An Investigation into Meadow Encroachment of Sub-Alpine Fir in Mount Revelstoke National Park, British Columbia, 2009

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Abstract

Meadow encroachment by Sub-alpine fir (*Abies lasiocarpa*) was investigated in Mount Revelstoke National Park by using dendrochronological analysis to identify tree ages which were correlated with historical climate data. In-situ analysis occurred on September 16-17, 2009. Seedling age and height were recorded along eight transects within the meadow, and tree cores were taken from mature trees. In total, 45 seedlings were sampled on the transects, and 20 trees were cored. Dendrochronological analysis found a significant positive correlation between tree-ring growth and current(?) July temperature. Climate may not be the only factor affecting tree establishment in sub-alpine meadows: changing fire regimes, and land use patterns may also impact meadow landscapes. These relationships are pertinent to management strategies within the park, and raise important questions. Should park policy address the need to interfere with this natural successional process by removing the established trees, or allow nature to play out its course? This study contributes to the overall understanding of meadow encroachment in the Pacific Northwest.

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Introduction

Sub-alpine meadows are ecologically diverse, aesthetically pleasing, and economically valuable landscapes. Parks, such as Mount Revelstoke National Park (MRNP) in British Columbia, Canada, rely on the beauty of sub-alpine meadows to attract visitors. Travelers from all over the world visit the park during the summer months primarily for the spectacular wild flowers displayed in the sub-alpine meadows (Parks Canada, 2008).

Encroachment of the surrounding forest is threatening sub-alpine meadows (Franklin *et al*., 1971; Jakubos & Rommer, 1993; Woodward *et al*., 1995; Vale, 1987). Encroachment, also known as infilling or ingrowth, is the increased abundance and invasion of tree seedlings into meadow zones from more established surrounding forests. Tree establishment in meadows may be allogenic (e.g., climate change or grazing disturbance) or autogenic (e.g., alteration of microclimate by established trees) (Miller & Halpern, 1998). Miller & Halpern (1998) suggest that once the encroachment of trees initiates, autogenic factors alter the physical and biotic conditions so that establishment is perpetuated. Encroachment in sub-alpine meadows by conifers is thought to be a response to changing climate (Franklin *et al*. 1971), fire suppression (Haugo & Halpern, 2007), or change in land use, such as grazing animals (Miller & Halpern, 1998).

Of the three possible factors influencing meadow encroachment, changing climate has been thoroughly studied and documented as being a major contributing component (Franklin *et al*., 1971; Jakubos & Rommer, 1993; Peterson *et al*., 2002; Woodward *et al*., 1995). Vegetation in the sub-alpine zone of the Pacific Northwest may be particularly sensitive to climate variability (Woodward *et al*., 1994). In particular, changing climate may cause less snowpack which will influence the length of the growing season in the sub-alpine zone (Franklin *et al*, 1971). Climate variables associated with winter snowpack are strong predictors of annual growth variations: earlier melting of the snowpack allows trees to germinate earlier in the year (Lapofsky *et al*., 2003; Peterson *et al*., 2002). More specifically, the growth of Sub-alpine fir, a common species at higher elevations, is negatively influenced by winter precipitation and spring snowpack depth, indicating that growth can be limited by short growing seasons (Peterson *et al*., 2002).

Studies related to meadow encroachment and climate variability in meadows have been carried out in the Cascade Mountains (Fraklin *et al*., 1971), Olympic Mountains (Woodward *et al*., 1995), Wyoming (Jakubos & Rommer, 1993) and much of North America (Peterson *et al*., 2002; Vale, 1998). Additionally, some studies of encroachment are documented in Europe (Heiri *et al*., 2006) and China (Dang *et al*. 2006; Dang *et al*. 2008). Observations of widespread meadow encroachment suggest that meadows are not stable features of the landscape. The forest-meadow boundary is dynamic (Miller & Halpern, 1998), and in studying it dendrochronological analysis is often used (Miller & Halpern, 1998; Woodward *et al*., 1995). Dendrochronology studies the chronological sequence of annual growth rings in trees used to determine tree age (Stokes & Smiley, 1968). Dendrochronological studies provide valuable information concerning historic influences of climatic variability on tree growth and forest productivity (Peterson *et al*., 2002).

This study examines seedling encroachment in a sub-alpine meadow in Mount Revelstoke National Park. Dendrochronological analysis of Sub-alpine fir (*Abies lasiocarpa*) is used to compare growth chronologies to climatic and disturbance records. The intention is to connect links between seedling establishment and factors that may be

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contributing to the encroachment. The current state of the encroaching seedlings creates concern for meadow integrity and management. With potential irreversible consequences related to encroachment, management questions arise whether to destroy the invading trees, therefore restoring the meadow, or let nature take its successional path and allow the meadow to be eventually transformed into a forest.

Methods

Site Description

The study site is located in Mount Revelstoke National Park (51°02'38" N, 118°08'33" W) which lies within the interior wet belt of southeast British Columbia in the Selkirk mountain range (Parks Canada, 2009). The Monashee Mountains lie to the west and the Purcell Mountains lie to the southeast. All three mountain ranges are part of the larger Columbia Mountain Range, delineated by the Columbia River. The Trans-Canada Highway makes up the western borders of MRNP. The more well-known Glacier National Park is 25km east and Revelstoke town site is located on the Columbia River just outside the southwest corner of the national park. RNP covers an area of 260km^2. The topography is generally rough and steep with deep narrow valleys, avalanche chutes, snowfields and alpine glaciers. Some of the highest peaks in the park are over 2500m in elevation. RNP is considered to be an example of the Montane Cordillera Ecozone (Parks Canada, 2009). The climate is dominated by relatively mild temperatures and heavy precipitation that is mainly snow fall; annual average precipitation 1995mm in the sub-alpine zone (Parks Canada, 2009).

