CLIMATE CHANGE, WILDFIRE, AND LANDSCAPE HOMOGENIZATION IN WESTERN CANADA
2014 Report to the Rocky Mountain Trench Natural Resources Society

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Dense forests in the southern Rocky Mountain Trench (Photos by G.A. Greene)

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Introduction

Wildfire is the most important mechanism of ecological disturbance in western North America. Thus, understanding the associations between wildfire, climatic variability and vegetation dynamics is essential for effective management, conservation and restoration of forests and grasslands. The combined effects of human land use, fire suppression and climate variation are hypothesized to have homogenized fire regimes in many regions of western Canada. This homogenization has reduced structural and compositional diversity of forests, increased average patch sizes, and increased vulnerability to environmental stressors such as climate change and invasive species.

Our ongoing research conducted in British Columbia and Alberta uses multiple lines of evidence, combining analysis of aerial photographs, tree-ring research on fire scars and tree ages with analyses of charcoal, pollen and diatoms, to reconstruct fire history and links climate and vegetation change over the previous decades, centuries and millennia. Within the scope of this inter-provincial, multi-year project, we have five primary aims:

(1) To quantify the historical frequency, extent, and severity of wildfire along a gradient in climate and management intensities in the Western Canadian Cordillera.

(2) To evaluate the degree to which recent fire exclusion has altered fire regimes and homogenized forested landscapes.

(3) To characterize the climatic and landscape contexts in which mixed-severity wildfire regimes were historically important.

(4) To quantify the association between fire occurrence, fire severity, and antecedent climate over interannual to multidecadal timescales in the context of the dominant vegetation.

(5) To evaluate the effects of climatic variability, wildfire activity, and land cover change on water quality.

Research in the Rocky Mountain Trench

In British Columbia, our research investigates the effects of fire exclusion on the dynamics of the grassland-forests ecotone in the valley bottom of the Rocky Mountain Trench in southeastern British Columbia. Fire-scar records from this area indicate that low- and moderate-intensity surface fires burned frequently prior to European settlement. However, land-management practices over the last 140 years have significantly reduced surface fire occurrence. Our research is designed to improve understanding of the mechanism and rates of grassland-to-forest conversion and to supply baselines to guide ecological restoration aimed to reinforce forest and grassland resilience to future environmental change. This report summarizes the progress on two complementary research projects conducted in 2013-14, supported by funding from the Rocky Mountain Trench Society, BC Ecosystem Restoration Program and the Natural Sciences and Engineering Research Council of Canada.

I. Fire-Resilient Forests in Dry Ecosystems

What are the impacts of fire exclusion on the structure and dynamics of ponderosa pine and Douglas-fir forests in the Rocky Mountain Trench of British Columbia?

In southeastern BC fire is a dominant disturbance mechanism that shapes forests for decades to centuries. However, our understanding of historic fire regimes and the impacts of fire exclusion are poorly understood. As a result, management policies lack insight as to how forests recover, restructure and expand over time. This is particularly problematic in light of increasingly severe and catastrophic fires that are being linked to a changing global climate. This component of our research aims to address this knowledge gap by achieving the following objectives:

1. Understand the impacts of fire exclusion on landscape-level forest dynamics. Specifically, to determine the spatial and temporal patterns of forest encroachment into grasslands since the 1950s.
2. Understand the impacts of fire exclusion on the historic fire regime.
3. Understand the impacts of fire exclusion on stand-level forest dynamics. Specifically, to determine the impact of forest infilling on large, veteran trees.

Objective 1
How much area has been affected by infilling and encroachment since the 1950s?

We are using paired aerial photographs (Fig. 1) to quantify landscape-scale change in vegetation cover throughout the Ponderosa Pine and Interior Douglas-fir BEC zones in the Rocky Mountain Trench from Invermere to the Canada-US border. We have ortho-rectified 520 of 620 (remaining 100 to be completed in April 2014) historical photographs taken in 1951 and 1952. The resulting photo mosaic of the landscape will be classified into three categories: open range or grassland (≤15% canopy cover), open forest (16-40%) and closed forest (≥41%).

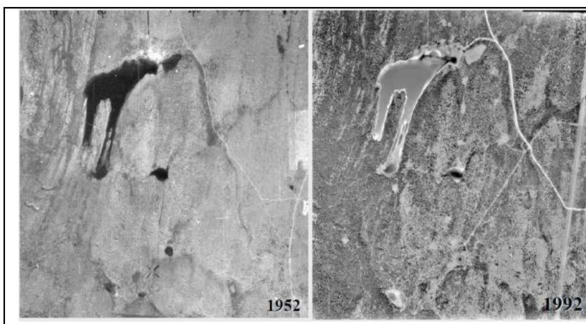


Fig 1. Example of a pair of air photos comparing vegetation cover in 1952 (left) and 1992 (right) (Taylor et al. 1998).

