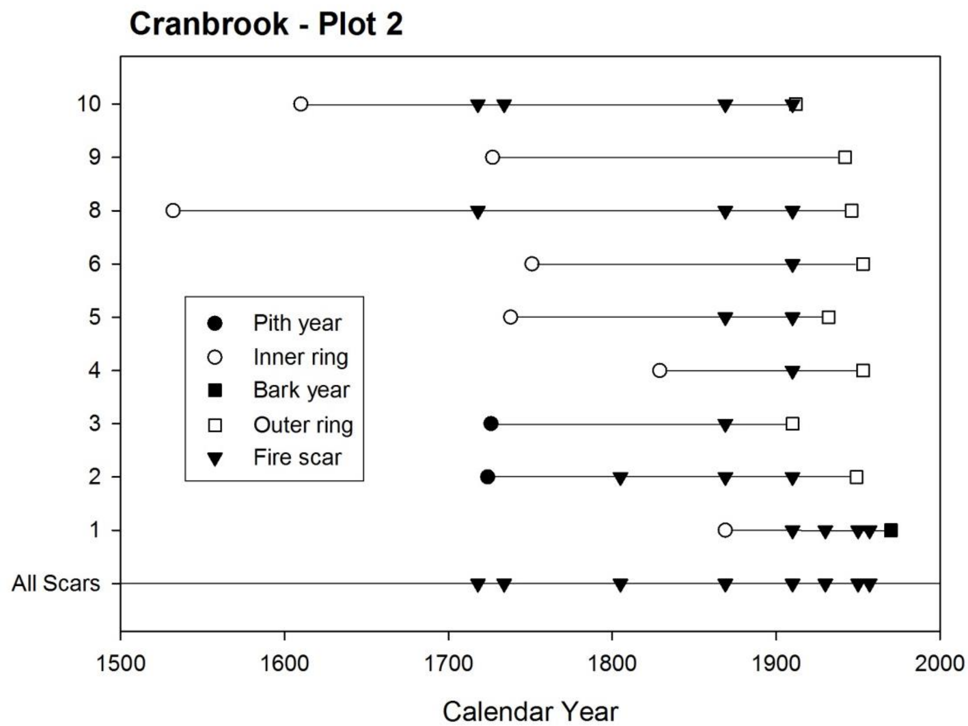

Figure 5. Fire history records for the CRN2 site. Horizontal lines represent the individual tree-ring records (bottom to top: tree 1 to 10). The length of each line represents the period of record, starting from the pith or innermost ring of each tree to the outermost ring. Fire evidence includes crossdated, annually-resolved fire scars.

Of the 13 samples taken from 10 different trees on the CRN4 plot, 12 were crossdated successfully (Appendix A). One sample did not correlate properly (5972A), but the other sample from that same tree (5972B) yielded a strong correlation. Therefore, 10 ten trees were included in the composite fire chronology. Thirteen fire scars were identified between 1647 and 1916 (Figure 6). Fires that occurred in 1647, 1665, 1669, 1748, 1731, 1738, and 1869 were only recorded by one tree. The 1766 fire was recorded by three trees; the 1751 and 1831 fires were recorded by four trees; the 1883 fire was recorded by five trees. The 1802 and 1865 fires were recorded by seven and eight trees, respectively. Fire intervals ranged from 4 to 49 years, and had an average of 19.7 years. Time since last was 130 years and exceeded the mean and median fire intervals as well as the maximum fire interval.