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From the top of the Meadow in the Sky Parkway, RNP, the study site is found approximately 1.5km along the Eva Lake hiking trail. The study site is a high alpine meadow, with an approximate elevation of 1900m, surrounded by mature forest of mainly Sub-alpine fir with a few mountain hemlocks (*Tsuga mertensiana*). At all meadow-forest boundaries, the meadow has extensive conifer seedling encroachment. In addition, there is a large stand of mature trees (Figure 1) that form a tongue, splitting the meadow in two, referred to in this study as the east and west side of the meadow. The

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meadow is adjacent to a well-used, well -maintained summer hiking trial. There is an old, abandoned hiking trail visible on the west side of the study site. The meadow is very moist and contains several shallow standing ponds on the upper west side and three very small creeks. The east side of the tree tongue was slightly drier and has small dry creek beds. There are several drainage ditches cut into the slope, presumably to manage excess water and encourage the prolonged maintenance of the summer hiking trail. In the meadow there is upturned soil, an indication of winter animal burrowing. In the mature forest tongue several small rodents were seen, as well as burrow holes at several tree bases. Evidence of past fire activity is extensively shown by several burned fallen logs and burn scars on standing trees. Looking north from the study site a south facing alpine meadow can be seen. The south facing meadow appeared to have significantly less seedling encroachment in comparison to the study site.

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The Meadow in the Sky becomes snow free in late June to mid July (Parks Canada, 2009). Precipitation in the form of snow occurs at high elevation beginning as early as September (Parks Canada, 2009), leaving a very short snow free period where plant growth is possible.

The vegetation of the meadow consists of grasses and wildflowers. Dominant meadow species are Indian hellebore (*Veratrum viride*), steam violet (*Viola glabella*), low mountain lupin (*Lupinus Lepidus*), Sitka valerian (*Valeriana sitchensie*), Indian paintbrush (*Castilleja spp.*), mountain arnica (*Arnica latifolia*), arrow-leaved groundsel (*Senecio triangularis*), Western pasque flower (*Anemone occidentalis*), red mountain heather (*Phyllodoce breweri*), and white mountain heather (*Cassiope mertensiana*). As well, there are several grass and rush species in the meadow that were not identified.

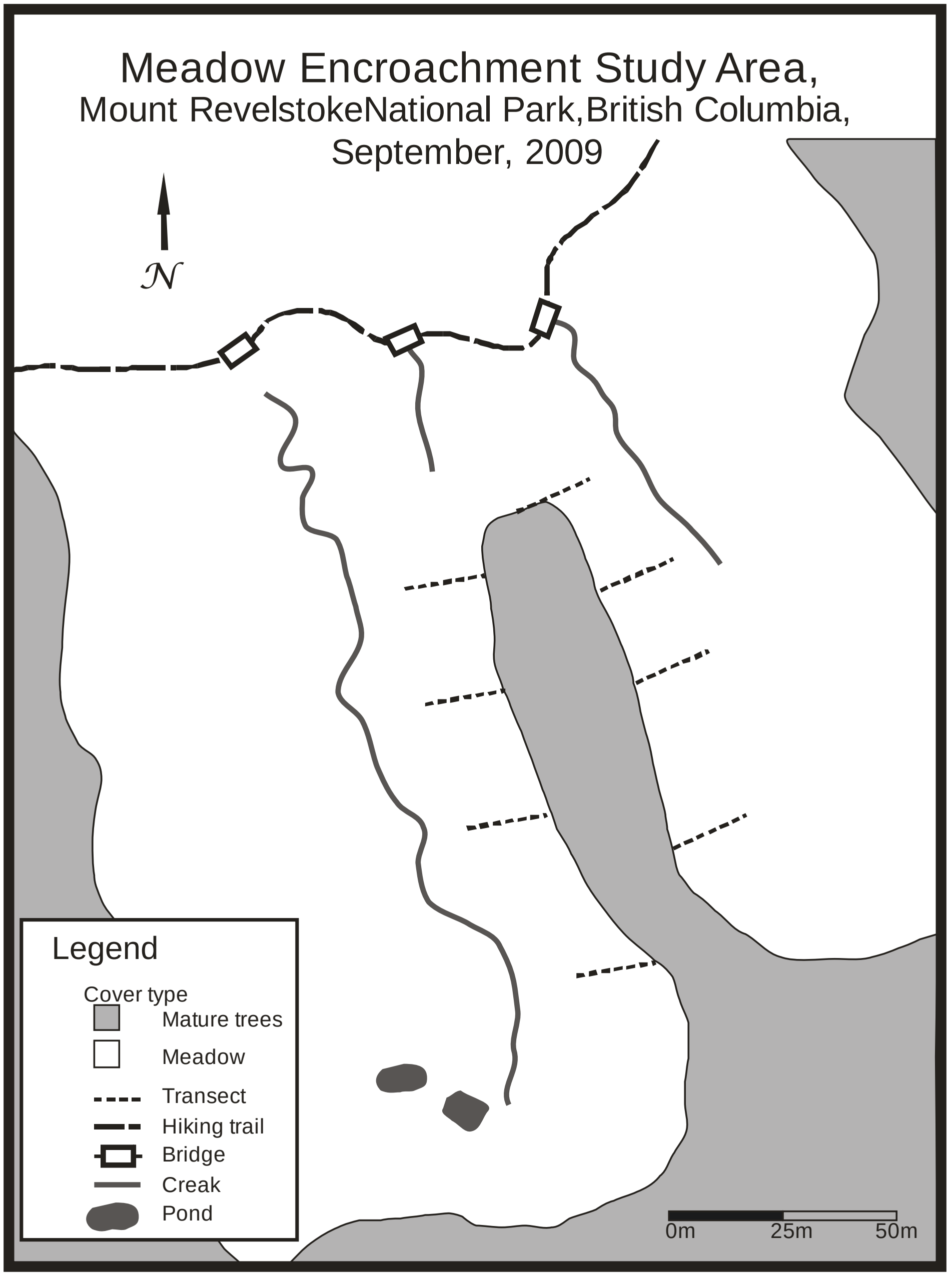

Figure 1: The meadow study site on Mt. Revelstoke.

