The Use of Dendroecological Techniques to Build a Master Chronology and Determine Fire Effects in a Mixed-Severity Fire Regime Forest of Northern Montana

By
Kelly A. Anderson
University of Colorado at Boulder

A thesis submitted to the
University of Colorado at Boulder
in partial fulfillment
of the requirements to receive
Honors designation in
Geography, May 2014

Thesis Advisors:
Dr. Thomas T. Veblen, Geography, Committee Chair
Dr. William Travis, Associate Professor, Department of Geography
Dr. Lewis Harvey, Department of Psychology
With special thanks to Cameron Naficy, Biogeography Lab

Abstract

Forest management largely depends on an accurate understanding of disturbance history and how disturbances, especially fire, affect species composition and forest structure. Understanding fire history allows forest managers to act within the historical range of variability. To characterize the historical fire patterns of the Middle Fork Valley of the Flathead River in north-central Montana, I constructed a master chronology of tree ring growth patterns that could be used to date fire scars and tree establishment dates from the same region with annual accuracy. Due to differences in species physiology and growth patterns, I created two separate chronologies, one for Douglas-fir and one for the western larch. Cross dating of tree establishment dates revealed that there was a high-severity fire in the 1780s, in one of my stands. Additionally, fire scar analysis indicates a fire of mixed severity in 1929. Fire severity was determined by the percentage of forest establishment following the fire. These results indicate that the Middle Fork Valley is not acting outside of the historical range of variability and that fire patterns have not been significantly impacted by fire suppression.

Preface:

I would like to begin by thanking Cameron Naficy, Dr. Thomas Veblen, Dr. Lewis Harvey, and Dr. William Travis for their support throughout this project. I spent the summer of 2013 with Mr. Naficy in the Montana helping collect data for the Veblen lab and for Mr. Naficy's personal research. During the field season I developed a great interest in forest ecology and decided to expand upon what I learned in the field in a laboratory setting. I wish to thank Mr. Naficy for dedicating so much of his time to helping me through the research process, but most importantly, I wish to thank him for sparking my interest in forest ecology.

Through this process I have learned an incredible amount about forest ecology and dendroecological methods; however, I have also found a passion for research and for a deeper understanding of the amazing biological processes occurring all around us. During my time as a field assistant I gained first hand knowledge that has taught me more than any class I have taken and I value this project as the most educational and influential experience of my undergraduate career. I would also like to thank Darla Shatto for all of her help keeping me on track and for guiding me through the UROP and Honors application process. Without the continued support from everyone involved, including the Undergraduate Research Opportunity Program (UROP) and the Honors Program Council none of this would have been possible.

Table of Contents

Introduction:

In Montana, Euroamerican settlement began around 1870, this settlement may have altered the natural fire patterns due to a combination of fire suppression, grazing, and logging (Habeck 1994). In mixed conifer forests, fires play a key role in structuring tree stand density and species abundance (Sherriff and Veblen 2006). Alteration of fire regimes and changes from historical mean fire intervals is thought to influence the successional rates of mixed conifer forests and may play an important role in forest density, structure, and overall community health (Brown et al. 2001). The goal of this research is to characterize the natural fire regime in the Middle Fork of the Flathead River drainage located in north-central Montana. Knowledge of historical fire patterns will aid in the understanding of how Euroamerican settlement may have altered natural fire patterns. In order to discover the fire history, I will construct a master chronology that will allow accurate cross dating of fire scar samples and tree ring samples collected from multiple sites in the Middle Fork drainage.

The abundance of certain tree species serves as an indicator for the disturbance history of a forest due to differential rates of establishment following a disturbance as well as differences between species adaptations to fire. Historical fire regimes have been altered especially in lower and mid elevations, which have been reflected by the changes in tree density (Falk et al. 2007 & Turner 2010). Williams et al. 2012, claim that the "landscape pattern of forest patches is influenced by both the severity and the frequency of fire," indicating that, while fires are not the sole factor in determining forest composition, they effectively "manage" mixed conifer forests (Williams et al. 2012). Forest fires occur at differential rates because of climate as well as a host of other factors (Sherriff et al. 2006).

The extent to which human factors affect forests are highly variable due to the unique qualities of each forest, including their topography, soil type, and climate patterns (Falk et al., 2007 and Arno et al. 2000). In recent decades, the amount of research regarding alteration of natural fire regimes has greatly increased; however, many of these studies focus on fire in the Southwestern portion of the United States. Therefore, while studies have examined the role of fire in the Northern Rockies, the understanding of these complex ecosystems is incomplete (Barrett et al. 1991). Understanding the temporal and spatial variability in natural fire regimes in crucial to forest management and for understanding factors impacting successional processes.

Due to the complex nature of the forest ecosystems, in the lower to mid elevations of the Middle Fork drainage the effects of fire suppression are not clear. Through a reconstruction of the fire history, I will be able to illustrate historical fire patterns. Furthermore, the reconstructed fire history will illustrate how mixed severity fire regimes (MSFR) impact mixed conifer forests, with respect to the climatic, topographic, and species composition of spatially cohesive regions. In terms of management decisions, the fire history gained from the crossdating of fire scar samples will allow for a more historically accurate prescription that may include thinning, controlled burns, or a more "hands-off" approach to forest management in mid-elevation forests in the Northern Rockies.
The specific Objectives of this research are:

1. Create a regional master chronology of climate-sensitive tree-ring patterns that can be used to cross date other fire scar and tree ring samples with annual accuracy.
2. Use the master chronology to reconstruct historical fire patterns and ecological effects at 2 sample sites where we collected tree ring and fire scar samples during the summer of 2013.

Mixed Severity Fire Regimes in Mixed Conifer Forests

MSFRs operate in a different and more complex manner than low-severity fire regimes. Generalization of fire patterns may lead to a misunderstanding and subsequently, may lead to poor management of very different ecosystems. The typical mean fire interval in MSFRs ranges from around 30 to 100 years, during which an intricate composition of species and seral stages thrive (Arno et al. 2000 and Barrett el al. 1991). MSFRs often experience relatively frequent low-severity and moderate severity fires that thin the understory. Less frequent moderate or high severity fires thin the over story and allow shade-intolerant species to establish (Smith et al. 1997). However, because there are few high severity, stand-replacing fires, shade-tolerant species, such as subalpine fir and Engelmann spruce also thrive in these forests. The mix of nonlethal fires and less frequent high-severity fires result in even and uneven aged stands marked by remnant trees as well as a diverse composition of both shade tolerant and intolerant species in different stages of stand development (Arno et al. 2000).