Similarly, the contemporary landscape has been classified into grassland, open and closed forests (Fig. 2). Comparison between the historical and contemporary landscape will allow us to quantify the degree to which each vegetation type has changed, landscape positions in which different types of change have dominated and the degree to which the landscape has become homogenized.

Our field-based research has focused on the southern 257,702 ha of the Rocky Mountain Trench ("RMT study area"). In this area, we used GIS and photographs to identify the densest stands in the landscape. We sampled 123 stands, representing *c*.23,000 ha or 9% of the study area, to better understand forest composition, structure and disturbance history.

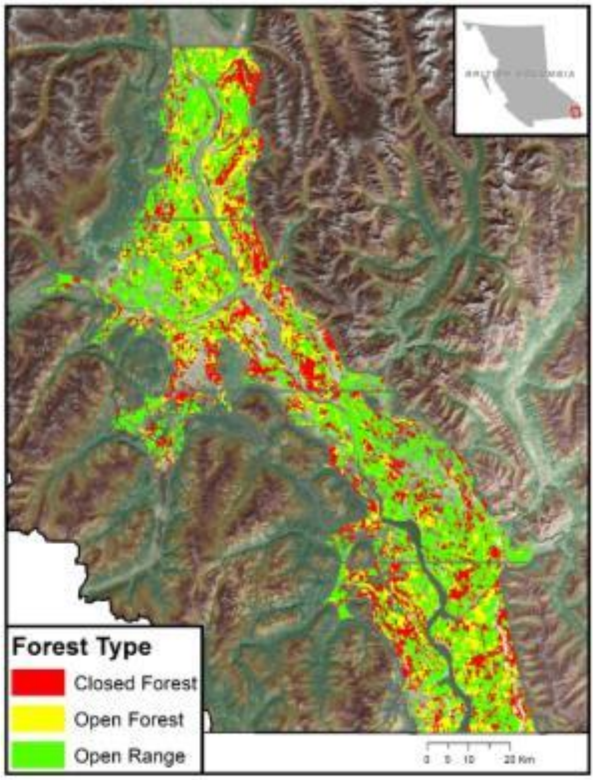


Fig 2. Classification of the contemporary landscape by forest type (BC Ecological Restoration Program 2012)

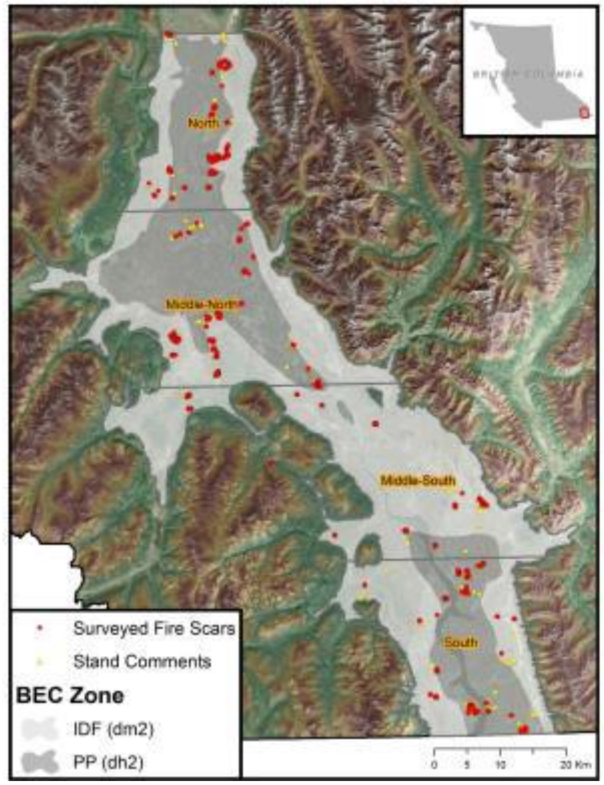


Fig 3. Location of 123 dense stands within the closed forest type surveyed in 2013.

We found fire scars on residual trees or remnant wood (stumps or logs) at 100% of the 123 sites. Additionally, all sites had stumps in various stages of decay, indicating past selective harvesting of canopy-dominant ponderosa pine, western larch and Douglas-fir. At 71 sites, recent logging or Ecosystem Restoration activities had removed or greatly altered the dense stands. At 22 sites, the forests remained dense but we found evidence of past thinning within the stand. Thirty sites had never been logged or thinned and were deemed most suitable for reconstruction of historic fire regimes and stand dynamics related to fire while controlling for confounding human impacts.