Data Collection

Data collection occurred between September 16 -17, 2009. In order to create a map of the study site, a Garmin Map 76 GPS was used to collect waypoints along the trails, the streams, and throughout the study area.

Heights and ages of Sub-alpine fir were collected along eight transects in the meadow (Figure 1). Four transects were laid on the east and west side of the tree tongue. The same methods were used for all eight transects. The first transect (i.e. T1) was laid at the tip of the tongue (i.e. at the lowest elevation of the mature tree patch) and ran parallel to the hill contour on the east side of the tongue. The next three transects (i.e. T2, T3, and T4) were made at 20m intervals walking up slope. On the west side of the tongue, the last four transects (i.e. T5-T8) were laid at 20m intervals; however, the first one (i.e. T5) began 10m up the hill from the lowest most point of the tree tongue. The starting point for T5 was chosen so that the transects on the west were staggered with those on the east side. Each transect began (i.e. 0m) at the edge of the mature tree patch and ran for 25m into the meadow. Data were collected for every seedling that lay on the 1m intervals (i.e. at 1m, 2m, 3m, etc) of the transects, as long as the tree was within +/- 10cm of the meter mark. The height, number of whorls, and location along the transect were recorded for each seedling that lay at a meter mark. GPS waypoints were taken at the start and end of every transect. Compass bearings were taken to calculate the direction of the transect.

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In order to verify the accuracy of the whorl counts, random samples of the seedlings were taken. Core samples were taken from larger seedlings and destructive samples were taken from the smaller seedlings. All samples were taken from the base of the trees. The core and cookie samples were labeled according to which transect they were nearest to and where along the transect the tree was located (i.e. T3/4.4m, T7/9m, etc).

Tree core samples were taken from the mature tree stand that extended into the meadow and from a few trees in the mature stand on the edge of the meadow. Trees were selected at random and cored at the base. Two cores per tree were taken at right angles to each other in order to cross date samples in the lab. The height of each cored tree was taken using a Nikon digital height gauge.

Data Analysis

Facilities in the University of Victoria Tree-Ring Laboratory were used for preparation and analysis of the tree samples. The wood was allowed to air dry, and then core samples were mounted to slotted mounting boards using water-soluble wood glue. Once the glue dried, the wood was sanded using four progressively finer grit sandpaper, ending with a 400 grit sandpaper. The cores were scanned into WinDENDERO (Version 6.1D, 1998) an image processing system for the tree-rings to be measured and crossdated. A 40x microscope and Velmex stage were used to verify the ring boundary positions for core (Laxton & Smith, 2008) and cookie samples that had difficult rings to identify. Measure J2X was used with the Velmex to measure the tree-ring widths and date them.

Marker rings were identified using the list method. COFECHA was used to verify the marker rings. COFECHA was used to determine the accuracy and correlation in the crossdating for each tree-ring series (Grissino-Mayer, 2001). When COFECHA identified an error in a series it was reduced either by editing the tree-rings manually in WinDENDRO or electronically in EDRM. Correlations of .328 or greater were identified for each series and the whole data population to give a 95% confidence interval. Once the cores were sufficiently crossdated, the data were standardized using a spline interpolation growth curve in ARSTAN (Cook & Holmes, 1986). Using ARSTAN, autocorrelation was removed and a residual chronology of the data was created (Cook & Holmes, 1986). When performing analysis on tree-ring chronology and climate data, DENDROCLIM was used to view statistical correlation in a robust way (Biondi & Waikul, 2004). The climate data used is from the town of Revelstoke, as it has the closest weather station to RNP. Temperature and precipitation are the two types of climate data used in this analysis. Specifically, the mean, maximum and minimum monthly temperatures dating back to 1898 and monthly precipitation dating back to 1926 were analyzed.

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Results

Ring counts from samples are used in order to validate in-situ whorl counts (Figure 2). The ages for one sample match perfectly (T8/4): the whorl count and ring count age the tree to 63 years old. The difference between age estimates from the two methods varies between 7% and 25% for the other samples.