Fires at differential rates of both frequency and severity largely maintain these complex ecosystems and provide opportunities for multiple and single cohort stands to survive simultaneously (Falk et al. 2007). Reduction or suppression of fires in these forests may alter the shifting mosaic of stand conditions; however, the effect of fire suppression largely depends on the species composition, previous disturbances, and life cycles of both over-story and under-story species (Falk et al. 2007 and Schoennagel et al. 2004).

In MSFR forests, fire spread and frequency is largely dependent upon climate variation (Schoennagel et al. 2004). Differences in fuel loading and topographic variation may impact the severity of fires. These complex relationships create a "complex moisture gradient resulting in a mosaic of tree species and densities" (Schoennage et al. 2004). The resulting mosaic complicates understanding of natural fire regimes and further hinders fire management. Nonetheless, beginning in the early 1900s, fire suppression through lower elevations was largely successful, and began to impact forests management decisions at lower elevations (Turner, 2010). Yet, due to the complex topography of mid-elevation forests, the impacts of fire suppression are much less clear than those at lower elevations.

Using historical photography and fire scar sampling on remnant trees, researchers have found that fire suppression affects MSFR forests differently than forests at lower elevations. Schoennagel et al. (2004) have found that fuel loading in MSFR forests varies greatly throughout seemingly similar communities. Differences in species composition impact the availability of fine surface fuels as well as available ladder fuels (Barrett et al. 1991 and Schoennagel et al. 2004). Specifically, trees that are highly fire resistant, especially larches and ponderosa pines, limit the amount of ladder fuels that allow fires to reach the upper canopy, whereas, shade-tolerant (and fire intolerant) species such as subalpine fir and Engelmann spruce maintain low-lying lateral branches that allow fires to easily spread into the upper canopy (Arno S. F., 1980).

MSFR Associated Species

In the Middle Fork Douglas-fir, larch, lodgepole pine, subalpine fir, and Engelmann spruce are commonly found together; however, each species reacts to environmental conditions and disturbances differently. Differential levels of shade tolerance have a distinct effect on the population dynamics in these forests and are a primary driver of successional rates. Additionally, these species respond differently to fire in regards to fire avoidance, adaptations, and colonization post-fire, these differences are also responsible for the complex mosaic in MSFR forests. Understanding these morphological differences is crucial to understanding the effects of fire as well as the historical successional patterns.

Fire is a crucial element to larch reproduction and success in a forest stand. Following a large-scale disturbance, particularly fire, larch is able to colonize as an early successional species. Larches are successful at colonizing after disturbances, primarily fires, due to the characteristics of their growth patterns and their reproductive characteristics. Parent trees, or older larch trees, are capable of producing a large quantity of seeds that are small and light-weight with a relatively large wing (Smith et al. 1997). This type of dispersal increases larch ability to establish in sites following a fire as adult larches are capable of dispersing seeds throughout much of the disturbed area (Shearer et al. 1991).

Douglas-firs exhibit some of the same characteristics as larch; however, in general, Douglas-firs are more shade tolerant and slower growing than larch. In forests that lack frequent disturbances, Douglas-firs often develop late in successional forests and experience a long life once initiated into the upper canopy. Mature trees develop a thick bark and lose lower branches which serves to improve resistance to low severity fires and prevent low severity fires from moving into the canopy (Smith et al. 1997). Similar to larch, Douglas-firs employ wind dispersal into recently disturbed sites and are therefore successful in establishment within a few years of a large disturbance.

Subalpine fir and Engelmann spruce thrive in the mid to upper-montane zones, with a range that continues into higher elevations. These environments have cold winters and moderately warm summers (Smith et al. 1997). Unlike larch and Douglas-fir, subalpine fir and Engelmann spruce are highly shade tolerant and are favored by long periods of time between fires. In the Middle Fork, subalpine fir are far more numerous and likely experiences higher establishment rates once a Douglas-fir or larch canopy has established as it is highly shade tolerant (Uchytil, 1991 and Barrett 1991).

Following disturbance events, subalpine fir rarely establishes before shade intolerant species such as larch or Douglas-fir; however, once a full or partial canopy is developed (Uchytil, 1991 and Smith et al. 1997). Subalpine fir establishment is successful beneath the canopy and may begin to demonstrate dominance over other species due to isolated disturbance events that create openings in the upper canopy. At lower elevational habitats, subalpine fir is often less successful at growing into the upper canopy due to warmer temperatures and more frequent fires, for which subalpine fir is much less resistant than other more shade tolerant species (Uchytil, 1991). Subalpine firs are favored by long fire-free intervals and burn easily in even low severity fires. However, the tendency for growth on rocky soils may help protect some pockets of subalpine fir even in higher severity fires. Therefore, in MSFR forests, subalpine fir often is found in dense pockets beneath the canopy of more fire resistance species and is often a younger cohort as compared to larch and Douglas-fir.

Methods:

Study Area

The Middle Fork of the Flathead River drainage is largely characterized by Doulas-fir (*Pseudotsuga menziesii*), Western larch (*Larix occidentalis*), Subalpine fir (*Abies lasiocarpa*), Lodgepole pine (*Pinus Contorta*), and the Engelmann spruce (*Picea engelmannii*). Additionally, while the Middle Fork of the Flathead River drainage is comprised of a range of elevational gradients and climate patterns, the area under investigation is considered a lower to mid-montane zone and in an arid, cold, steppe or "Bsk" climate zone according to the Köppen-Geiger climate classification system. The Bsk climate zone is considered semi-arid with a large annual temperature variation consisting of cold winters and high temperatures during summer months (Kottek et al. 2006). These climate and species interactions greatly impact the fire regime of the Middle Fork, and while the area is highly diverse, the fire regime is considered a mixed severity fire regime

(MSFR). The study sites within the Middle Fork were chosen because they did not appear to have been affected by logging and, *prima facie,* seem to have patches of different aged forests. More specifically, while sampling in MF – 11909 – 59 the forest seemed older than the neighboring site (MF – 12545 – 56), which may indicate a different disturbance history (see figure 9).