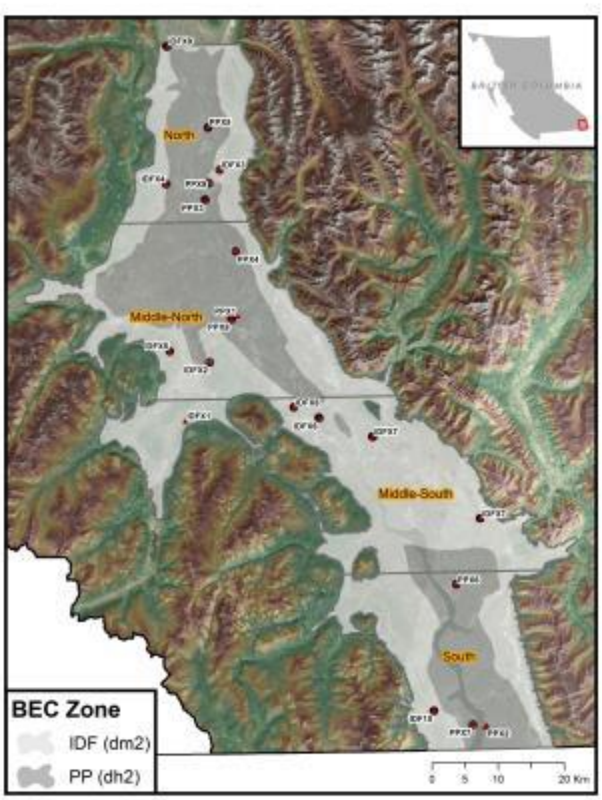
Objectives 2 and 3

What was the historic fire regime? Were dense stands characteristic of the historic fire regime? Are dense stands of small trees affecting the growth of large veteran trees?

To quantify the historic fire regime and forest dynamics, we are conducting detailed stand-level analyses of fire scars, stand structure and tree growth rates at representative sample sites. We stratified the 257,702 ha RMT study area by BEC zones and into four regions along a north-south latitudinal gradient (North, Middle-North, Middle-South and South; Table 1; Fig. 4). We randomly selected study sites within the Ponderosa Pine (n = 7) and Interior Douglas-Fir (n = 13) zones.

Table 1. Distribution of plots among zones and regions with the RMT study area.

Zone		Region	Area	Percent	Plot Distribution
IDF	Interior Douglas-fir	North	21,234	51%	3
PP	Ponderosa Pine	North	20,420	49%	2
IDF	Interior Douglas-fir	Middle-North	39,001	49%	2
PP	Ponderosa Pine	Middle-North	41,062	51%	3
IDF	Interior Douglas-fir	Middle-South	70,593	93%	5
PP	Ponderosa Pine	Middle-South	5,650	7%	0
IDF	Interior Douglas-fir	South	32,113	54%	3
PP	Ponderosa Pine	South	27,628	46%	2



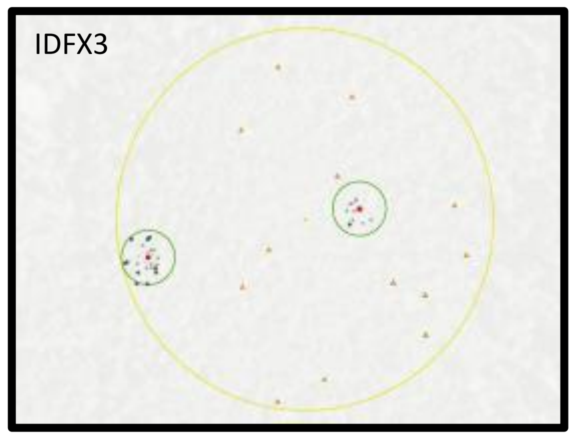


Fig 4. Location of 20 sites within the RMT study area stratified by BEC zone and region (left). At each site, all fire-scarred trees, snags, stumps and logs were located within a 1-ha circular plot (above). Veteran trees and their neighbours were sampled in fixed-area subplots.

At each site we established a 1 ha fixed-area plot (i.e., either a 56.4m radius plot or a 50m x 200m plot), and sampled at least 10 fire-scarred trees within each plot to determine the site-level fire history. Additionally, the location (i.e., UTM coordinate), diameter at breast height (dbh, 1.3m above ground level), species, condition (live or dead) and decay class of all veteran trees (emergent trees ≥ 2m above the canopy) were documented. The veteran tree with the largest dbh of each species was identified and a "focal tree" plot (11.28 m or 8 m radius plot, depending on density) was established around a subset of these trees to assess the impacts of infilling on tree growth. In each focal tree plot, we documented the species, dbh, dbh class (dominant, mature, pole, sapling) and height class (emergent, dominant, intermediate, suppressed) of all live trees with dbh ≥ 2.5cm, and all dead trees with dbh ≥ 2.5 cm and standing at an upright angle ≥45°. The 10 nearest trees of each dbh class were sampled, including the azimuth and distance from the focal tree and age samples within 30cm of the ground. Increment cores were obtained from trees with dbh > 12.5 cm and basal disks were cut from poles and saplings with dbh ≤ 12.5 cm. Whenever possible, cores were extracted by boring completely through trees to capture variation in growth within each tree. When trees were too large to core through, two separate cores oriented at 180° from each other were extracted.