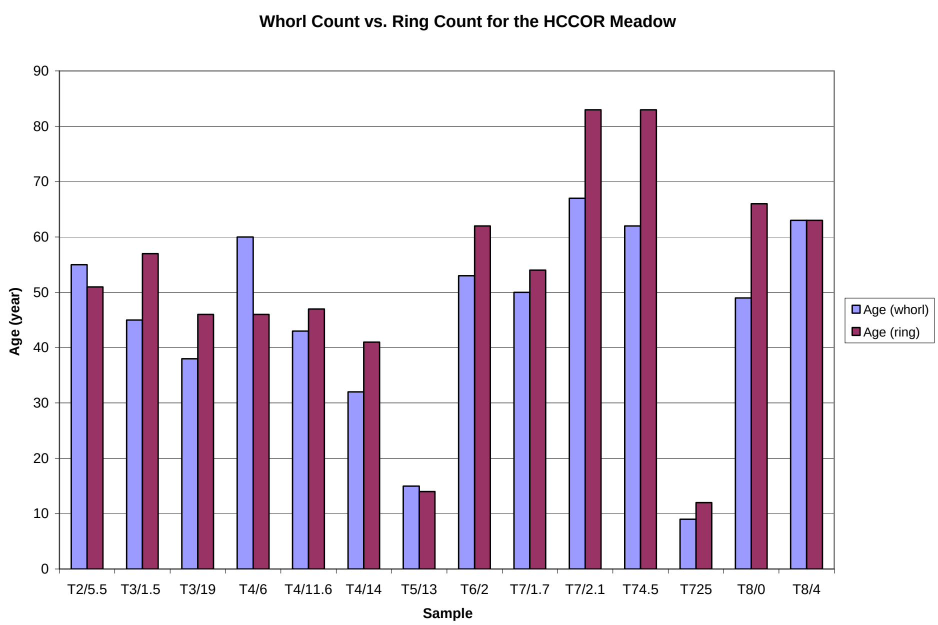


Figure 2: Ages of seedlings as determined by whorl count and ring count.

The age and distance along the transect are plotted and used in a regression analysis in order to quantify the relationship between age and distance from the mature tongue of trees (Figure 3). The regression created for the total sample set has an R^2 value of 0.2597. The regression created for the samples on the east side of the study site has an R^2 value of 0.0911. The regression created for the samples on the west side of the study site has an R^2 value of 0.3986. All relationships are positive, with the correlation on the west side of the tongue being the strongest. As shown in Figure 3, the trees are evenly distributed along the transect with the older trees closer to the mature tree tongue, and the younger trees extending into the meadow.

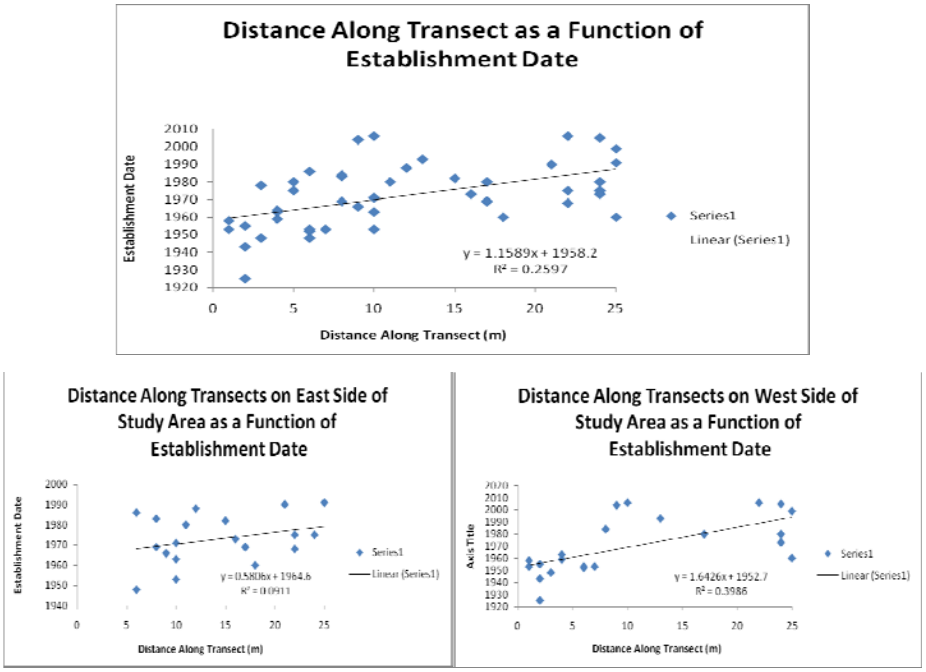


Figure 3: Distance along the transects as a function of age for seedling establishment.

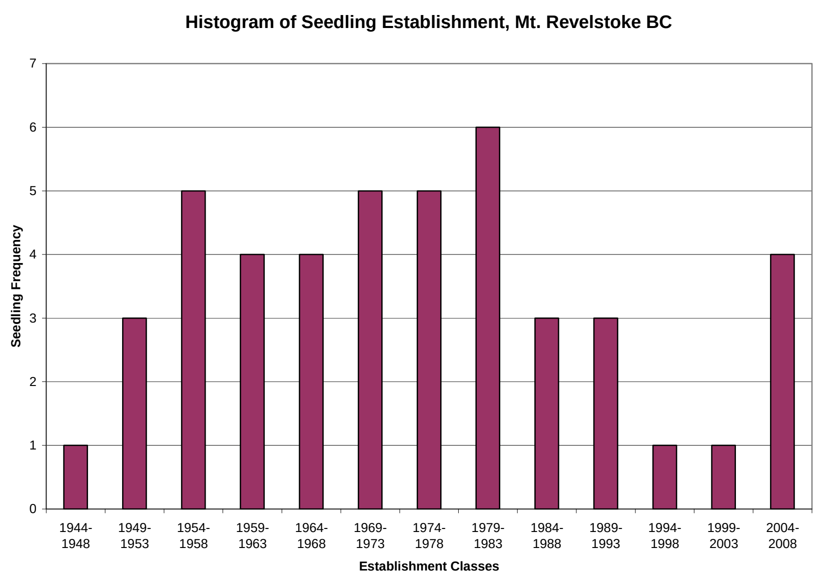


Figure 4: Frequency of tree establishment by age groups since 1944.