Data collection and analysis

As part of a larger project underway in Dr. Veblen's lab, over 4500 tree cores and more than 300 fire scars were collected throughout much of Montana. More specifically, each site averaged around 40 cores (range 25-85) depending on cohort structure and 3-8 fire scars per site depending on the availability and the complexity of fire history. In the Middle Fork region there were 17 sites, of which I selected two sites.

In order to attain a correct establishment date, cores were cross dated and corrected for both the years to pith as well as for coring height. To correct for years to pith, the Duncan method measures the innermost ring's height, width, and the average width of the three innermost rings. From these measurements, through a series of geometric equations, the Duncan method estimates the number rings missing in between the innermost ring and the pith (Duncan, 1989). To correct for coring heights, an average of missing years for each species was found by sampling saplings at 0cm and 30cm and determining the difference in the number of rings at each height. These averages were then applied to the respective species and coring heights of each sample.

Development of master chronology

From the sites selected in the Middle Fork, (on average) 20-25 of the clearest tree cores were selected from each of two species, Douglas-fir and western larch, and measured in order to create the master chronology. Separate chronologies were developed for Douglas-fir and western larch in order to test for differences in climate-growth relationships between species. The cores were individually mounted and sanded in order to reveal a detailed view of tree rings. Measurements with accuracy of 0.001 mm were obtained using a microscope compatible with a sliding bench system. In order to demonstrate the growth pattern, to identify the common signal throughout all of the cores in each site, and statistically evaluate the characteristics of each chronology, the program COFECHA was used. COFECHA allows for a statistical analysis of growth patterns, which is then compiled into a master chronology. COFECHA generates a master chronology by averaging growth patterns in each year and comparing it to neighboring years (Grissino-Mayer, 2001). These year-by-year comparisons illustrate a pattern of growth that can be expected for other samples taken from the same area including samples taken from dead trees. Thus, by using the master chronology, fire scars taken from dead trees can be successfully dated and used to illustrate historical fire patterns.

Fire history

Using this master chronology, the fire scar samples were cross dated, which allows for an accurate annual dating of the fire scar. By establishing an accurate date for past fires as well as determining establishment dates for each core in the two study sites, both fire history and severity can be determined. Following a fire, incremental percentages are designated to indicate fire severity: if 20% or less of the trees appear to have established post-fire it is considered a low-severity fire, if 80% or more have established post-fire it is considered a high-severity fire, and percentages greater than 20 and less than 80 indicate a moderate severity fire.

Results

Master Chronology

The larch master chronology contains 19 (*n = 19*) cores, the oldest core dates to 1662 while the youngest extends to 1942. Fifteen of the 19 samples contain an inner ring dating to 1850, after which the number of samples steadily decreases. The average series length is 203 years, indicating that the average establishment date is 1809. The series intercorrelation is 0.524, and the average mean sensitivity is 0.271. In COFECHA, each sample is individually correlated with the master chronology, the highest correlation found is 0.654 and the lowest is 0.231, the range of correlations is 0.432 (see table 1).

The Douglas-fir master chronology contains 23 samples (*n = 23*), the oldest core dates to 1800, and the youngest core dates to 1958. The index contains 10 cores that date to 1850 and 15 cores that date to 1863. On average, there are 158 rings, indicating that the average establishment date is 1854. The series intercorrelation is 0.435 and the average mean sensitivity is 0.219. Individual sample correlations as compared to the master chronology range from 0.587 to 0.285 (see table 1).

Though larch and Douglas-fir respond similarly to climate signals, differences in physiological behavior and species-specific result in distinctive growth patterns. For example from 1933 to 1946 there appears to be an insect affecting larch growth that is not apparent in Douglas-fir (see figures 2 and 3). Comparison between the Douglas-fir and larch master chronologies reveal that separate chronologies provide a more accurate depiction of growth patterns than a combined chronology. For the combined chronology, the number of cores (*n = 42*), the series intercorrelation is 0.384, and the average mean sensitivity is 0.246. In relation to the species-specific chronologies, the combined series intercorrelation is 0.14 less than the larch cores alone, and is 0.051 less than the Douglas-fir series intercorrelation (see table 1).

Cross Dating Analysis and Stand Initiation Information

MF-11909-59 contained 42 samples (*n = 42*), most of which were Douglas-fir and subalpine fir; however, larch, lodge pole pine, and western white pine (*Pinus monticola*) were also present. Of the 42 cores, all were successfully cross dated and establishment dates were corrected for both the number of rings to pith as well as for the respective coring height. However, for one core (MT – 2735 - 2013), due to an error during the collection of the core, the establishment date was not corrected for the number of rings to pith. The average establishment date is 1896, the oldest sample in the site established in 1774, and the youngest tree established in 1974 (see figure 4).

The second site, MF-12545-56 contained 48 samples (*n = 48*) dominated by Douglas-fir with subalpine fir, larch, Engelmann spruce, and lodgepole pine also present. Of the 48 cores, all but three cores were successfully cross dated and establishment dates were corrected for both years to pith as well as coring height. The average establishment date for this site is 1947, the oldest core established at 1934 and the youngest established at 1964 (see figure 5).

Tree establishment dates are useful in determining fire patterns and for visualizing a forest's history. However, including information regarding the standing forest structure, particularly the diameter at breast height (DBH), aids in predicting past fire patterns and successional patterns. The range of DBH's in site MF-11909-59 was 68.2 cm, the largest sample was a PIMO at 72.8 cm and the smallest was an ABLA at 4.6 cm. For site MF – 12545-56, the range of DBH's was 37 cm, the largest sample was a LAOC at 41 cm, and the smallest was an ABLA at 4 cm (see figures 6 and 7).

Fire Scar Analysis

Determining fire severity depends upon the establishment patterns in each site in relation to fire dates. Three fire scars were successfully cross dated from the Middle Fork, both of which indicate a fire in the fall of 1929. The first scar, MF-11909-001 was sampled in 2013 from a living larch. Using cross-dating techniques, the sample was successfully dated until 1931, at which point rot is responsible for a number of missing rings. Though there was no visible fire scar tip, the presence of other fire-scars dating to 1929 in the nearby area and through cohort establishment dates, it can be reasonably inferred that the fire scar dates to 1929.