We sampled 20 fire history plots and extracted 213 fire-scar samples (Fig. 5). We preferentially sampled stumps or logs of ponderosa pine and western larch with multiple scars. Douglas-fir were also present but decompose more quickly, so most could not be sampled for datable fire scars. The majority of samples had at least 3 scars. Several samples had more than 15 scar lobes, with a maximum of 30 scars on one ponderosa pine.

Veteran trees were present at18 of the 20 fire history study sites, 8 in the Ponderosa pine and 10 in the Interior Douglas-fir zone (Fig. 6). Veteran tree density averaged 25 ha^{-1} (range: 13-37). Most veterans were Douglas-fir (64%), followed by ponderosa pine (20%) and western larch (16%).

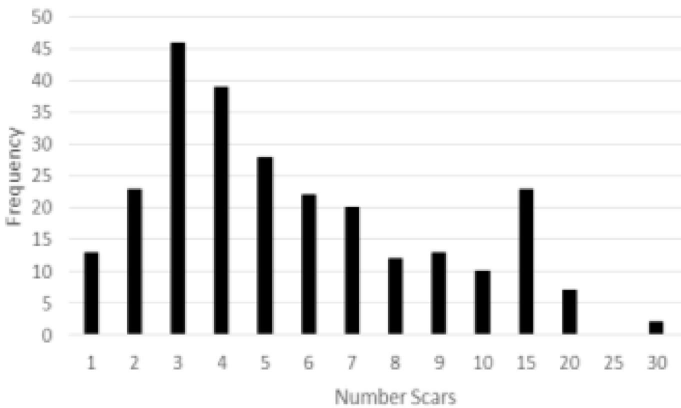


Fig. 5. Distribution of the number of scar lobes per tree (n = 213).

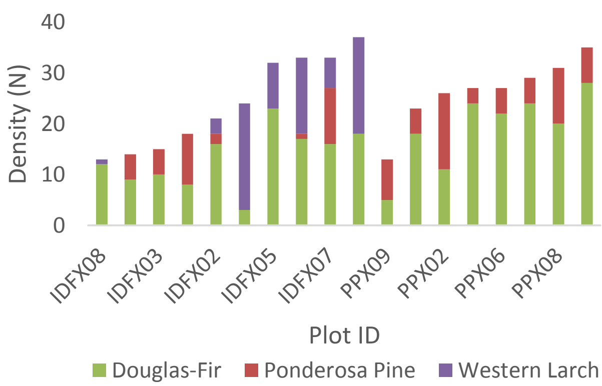


Fig 6. Density of veteran trees among plots, sorted by BEC zone and increasing density.

We sampled 26 focal tree plots (11 ponderosa pine, 7 Douglas-fir and 8 western larch) and 846 age samples were taken to assess competitive effects of small trees on large veteran trees. Tree densities ranged from 1,401 to 18,452 ha^{-1} (Fig. 7). In plots with densities >4,000 ha^{-1}, saplings accounted for the majority of trees. Average tree diameters ranged from 4.5 to 13.5cm, with the lowest averages at the sites with the highest densities.

Figure 8 illustrates the comparative analysis of the growth histories of a single focal Douglas-fir relative to eight mature trees (two ponderosa pine, six Douglas-fir) growing nearby. The focal tree established in 1880 and grew rapidly, forming the emergent stratum of the canopy. The mature trees established between 1890 and 1910, within 20 years of the focal tree, but grew slowly. Although we expected the basal area increment of the focal tree to be sustained at a relatively constant rate (>10 $cm^2\ yr^{-1}$), it decreased to <5 $cm^2\ yr^{-1}$ after 1960. Since 1980, the annual growth increment of two of the mature Douglas-fir trees has surpassed that of the focal tree (Fig. 8) and the cumulative basal area increment of the mature trees has surpassed that of focal tree (data not shown). Despite the dominant height stature of the focal tree, its growth appears to be limited by the surrounding smaller trees. With large sample sizes and by testing multiple competition indices we aim to determine if this pattern is common among focal trees and the thresholds governing these dynamics.