As found in Figure 4, most trees are between the ages of 25 and 54 years. Peak establishments occurred between 1954-1958 and 1969-1983, which corresponds to 47% of all sampled trees. Out of a sample size of 45, only one tree is 65 years old and two trees are between 5 and 10 years old. Figure 4 also displays an upward trend in tree establishment in the last five years; four of the sampled trees have established in the meadow since 2004.

Figure 5 compares the standard to the residual chronology for the mature trees. The standard chronology often contains autocorrelation, and since this study looks at current year tree-ring chronology and climate data, the residual value was used. The residual chronology values were whitened to remove any autocorrelation. The residual chronology shows the growth frequency of the mature tree-ring series around the mean on a current year basis. Peaks above a value of 1 are considered above average growth and troughs below 1 are considered below average growth of the Sub-alpine fir.

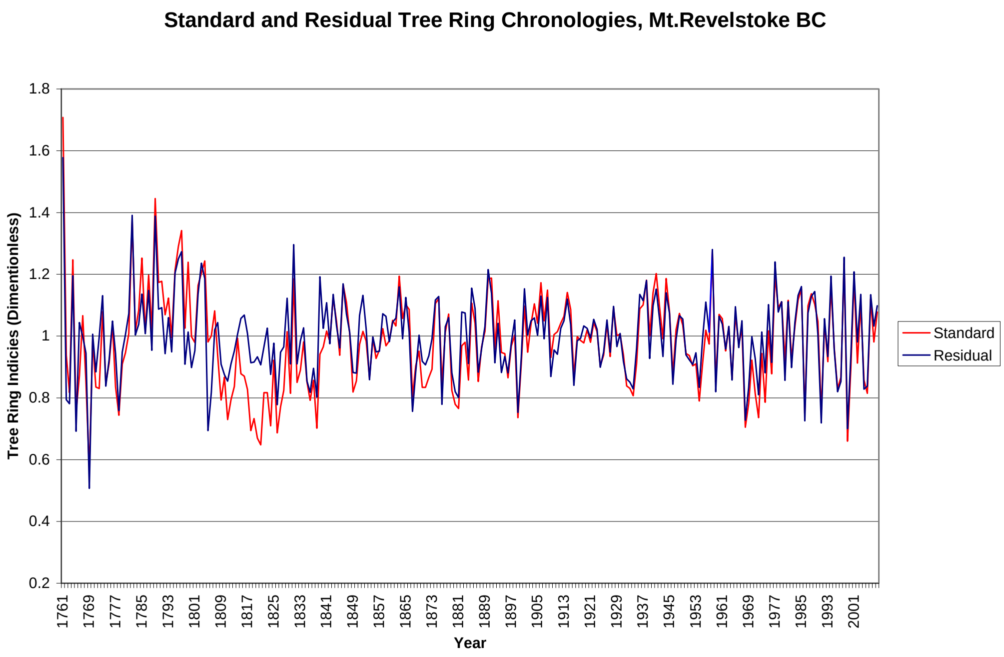


Figure 5: A graphical representation of the similarities between standard and residual tree-ring chronologies. The scale shows average growth as having the value 1.

Shown in Figure 6 is the residual tree chronology compared to the tree series sample depth. Tree sample depth is the count of tree-rings from individual tree series that exist within each growth year over the period 1761 to 2008. More variability around the mean (1) is evident from 1761 to the 1940's where the sample depth is much smaller. The majority of the tree-ring series exists from the 1920's to 2008 and less variability about the mean is evident as sample depth increases.

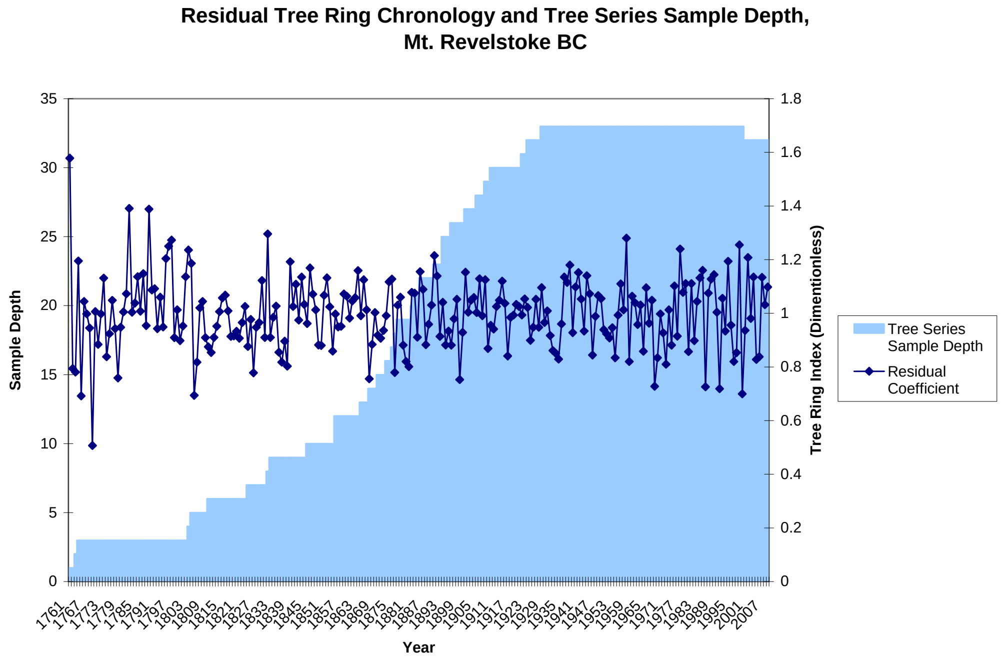


Figure 6: Residual chronology of Sub-alpine fir showing annual growth and tree series sample depth. The scale shows average growth as having the value 1.