MF-12566-001 was also sampled in 2013 from a living larch; however, due to severe wind damage to the canopy, the tree stopped experiencing annual growth in 2005. The fire scar in this sample revealed a fire-scar tip in the dormant period in the fall of 1929, after the 1929 growing season and before the growing season of 1930.

The third fire scar, MF -10664-002 was sampled in 2012 from a dead larch, and revealed a fire in 1929. In order to determine the scar date, the sample was cross dated using the larch master chronology, and despite a relatively low number of rings (80), the cross-dating pattern and fire scar tips are consistent with both other fire scars and the master chronology.

Discussion

Stand Structure and Cohort Establishment

The primary objectives of this research were to establish a master chronology and to determine fire history of the Middle Fork Valley. In order to create a master chronology that is useful in dating samples of different species, two master chronologies were necessary due to physiological differences between species. Douglas-firs, which are relatively shade intolerant, and considered an early successional species, produced a master chronology with different ring width patterns than the larch master chronology. Larch, considered highly shade intolerant and is very long-lived, experienced differential growth rates due to both physiological differences but also due to an apparent insect outbreak from 1933 to 1946 (see figures 3 and 8). During this period growth was highly suppressed for most larches but not for Douglas-firs or other associated species. Additionally, in some larch samples there appeared to be missing rings during this period. Therefore, because this growth suppression was not apparent in any other species, using two separate master chronologies allowed for a more accurate demonstration of ring width signals than a combined chronology (see figure 1).

Site MF – 11909 – 59 exhibits a more complex fire history than the other site despite their similar location. At this site there are two clear cohorts with over 50 years between establishment. The first cohort appears to have established between 1790 and 1810, indicating that there may have been a severe fire in the late 1780s. This conclusion is based purely on forest structure and establishment dates and lacks a fire scar confirming this date, and is therefore limited. However, other research in the Middle Fork reveals a fire during this same time period that occurred in the northwest portion of the valley (Barrett et al. 1991). Therefore, while there is no fire scar evidence of a fire, cohort initiation and past research indicates the occurrence of a high severity fire.

During this first stage of stand establishment, the vast majority of trees were Douglas-fir, with a few larches and Engelmann spruce. Douglas-fir initiation indicates that the canopy was relatively open, as Douglas-fir are less successful at establishing under a full canopy. Thus, it can be concluded that the disturbance prior to establishment in the 1800s was severe and likely stand replacing. During the period following the initial establishment, it is possible that trees began to establish in the understory; however, the data cannot demonstrate this due to the 1929 fire which may have killed young trees in the understory but left the majority of the older cohort intact (see figure 4). After this gap in establishment, the second phase of initiation consisted of almost purely subalpine fir, with the exception of one lodgepole pine. The highly shade tolerant nature of subalpine fir and the lack of post-fire establishment of shade intolerant trees indicates the presence of an over story canopy. Additionally, because over 20 percent but less than 80 percent (establishment post-1929 is equal to 47%) of the forest appears to have established post-1929, the fire severity is classified as moderate severity. These findings are consistent with past research revealing fires stemming from an escaped slash fire in 1929 (Barrett et al. 1991, Gruell, 1983).

The second site MF – 12545 – 56 has a similar establishment pattern to MF – 11909 – 59; however, there is no evidence of a fire prior to 1929 (see figure 5). In this site there are no remnant trees pre-dating the fire in 1929, indicating that the 1929 fire was high severity and stand-replacing for certain areas of the Middle Fork. Furthermore, the combination of both shade-tolerant and shade-intolerant species establishment post-fire indicates that there was no standing canopy blocking light availability. Fire severity throughout the Middle Fork appears to vary depending on the specific location. The extreme topography of the Middle Fork Valley, in addition to the differences in forest structure may result in differential patterns of fire. The data collected from the two sites reveal a pattern of burning typical of a high severity, low frequency fire regime with areas of moderate severity. Assuming there was a fire in the 1800s that resulted in the burst of establishment in site MF – 11909 – 59, there appears to be approximately 140 years between fires.

It is important to note that fire severity is not consistent through out the Middle Fork. In site MF – 11909 - 56 the size of trees indicates that the fire was not stand replacing and was of moderate severity (see figures 6 and 7). Similar to the establishment date data, there are two clear cohorts, one that is still living from before 1800, and one, which established following the 1929 fire. From this site, there are several large trees with DBH's above 65 cm; these samples are primarily from Douglas-fir and western white pine, both of which are long-lived species. The second cohort consists primarily of subalpine firs that are capable of becoming a climax species; however, due to their lack of fire defenses, in areas that experience moderate to high severity fires, it is unlikely that any subalpine firs will survive. This explains, for both sites, why larch and Douglas-fir make up the majority of old trees, which in moderate severity fires, are often capable of survival.

Historical Range of Variability

The evidence in the Middle Fork illustrates a fire regime that is moderate to high severity and low frequency. Though the conclusion that there was a fire in 1789 is not absolute, the fire regime does not appear to be acting outside of the range that is considered historically normal. In a fire regime that is not historically of moderate or high frequency, the impact of human fire management is harder to discover, as fires are already infrequent. Human fire suppression was most prominent in the late 1800's through the 1920's; however, given the fire evidence in 1929, there does not appear to be a significant impact on either fire severity or frequency due to suppression efforts. Further research into the Middle Fork may reveal areas that experienced different fire intervals and severities; however, based upon the establishment dates, fire scars, and structural make-up of both studied sites, the fire intervals appear to be with the historical range.

Appendix:

	Larch	Douglas-fir	Larch and Douglas-fir Combined
Number of dated series	19	23	42
Master Series Year Range	351	213	351
Series Intercorrelation	0.524	0.435	0.384
Average Mean Sensitivity	0.271	0.219	0.246
Mean Length of Series	203	158	179

Table 1: Displays master chronology information obtained through COFECHA for larch, Douglas-fir, and combined data.

	Site Number	
Species	**MF-11909-59**	**MF-12545-56**
PSME	13	21
ABLA	24	15
LAOC	2	5
PIEN	1	4
PICO	1	3
PIMO	1	0
Total	42	48

Table 2: Core count relative to each site.