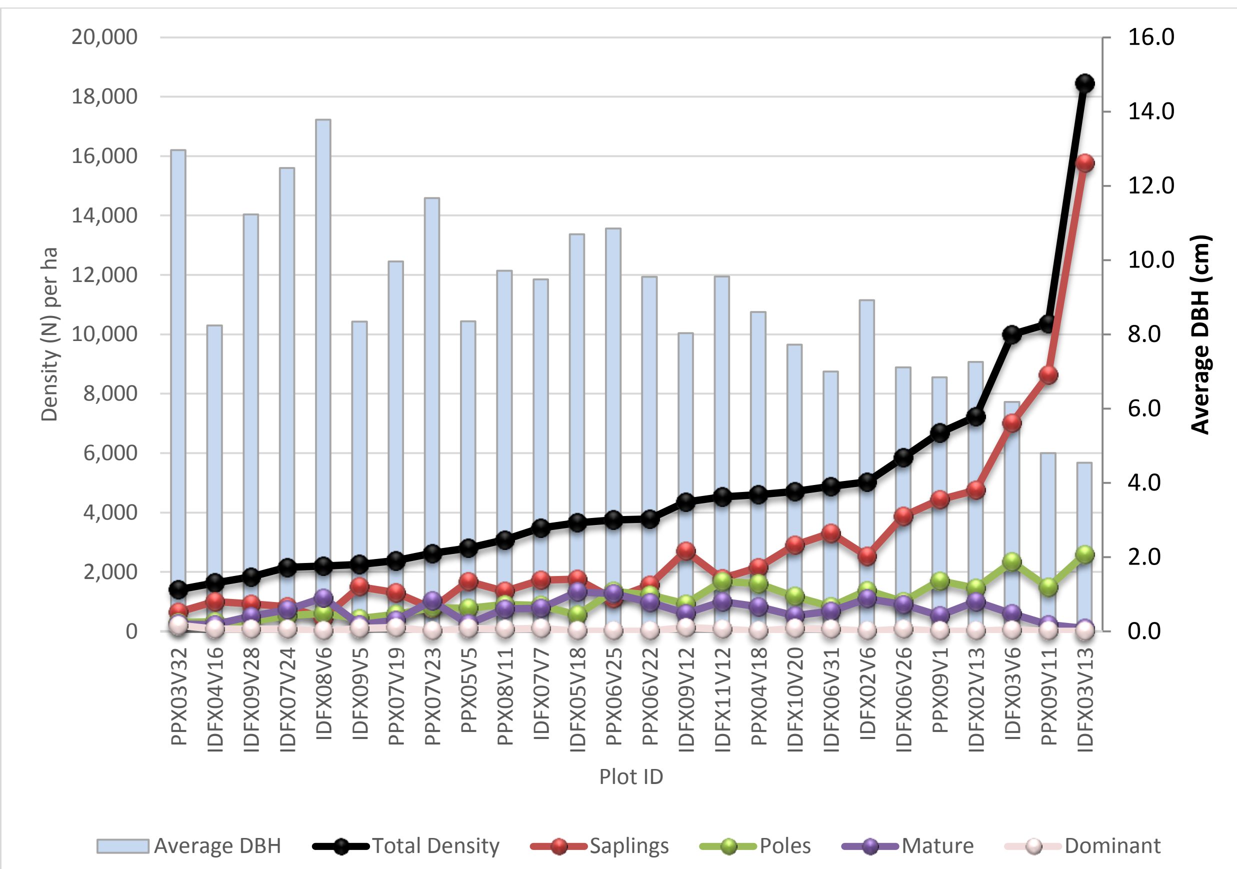


Fig 7. Variation in tree density and size (dbh) among the 26 focal tree plots. Plots are sorted from low to high (left to right) density based on all trees in each plot.