Figure 7 displays climate data between 1898 and 2007 shows periods of highs and lows. Mean annual temperature for the area ranges between 5.1°C and 8.6°C. Annual precipitation for the area ranges between 161mm and 1355.1mm. Figure 7 clearly shows a gradual rise in annual temperature of approximately 1.25°C from 1898-2007.

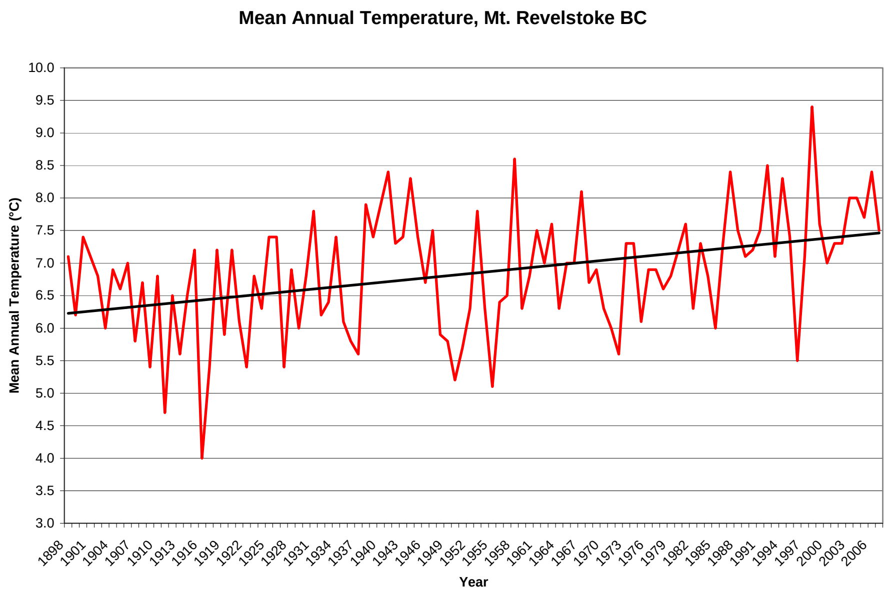


Figure 7: Mean annual temperature for Revelstoke shows a warming trend since 1898. (give data source ref.)

Seen in Figure 8, the output from DENDRCLIM shows a strong correlation between mean July temperature from 1898 to 2007 and the residual chronology. The R^2 value is 0.50 in the 95th percentile.

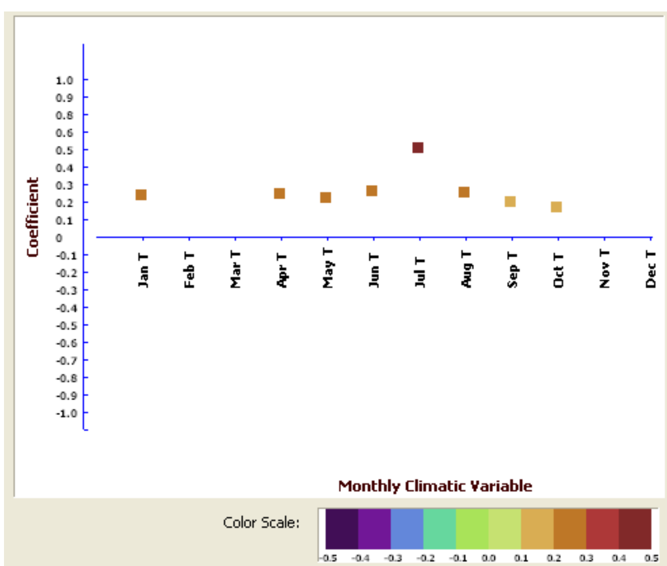


Figure 8: Output of results from the residual tree-ring chronology and mean monthly temperature climate data from DENDROCLIM.

The correlation output for the current year residual tree-ring coefficient and monthly precipitation is not significant, and thus precipitation has no statistical significance on the mature trees in our study area. However, as seen in Figure 8, mean monthly temperature data significantly correlates with the residual chronology. Figure 9 shows the correlation between the residual chronology and mean July temperature data. Coefficient values prior to the 1930's show little correlation; nonetheless, a trend is established with high correlation evident from the 1930's to 2007.