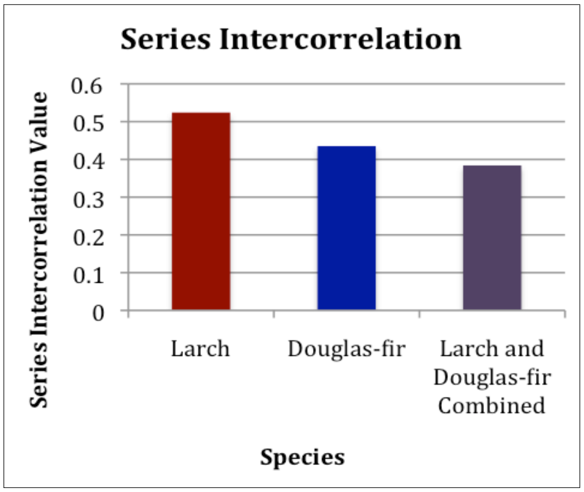


Figure 1: This graph illustrates the differences between the master chronologies, including the larch, Douglas-fir, and combine chronologies.

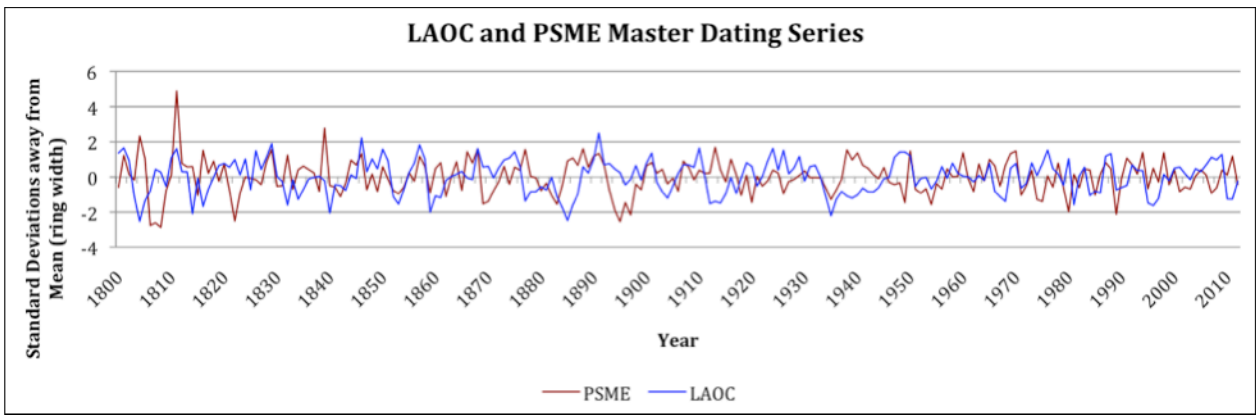


Figure 2 (Above): This graph illustrates the species-specific master chronologies, differences in ring width variation are apparent in the respective growth rates for LAOCs and PSMEs. Growth has been standardized with a mean of zero and a standard deviation of 1.

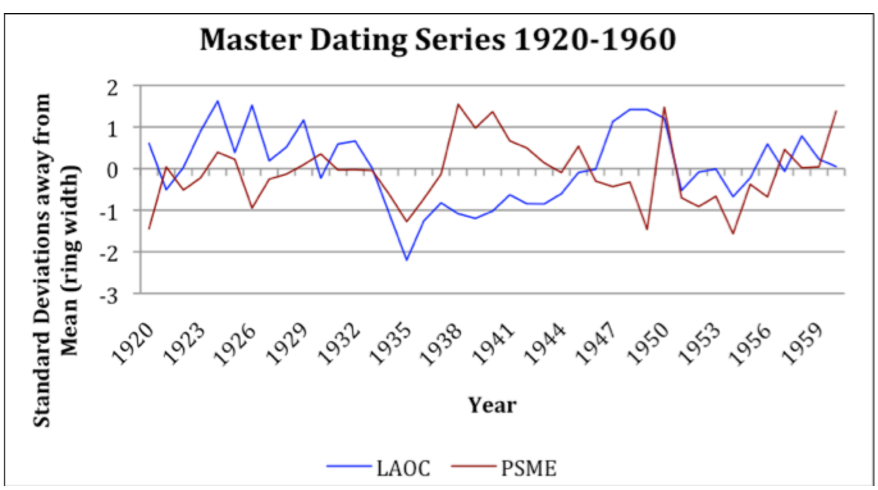


Figure 3 (Left): Using the same data displayed in Figure 2, this graph illustrates the differences between chronologies during the suspected insect outbreak from 1933 to 1946.

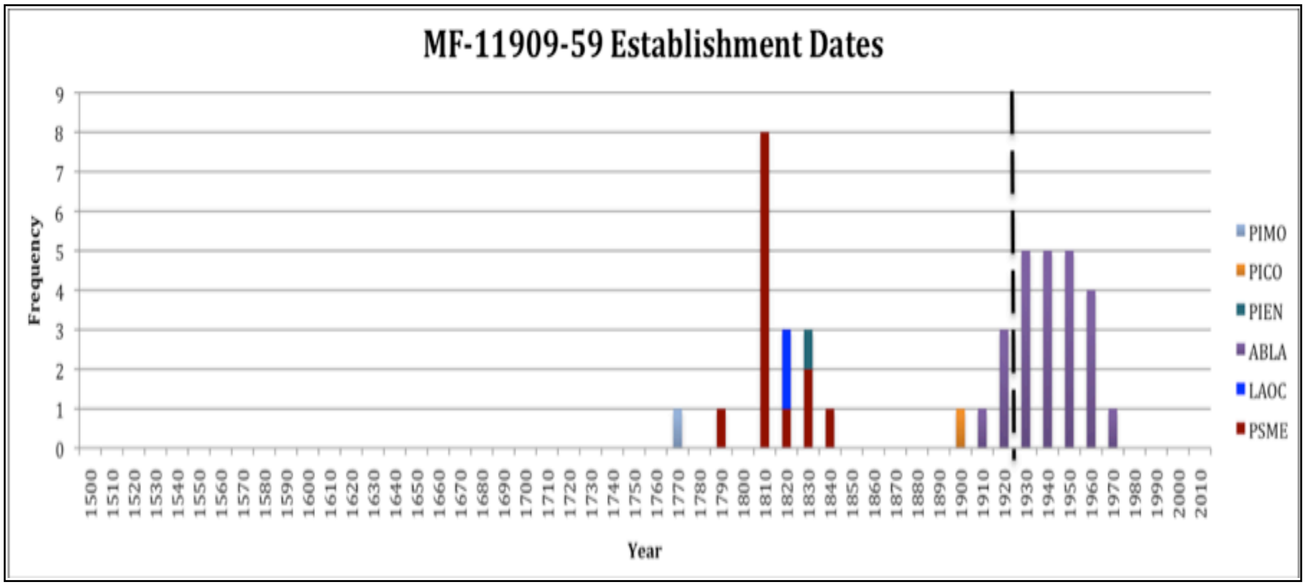


Figure 4 (Above): This graph shows the establishment dates, and potential fire year as indicated by the dashed line. Establishment dates indicate two bursts of establishment, one in the 1810's and another following the 1929 fire.