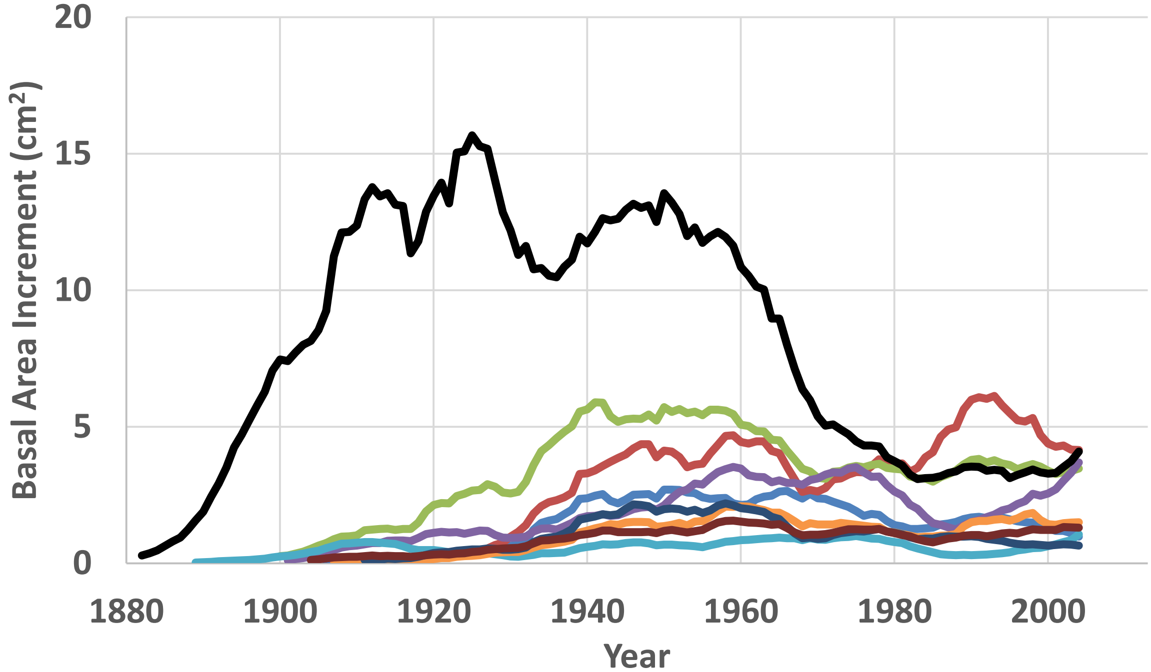


Fig. 8. Example analysis of basal area increment over time of one focal tree (black) relative to the eight mature trees (colours) growing nearby.

Next Steps

In the next phase of this research we aim to complete (1) orthorectification of the aerial photos; (2) sampling of the remaining fire history, emergent and focal tree plots throughout the study area; and (3) measurement and cross-dating of the emergent and focal tree plot samples. Approximately 100 historical photos require orthorectification, and this process should be completed by the end of April, 2014. Mosaicking of the orthorectified images into a larger composites, followed by image classification into Grassland, Open Forest and Closed Forest categories based on canopy cover percent will be completed by the end of March, 2015. Four remaining fire history and emergent tree plots require sampling, plus any associated focal tree plots; the number of focal tree plots will depend on the number of emergent tree species identified in each 1 ha plot. Twelve additional focal tree plots (10 Douglas-fir, two ponderosa pine) remain to be sampled within emergent tree plots that were established in the 2013 field season. All field sampling will be completed by the end of August, 2014. Finally, measurement and cross-dating of emergent and focal tree data will be completed by the end of March, 2015.

II. Fire History of Two Sites Near Cranbrook, British Columbia

How frequently did surface fires burn the forests surrounding two small lakes near Cranbrook?

We reconstructed the fire history at two new sites (CRN2 and CRN4) located immediately south of Cranbrook (Table 2). CRN2 is a mesic site dominated by western larch with some lodgepole pine and Douglas-fir. It is located in the Dry Cool Montane Spruce (MSdk) BEC subzone. CRN4 is a dry site dominated by Douglas-fir with some western larch in the Dry Mild Interior Douglas-fir (IDFdm) BEC subzone.

Table 2. Location and description of two fire history study sites near Cranbrook, BC.

	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)	1246	1082
Slope angle (^{o})	12	20
Slope aspect (^{o})	11	157
Topographic position	Valley bottom	Lower slope
BEC zone	Montane Spruce	Interior Douglas-fir
Plot size and shape	56.4m radius	200 x 50m

The forests surrounding the two lakes were searched to locate all trees, snags, logs or cut stumps with fire scars (hereafter "fire-scarred trees"). One hectare plots were oriented to include at least 10 fire-scarred trees (Fig. 9). 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 trees per site were cored to determine the age structure of the forest.

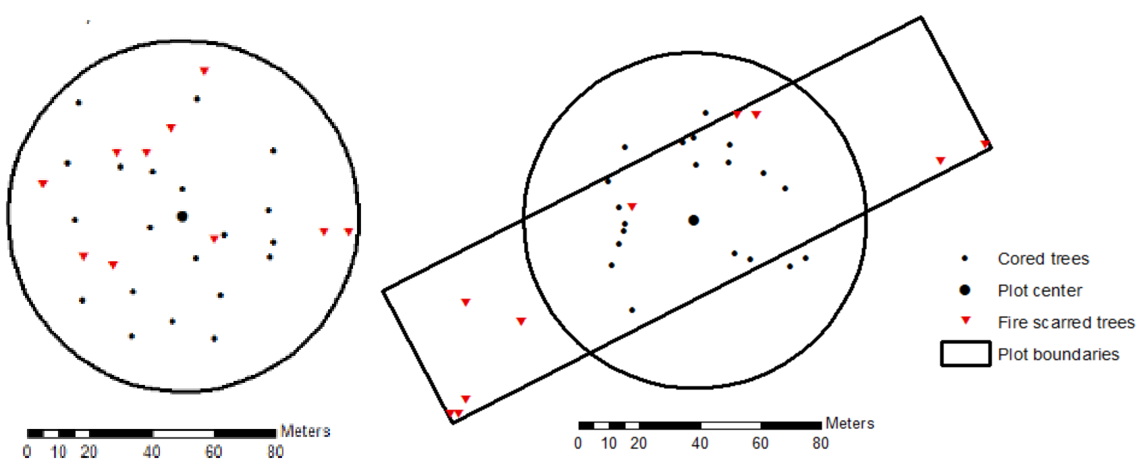


Fig. 9. Location of fire-scarred trees and cored trees in 1 ha circular or rectangular plots.