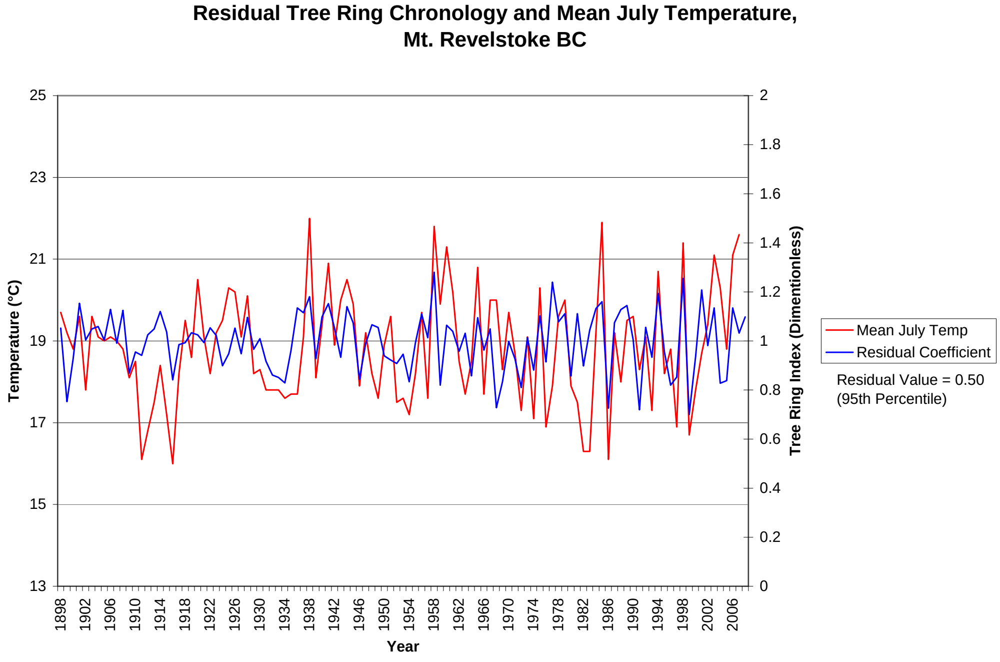
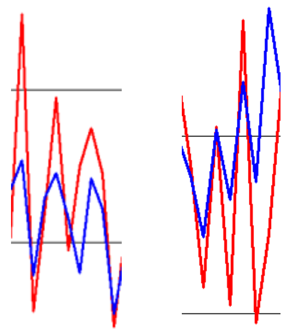


Figure 9: A graphical representation showing the correlation between the annual residual tree-ring chronology and mean July temperature.



1938-1946 1970-1976

Figure 10: Enlarged images from Figure 9 showing the two main periods of high correlation from 1938-1946 and 1970-1976. This indicates that mean July temperatures in the meadow has a high, positive correlation with tree-ring growth of the mature Sub-alpine fir trees.

In DENDROCLIM, an evolutionary and moving response analysis was performed with a 24 year window placed on the data. The output is a linear trending correlation coefficient for mean July temperature. In Figure 11, this line was placed on top of the seedling establishment frequency from 1944 to 2008 to show any correlation between mean July temperatures and the establishment dates of the Sub-alpine fir seedlings. There is evident correlation during the period from 1954 to 1967 when seedling establishment rates increase. However seedling establishment during the 1970's into 1985 does not correlate with the mean July temperature coefficient.

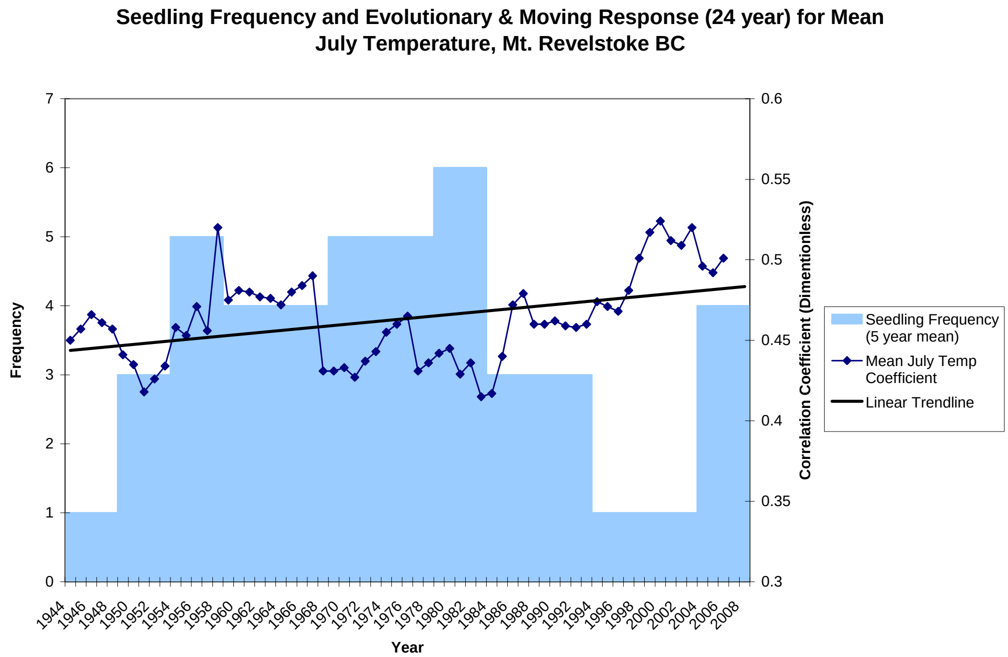


Figure 11: A graphical representation of the Sub-alpine fir seedling frequency with a 5 year mean and how it relates to mean July temperature over a period of establishment from 1944 to 2008.

Discussion

Comparison of whorl count and ring count in Figure 2 shows that the two methods of seedling dating have similar results (i.e. 0-25% difference). The analogous ages affirm the accuracy of the dating method used and it was decided that the whorl counts of the seedlings could be used as accurate estimates of the seedling ages found on the transects.

The age of the encroaching trees decreases with distance away from the meadow-forest boundary (Figure 3). When rationalizing seed dispersal over time, the age-distance relationship appears logical. The results indicate that the meadow-forest boundary is indeed moving further into the meadow over time, as new seedlings are established. The movement of the boundary is similar to the upward movement of tree lines on many North American mountains, the rates of which are being affected by changing climates (Roland & Matter, 2007). However, the results of this study are contrary to the findings of the study done by Lepofsky *et al*. in which conifer establishment over a similar time span lacked a relationship between establishment and distance from the meadow-forest boundary (2003).