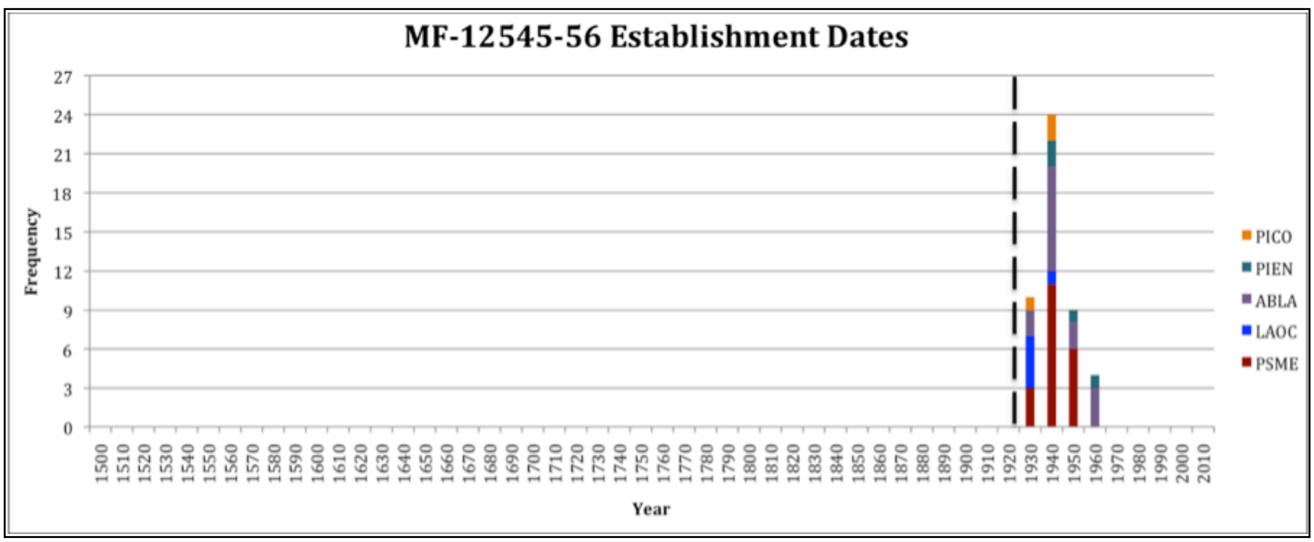


Figure 5 (Above): This graph shows the establishment dates, and potential fire year as indicated by the dashed line, unlike the previous site, there appears to be only one burst of establishment following the 1929 fire.

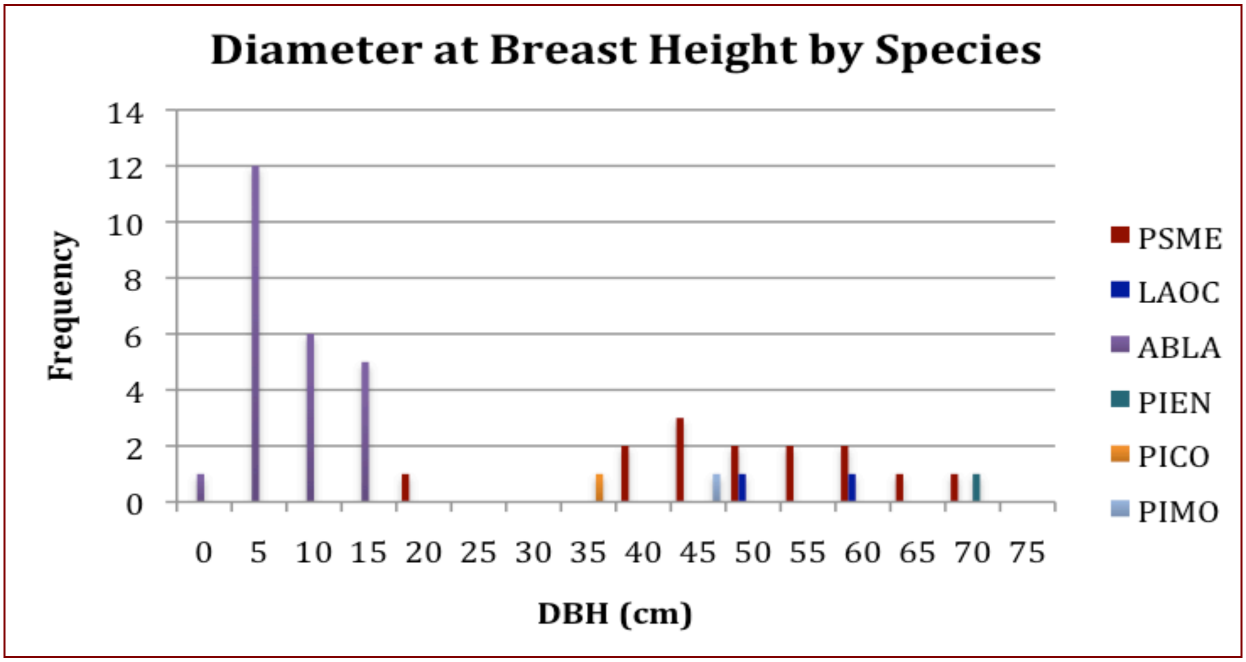


Figure 6: Site MF – 11909 – 59, showing measured DBH (cm) in 5 year bins.