The fire-scar samples were dried and decomposing samples were glued to reinforce their structural integrity. Each sample was sanded using a belt sander with multiple grits of sand paper from 80 to 400 or 600 to ensure all rings were visible. Using a large-format scanner, we generated a high-resolution (1200 dots per inch (DPI)) digital image of each sample. Each sample included the outer and inner rings plus all fire-scar lobes and the tips of each fire scar. On structurally sound samples, we measured ring-widths along a single straight-line radius from bark to pith. Most samples were highly decayed, so we had to measure the rings in segments where the wood was sound. Annual radial growth was measured using CooRecorder software (Larsson 2011b). 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 us to determine the calendar year of the outer-most ring and the estimated year of death of each sampled stump, to identify false and missing rings, and to assign a precise calendar year to each growth ring and fire scar. For fire scars that were on the boundary between two annual rings, we assigned the calendar year associated with first of the two rings. This approach assumed the fire burned in late summer or early, based on the occurrence of fires at that time of year in the modern fire records (BC Wildfire Management Branch 2010).

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. The composite record was intended to represent all fires in the vicinity of the small lakes. From the composite fire-scar records, we calculated the number of fires, the length of fire-to-fire intervals in years, and the minimum, maximum and mean fire return interval at each site.

At the CRN2 site, nine fire-scarred trees were successfully crossdated (Table 3, Fig.10). The period for fire analysis was from 1532 (inner-ring date of the oldest sample) through 1970 (most recent outer-ring date on a fire-scarred sample) and included 8 fire years between 1718 and 1970. The mean fire return interval was 34 years; the minimum and maximum intervals between successive fire scars were 7 and 71 years. The shortest intervals were during the 20th century, but were only recorded by one tree. Fire years in which multiple trees scarred were 1718, 1869 and 1910. The 1869 fire scarred five of eight trees alive at that time and the 1910 fire scarred eight of nine living trees.

Similarly, 10 fire-scarred trees from the CRN4 site were successfully crossdated (Table 3, Fig.10). The period for fire analysis was from 1618 through 1916; many trees died around 1910. Thirteen fires scarred trees between 1647 and 1883. The mean fire return interval was 20 years, ranging from 4 to 49 years. Multiple trees scarred in six fire years: 1751, 1766, 1802, 1831, 1865 and 1883. The outer ring dates of all samples were from 1896 and 1916, with several just prior to 1910. It is possible this site burned during the 1910 fire and both living and dead trees were cut during subsequent salvage harvesting.

Table 3. Fire history of forests surrounding two small lakes near Cranbrook, BC.

Site	Recording period	Number of samples	Number of fire scar years	Fire intervals (years)		
				N	Range	Mean
CRN2	1532-1970	10	8	7	7-71	34
CRN4	1647-1916	10	13	12	4-49	20