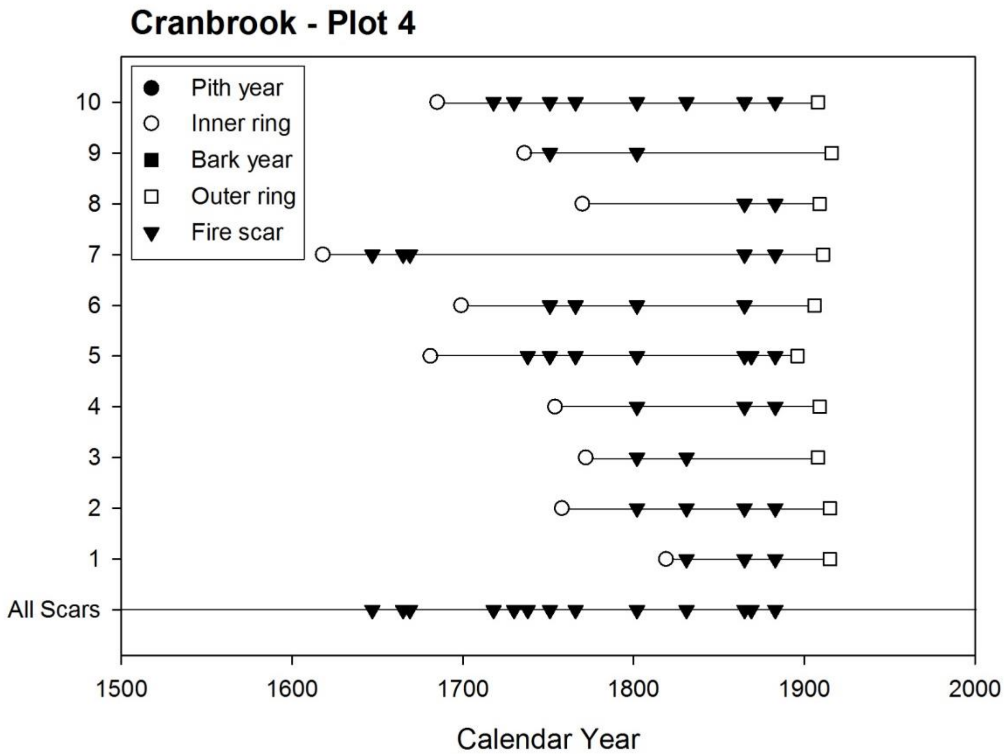

Figure 6. Fire history records for CRN4. Horizontal lines represent individual tree-ring records (bottom to top: tree 1 to 10). The length of each line represents the period of record, starting from the pith or innermost ring of the oldest tree to the outermost ring. Fire evidence includes crossdated, annually-resolved fire scars.

Table 2. Fire history summary statistics for sites CRN2 and CRN4, as well other sites in their vicinity: Joseph Creek West and East (Gray and Daniels 2007), McLeary Park (Gray et al. 2009), and selected plots from Joseph and Gold Creek (Da Silva 2009) with similar elevation (difference < 100m), in the same BEC zone, and in proximity (<10km) of CRN2 (plots 10, 11) and CRN4 (plot 25).

Site	Recording Period	Number Of Samples	Number of Fire Scar Years	Fire Intervals				
				N	Range	Mean Interval	Median Interval	Time Since Last Fire (years)
CRN2	1718-1970	10	8	7	7-71	34.1	20	56
CRN4	1647-1916	10	13	12	4-49	19.7	15	130
Joseph Creek West	1449-2006	13	32	17	3-93	17.2	N/A	97
Joseph Creek East	1302-2006	15	46	26	3-69	20.0	N/A	71
McLeary Park	1533-1938	29	123	32	3-23	8.2	N/A	111
Plot 10	1600-2007	N/A	N/A	14	4-91	24.4	N/A	66
Plot 11	1812-2007	N/A	N/A	4	11-45	24.5	N/A	97
Plot 25	1578-2007	N/A	N/A	5	9-148	36.6	N/A	85

Discussion

Fire Histories at CRN2 and CRN4

At the CRN2 site, fire scars resulted from eight fires over c.250 years. The outer-most rings on the sampled trees ranged from 1910 to 1970, suggesting that no stand-initiating fire happened during the recording period. Two widespread fires were recorded by multiple trees, in years 1869 and 1910. While the shortest intervals occurred in the 20th century, after the great 1910 fire, they were only recorded by one tree.

At the CRN4 site, fire scars resulted from 13 fires over c.260 years before a high-severity fire appears to have burned in 1910. The outer-most rings on the sampled trees ranged from 1896 to 1916. When sampled in 2013, no sample had bark or signs of char on the outside. This suggests that the 1910 fire could have killed the cambium without charring the wood. As well, six of the 10 samples had their outer ring just before 1910, suggesting that they died in 1910 and that some rings were eroded over the last 100 years. The remaining four samples died just after 1910, suggesting that they were potentially damaged by the fire and subsequently died or were harvested. As Da Silva (2009) reported, the late summer fire of 1910 was the largest forest fire on record in the United States, raging through an estimated 1.2 million hectares of virgin timber in northern Idaho and western Montana. This fire also extended into British Columbia was regarded as a mixed-severity fire because of the various impacts it had over the landscape (Marcoux 2013; Marcoux et al. 2013), including high-severity or stand-replacing effects in the Joseph and Gold Creek watersheds (Da Silva 2009). The fire burnt much of the Joseph and Gold Creek watersheds, the two Da Silva and Marcoux study areas. It is also possible that any trees that survived the fire were salvaged along with dead trees shortly after 1910. This is consistent with the presence of an old steam-powered mill that operated in proximity to the lake in the early 20th century (Courtney Mustaphi 2013b). The trees at the CRN4 site could have been salvaged shortly after the fire or could have been harvested in 1916, the most recent outer-ring date on the sampled trees (tree 5980 at CRN4 in Appendix A) without having been affected by the widespread fire.

Comparison with other local fire histories

Only the 1718 and 1869 fires burnt at both sites. However, numerous fire history analyses have taken place near Cranbrook in the last few years, and many of the fire years identified in these studies correspond with the dates found at the CRN2 and CRN4 sites. Gray and Daniels (2007), Da Silva (2009) and Marcoux (2013) studied sites located in the Joseph and Gold Creek watersheds and also found evidence of fires in 1831, 1869, and 1910. Additionally, Daniels et al. (2011) found evidence of fire at multiple sites in 1665. Gray et al. (2009) sampled fire scarred trees from McLeary Park, located near Cranbrook's eastern limits, and found fire years consistent with the findings of this study: 1718, 1751, 1802, and 1831. McLeary Park is located approximately 6 km east from the CRN4 site at a similar elevation; its fire record shows consistency with the CRN4 site, but not CRN2. This suggests that the four fires mentioned above burnt through the relatively flat ground surrounding Cranbrook, but did not make it all the way to the CRN2 site located 16 km down the valley.