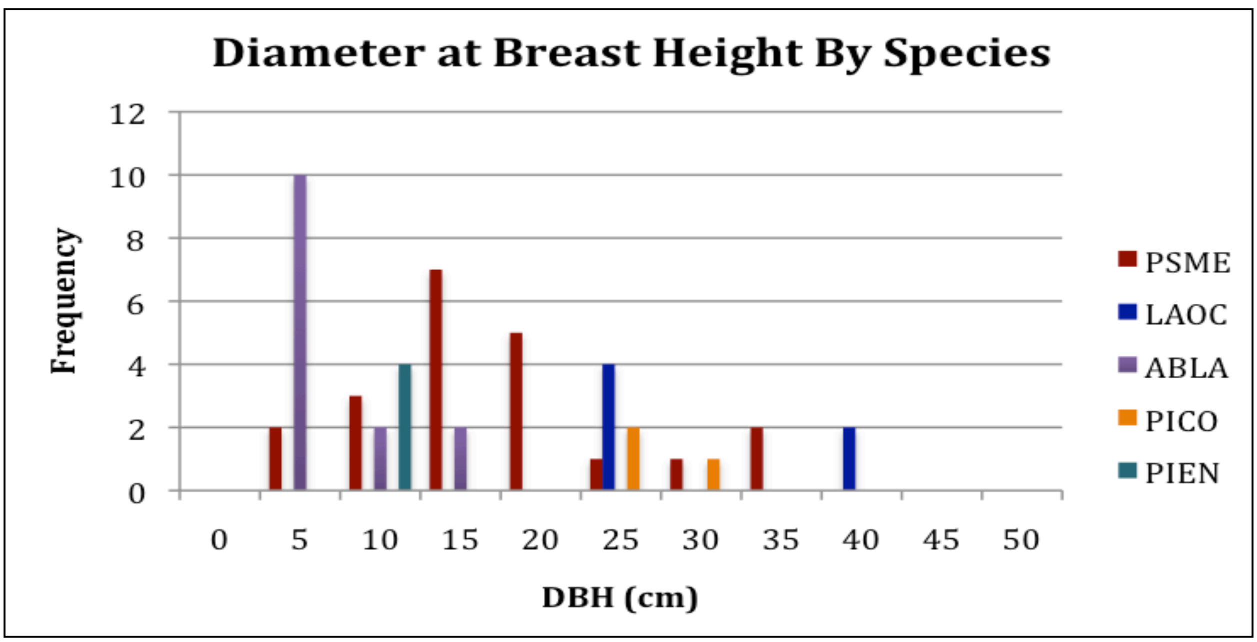


Figure 7: Site MF – 12545 – 56, showing measured DBH (cm) in 5 year bins.

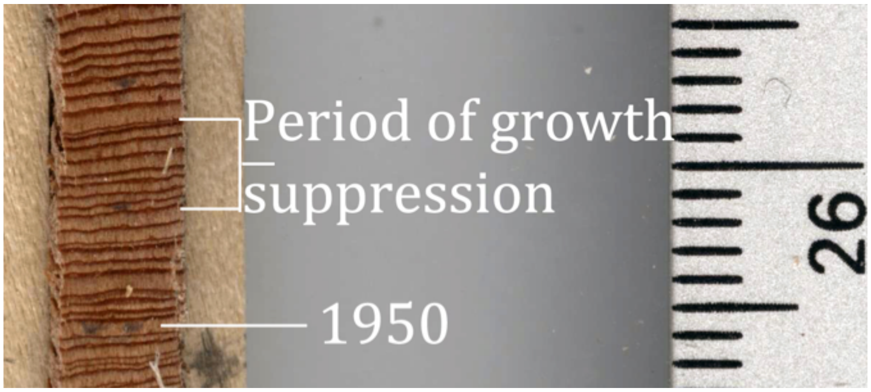
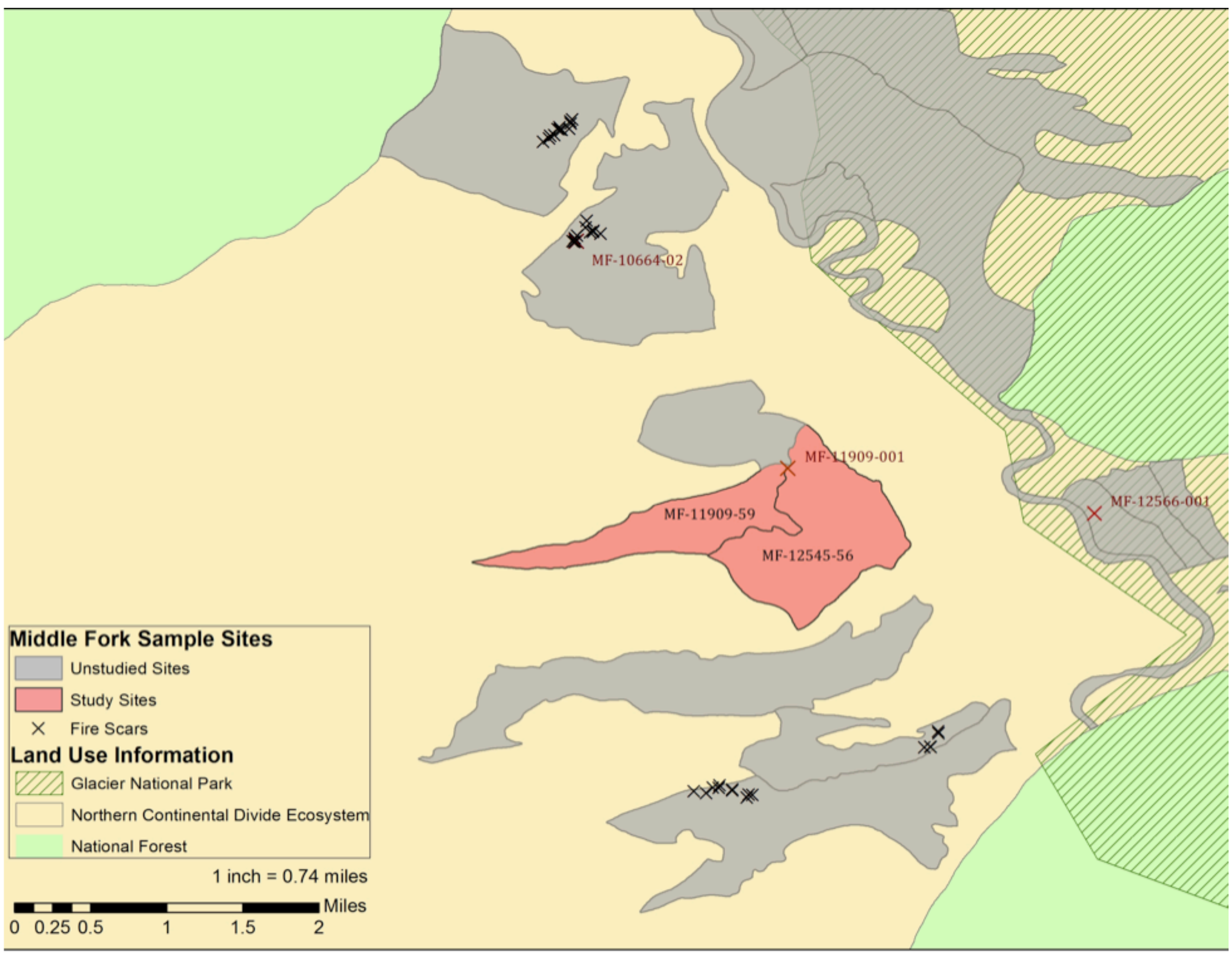