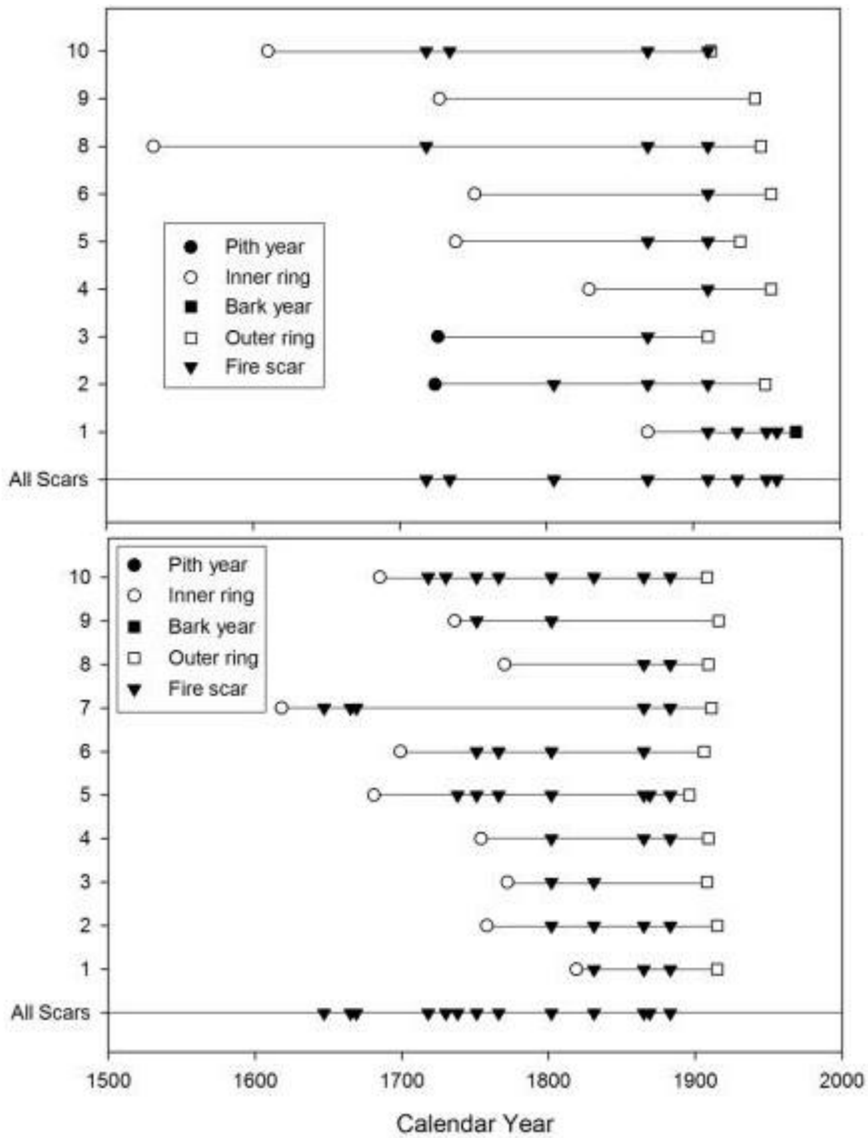


Fig. 10: Composite fire records for the CRN2 (top) and CRN4 (bottom) sites. Horizontal lines represent individual trees. The length of each line represents the period of record, starting from the pith or innermost ring of each tree to the outermost ring. Fire evidence includes crossdated, annually-resolved fire scars.

Next Steps: Linking Dendrochronology and Tephrochronology
Long, rich fire histories were reconstructed for the past 300 and 350 years at the two study sites. By crossdating the fire-scar samples against a regional chronology, we ensured the fire record is accurate at an annual level of resolution. However, the length of our records were limited by the maximum age of the trees, interactions with severe fires, and the inevitable loss of fire-scar evidence due to subsequent fires and wood decay through time. In the next stage of this project, we will link our dendrochronological fire records with the results from research conducted on the lake sediments sampled from the two study sites. Tephrochronology, the study of charcoal in lake sediments, allows researchers to investigate fire history back over thousands of years at a decadal resolution. The records from CRN2 and CRN4 extend several thousand years, thus combining these two complimentary methods will provide a novel long-term perspective on fire history in the southern Rocky Mountain Trench.

Application to Ecosystem Management, Conservation and Restoration

Improved knowledge of the processes and dynamics of wildland fires, forests and forest-grassland ecotones in the Rocky Mountain Trench will provide an empirical basis for ecosystem management. Gaining knowledge in these areas will enable forest managers to plan for the future, including:

(1) developing ecosystem-specific target frequencies and intensities for forest harvesting/thinning to ensure fire-resilient forests in the future,
(2) understanding the scale, variability and appropriateness of ecosystem restoration treatments to recreate fire-resilient forests;
(3) developing a strategy to maintain and/or restore critical grassland habitat;
(4) understanding which tree species, if any, are being impacted by fire exclusion policies, and subsequently, and
(5) which tree species may need to be favored, or even introduced, to ensure fire-resilient forests in the future.

Our results will directly benefit the Rocky Mountain Trench Natural Resources Society and other RMT land managers by supplying baseline information needed to support efforts to restore key ecological processes like disturbance (i.e., reintroducing periodic low- and moderate-intensity prescribed fires or forest thinning treatments) and reinforce forest and grassland resilience to future ecosystem change (i.e., creating fire- and drought-resilient forests by thinning severely infilled and degraded forests).

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Literature Cited

BC Ecological Restoration Program. 2012. ER_Data. *RVI_LBU_2*. BC Ministry of Forests, Lands and Natural Resource Operations, Rocky Mountain Forest District, Cranbrook, BC.

BC Wildfire Management Branch. 2010. Review of the 2009 fire season. British Columbia Ministry of Forest and Range: Wildfire Management Branch. Victoria, BC.

Daniels, L.D., J. Cochrane and R.W. Gray. 2007. Mixed-severity fire regimes: Regional analysis of the impacts of climate on fire frequency in the Rocky Mountain Forest District. Report to Tembec Inc., BC Division, Canadian Forest Products Ltd., Radium Hot Springs, and the Forest Investment Account of British Columbia. March 2007. 26p

Larsson, L. 2011a. CooRecorder program of the CDendro package version 7.4. Cybis Elektronik & Data AB. Retrieved September 15, 2011, from: http://www.cybis.se.

Larsson, L. 2011b. CDendro program of the CDendro package version 7.4. Cybis Elektronik & Data AB. Retrieved September 15, 2011, from: http://www.cybis.se.

Taylor. S.W., G.J. Baxter, B.C. Hawkes. 1998. A stand and landscape level fire and successional modeling system for ponderosa pine and interior Douglas-fir forests. Final Report to Forest Renewal British Columbia, Victoria, BC. July 1998. 40p