Both the fire interval ranges and means are also similar between this study and previous ones. CRN2 however shows a time since last fire much shorter than what other studies have shown, both in McLeary Park and in the Joseph and Gold creek watersheds. More research would be required to understand this difference, as only a single tree captured the three fires that occurred after 1910 at the CRN2 site.

Linking dendrochronology and paleoecology

Other studies have identified years with numerous and/or intense fires that occurred near, but not at, the CRN2 and CRN4 sites. Verifying whether these widespread fires have caused the deposition of macrocharcoal in the two studied lakes can help to determine whether macrocharcoal can travel longer distances than what was initially thought. These regional fire years include: 1701, 1720, 1721, 1808, 1889, and 1905. Moreover, by comparing the two fire chronologies to the numerous other chronologies in the area, it was possible to identify the years where fires are likely to have burnt only at CRN2 (1734, 1805, 1930, 1950, and 1957) and CRN4 (1647, 1669, 1730, 1738, 1766, 1865, and 1883).

Fires that affected the most trees should have created more charcoal, and should therefore show bigger pulses in the paleoecology study. At the CRN2 site, the fires of 1869 and 1910 should show a bigger pulse, as they have affected the majority of the sampled trees. At the CRN4 site, the 1802, 1865 and 1883 fires should show the biggest pulse as they scarred the majority of sampled trees. The 1751, 1766, and 1831 fires should show a moderate pulse, and the remaining fires should show a smaller pulse. If charcoal spikes coincide with these fire dates, the interpretation that local fires contribute to macrocharcoal deposition would be supported.

Conclusion

I developed high-resolution annually-resolved fire chronologies for two study areas near Cranbrook, BC, using dendrochronology. The CRN2 site included eight fires over 252 years, and the CRN4 site included 13 fires over 269 years. Fires occurred at both sites in 1718 and 1869. While the 1910 fire can only be identified with certainty at CRN2, it is possible that it also burned through CRN4. Dendrochronological techniques, while accurate at the annual level of resolution, are limited by the maximum age that trees can reach and the decay of fire scar evidence that inevitably happens overtime. In the next stage of this research, my fire-scar dates will be combined with paleoecological chronologies reconstructed from sediments found in the CRN2 and CRN4 lakes. Studying lake sediments allows researchers to investigate fire history as far as 10,000 years back (Courtney Mustaphi 2013a) with a decadal resolution. Thus, these two complimentary techniques will allow us to extend fire chronologies farther back in time and expand our knowledge of fire history and the effects of fire suppression and climate change on fire regimes.

Moreover, this study contributes to the knowledge development needed to understand the effects of climate change and fire suppression on the landscape, both important for future land management decisions.

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Appendix A: Detailed tree-ring data for CRN2 and CRN4 sites

Table 3. Tree-ring data for 24 individual fire scar samples from the CRN2 and CRN4 study sites. In the sample identification, A and B mean more than one sample per tree and P1 and P2 indicate two parts of a single sample were crossdated separately. Dates in round brackets are scarlets, small scars of unknown cause. Dates in square brackets are scars caused by abrasion or insects. For samples 6073 and 6074 the inner ring was the pith; the pith was missing from all other samples. The bark was present on sample 6072 only.

#	Sample ID	Inner Ring	Outer Ring	Correlation														
1	6072	1869	1970	.37									1910		1930	1950	1957	
2	6073	1724	1949	.44			(1770)	1805	1869				1910	[1920]				
3	6074	1726	1910	.40					1869			[1885]						
4	6075p1	1913	1953	.33														
4	6075p2	1829	1917	.26									1910					
5	6076	1738	1932	.45					1869	(1871)			1910					
6	6077	1751	1953	.39							(1874)		1910					
7	6078	NA	NA	NA														
8	6079	1532	1946	.43	1718				1869				1910					
9	6080	1727	1942	.34														
10	6081	1610	1912	.47	1718	1734			1869				1910					
1	5971	1819	1915	.36										1831	1865			1883
2	5972A	NA	NA	NA														
2	5972B	1758	1915	.56									1802	1831	1865			1883
3	5973	1772	1908	.57									1802	1831	(1865)	(1869)	(1870)	
4	5974	1754	1909	.51									1802		1865			1883
5	5975	1681	1896	.40						1738	1751	1766	1802		1865	1869		1883
6	5976	1713	1908	.42				1718	1730		1751	1766	1802	1831	1865			1883
7	5977A	1706	1909	.53								1766	1802		1865			
7	5977B	1699	1906	.54							1751	1766	1802		1865			
8	5978A	1741	1911	.44											1865			1883
8	5978B	1618	1719	.41	1647	1665	1669											
9	5979	1825	1909	.34											1865			1883
10	5980	1736	1916	.42							1751		1802					