Figure 8: Image of a larch core, specifically showing growth suppression during the 1930s and 1940s, a sawfly outbreak is the hypothesized cause of this suppression.

Figure 9: Image of MF – 11909 – 59, photo illustrates the complex pattern of cohort establishment as well as the distinct difference between the overstory and understory species (Photo by Cameron Naficy, 2013).

Map 1 (Left): Area map of the general study area located in the Flathead National Forest. (Google Maps, 2014).



Map 2: Map of the Middle Fork area, showing the location of sites used in this research (highlighted in red) along with the location of fire scars used in this research (also highlighted in red).

Works Cited:

Arno, S. F. 1980. Forest Fire History in the Northern Rockies. Journal of Forestry , 78 (8), 460-465.

Arno, S. F., Parsons, D. J., & Keane, R. E. 2000. Rocky Mountains: Consequences of Fire Exclusion and Options for the Future. USDA Forest Service Proceedings , 5 (15), 224-232.

Barrett, S. W., Arno, S. F., & Key, C. H. 1991. Fire Regimes of western larch - lodgepole pine forests in Glacier National Park Montana. Canadian Journal of Forest Research , 21 (12), 1711-1720.

Brown, P., & Shepard, W. D. 2001. Fire history and fire climatology along a 5 degree gradient in latitude in Colorado and Wyoming, USA. Paleaobotanist , 50, 133-140.

Duncan, R. 1989. An Evaluation of Errors in Tree Age Estimates Based On Increment Cores In Kahikatea. New Zealand Natural Sciences , 16, 31-37.

Falk, D. A., Miller, C., McKenzie, D., & Black, A. E. 2007. Cross-Scale Analysis of Fire Regimes. Ecosystems , 10, 809-823.

Google. Flathead National Forest. 2014. 19 March 2014 https://www.google.com/maps/@46.8356321,-106.7519188,6z/data=!5m1!1e1.

Grissino-Mayer, H. D. 2001. Evaluating Crossdating Accuracy: A Manual and Tutorial for the Computer Program COFECHA. Tree-Ring Research , 57 (2), 205-221.

Gruell GE. 1983. Fire and Vegetative Trends in the Northern Rockies: Interpretations from 1871-1982 Photographs. Ogden (UT): US Department of Agriculture, Forest Service, Intermountain Forest and Range Experiement Station. General Technical Report GTR-INT-158.

Habeck, J. 1994. Using General Land Office Records to Assess Forest Succession in Ponderosa Pine/Douglas-fir Forests in Western Montana. Northwest Science , 68 (2), 69- 76.

Kottek, M., Grieser, J., Beck, C., Rudolf, B., & Rubel, F. 2006. World Map of the Koppen-Geiger climate classification updated. Meteorologische Zeirschrift , 15, 259-263.

Owens, J. 2008. The Reproductive Biology of Western Larch. Retrieved 2013 26-Novemeber from The Inland Empire Tree Improvement Cooperative: http://www.fgcouncil.bc.ca/IETC-ExtNote8-Feb08-web.pdf

Schoennagel, T., Veblen, T. T., & Romme, W. H. 2004. The Interaction of Fire, Fuels, and

Climate across Rocky Mountain Forests. BioScience , 54 (7), 661- 674.

Shearer, R. C., & Schmidt, W. C. (n.d.). Western Larch. Retrieved 2013 26-November from Silvics Manual: http://www.na.fs.fed.us/pubs/silvics_manual/Volume_1/larix/occidentalis.htm

Shearer, R., & Kempf, M. 1999. Coram Experimental Forest: 50 Years of Research in a Western Larch Forest. General Technical Report, United States Department of Agriculutre, Forest Service.

Shearer, R., & Stickney, P. 1991. Natural Revegetation of Burned and Unburned Clearcuts in Western Larch Forests of Northwest Montana. Fire and Environment, 66-74.

Sherriff, R. L., & Veblen, T. 2006. Ecological effects of changes in fire regimes in Pinus ponderosa ecosystems in the Colorado Front Range. Journal of Vegetation Science , 17, 705-718.

Smith, J., & Fischer, W. 1997 September. Fire Ecology of the Forest Habitat Types of Northern Idaho. Retrieved 2013 30-November from United States Department of Agriculture: http://www.fs.fed.us/rm/pubs_int/int_gtr363.pdf

Turner, M. G. 2010. Disturbance and landscape dynamics in a changing world. Ecology , 91 (10), 2833-2849.

Uchytil, R. J. 1991. Abies lasiocarpa. In: Fire Effects Information System. Retrieved 2014 11-February from Fire Effects Information System: http://www.fs.fed.us/database/feis/plants/tree/abilas/all.html#FIRE ECOLOGY

Williams, M. A., & Baker, W. D. 2012, May 12. Comparison of the Higher-Severity Fire Regime in Historical (A.D. 1800s) and Modern (A.D. 1984-2009) Montane Forests ‘ Across 624,156 ha of the Colorado Front Range. Ecosystems .