The majority of the seedlings established between 1954 and 1983 with peaks in establishment in 1954-1958 and 1969-1984 (Figure 4). The peak dates from 1969-1984 are similar to the conifer establishment dates found in several other studies in the Pacific Northwest (Lepofsky *et al*., 2003; Robichaud & Laroque, 2005; Woodward *et al*., 1995). The conifer seedlings in the Lepofsky *et al*. study were generally all established from 1970 to 1992 with a peak in growth around 1980 corresponding to the peak in this study (Figure 4) (2003). Other studies involving Sub-alpine fir seedling establishment in western Canada show most establishment occurred between 1974-1983 (Robichaud & Laroque, 2005) and between 1956-1985 (Woodward *et al*., 1995). Other studies have also found that seedling establishment declined after 1985-1990, which is similar to the establishment pattern on Mt. Revelstoke, which declined after 1984 until 2003 (Lepofsky *et al*., 2003; Miller & Halpern, 1998; Robichaud & Laroque, 2005). The comparable peaks and troughs of establishment dates indicate that the meadow on Mt. Revelstoke and other meadows in the Pacific Northwest have likely been impacted by similar environmental changes.

The results from DENDROCLIM, which can be seen in Figure 9, are comparable to those from the study done by Robichaud & Laroque (2005). Correlation between the residual chronology and monthly precipitation did not exist in either study, however both results conclude a significant correlation between mean July temperature and residual chronology (Robichaud & Laroque, 2005). There are a few possible factors that explain the significance between July temperatures, growth, and establishment. At high elevations, tree distribution and growing seasons can be limited by temperature and snowpack (Lepofsky *et al*., 2003; Woodward *et al*., 1995). Further, at high elevations, most of the growing occurs in July while August is a period for nutrient accumulation (Robichaud & Laroque, 2005). In addition, establishment has been found to increase during summers with above average temperatures and during warm, dry periods (Robichaud & Laroque, 2005; Rochefort & Peterson, 1996). Figure 9 shows this positive correlation between the tree-ring growth and the mean July temperature from approximately 1962-1980. Therefore, since the mean annual temperature (Figure 7) and July temperature (Figure 11) for Revelstoke show a warming trend, temperature will likely continue to correlate with growth and possibly establishment.

Using Robichaud & Laroque's hypothesis that "the factors affecting growth would also affect establishment trends," the seedling establishment frequency is compared to the mean July temperature coefficient in Figure 11. Figure 11 shows a warm trend in temperature that corresponds to the establishment from 1954-1968. The main peak in establishment (i.e. 1969-1983) does not relate to the temperature coefficient, which contradicts the expected results. Similarly, where there is very little establishment, from 1984-2004, it would be expected that July temperatures would be below average, but instead they are above average and increasing (Figure 11). As concluded by Robichaud & Laroque, July temperature has significant influence on growth, but it is not the only factor determining establishment (2005).

Not only are there factors possibly driving the establishment of the seedlings (i.e. climate change), but also, there are likely factors that no longer control the establishment. Because Mt. Revelstoke has been inside the boundaries of a national park since the early 1910's, the ecosystems have been modified by a history of fire suppression (Parks Canada, 2008). Parks Canada admits that there have been suppressed fires where the fires could be beneficial to an ecosystem and that the ecosystems lose their integrity when these natural processes are not intact (Parks Canada, 2008). The traces of past fires in the study site were not dated. Historically, stand-replacing fires in the Mt. Revelstoke area have an average fire cycle of 181yrs with a range between 150-240yrs (Wong *et al.*, 2003). The sampled mature trees from the meadow could have been established after a major fire disturbance and before the park was established. And since then, smaller fires could have played a role inhibiting encroachment of the seedlings. Unfortunately, fire records for the study site were not identified and the twenty mature trees cored in this study do not give a sufficient sample size for dating the mature forest.

There were several limitations in this study. First, Sub-alpine fir has a germination time of approximately three years which was not taken into account when dating the seedling establishment, and may have impacted the correlation between the samples and historical data. Second, climate lags were not taken into consideration, which may have unforeseen connections with tree-ring growth. The methods used in this report may also be flawed, in that there were discrepancies between whorl age count and ring count. This has consequences when it comes to identifying the peak periods of establishment in the meadow. Another limitation in the methods is the small sample size (n=20 mature trees, n=45 seedlings) which restricts the statistical operations that can be performed.

Conclusion

The purpose of this report was to study the meadow encroachment of Sub-alpine fir (*Abies lasiocarpa*) in RNP by collecting data in situ, conducting laboratory analysis of the data, interpreting possible causations of the data, and exploring possible impacts of the encroachment. The object of this report was to perform dendrochronological analysis on our field data and compare it to climatic and disturbance records to determine if correlations existed within the data. The intention was to explain the factors that could be contributing to the meadow encroachment and illustrate concerns the encroachment make for meadow integrity and management.

The results of in-situ transects showed that young fir seedlings are situated farther into the meadow, whereas older seedlings are closest to the mature tree tongue. The oldest seedling was 65 years old, but the majority of trees in the meadow established between 1954 and 1983, with peak establishment occurring between 1954-1958 and 1969-1983. Additionally, the results show a significant positive relationship between mature tree growth and July temperatures of the current year.

Climate records show a historic increase in local temperature, a possible factor in the increase of meadow encroachment. Additional factors affecting this habitat may include the cessation of natural disturbance regimes including fire and ungulate grazing. If these trends continue, future landscape alteration may be exacerbated and the meadows may be replaced by forest.

The implications for park management are vast. Mount Revelstoke National Park has a three pronged mandate: education, protection, and memorable visitor experience (Parks Canada, 2009). The Sub-alpine meadow, as a unique and important biosphere, offers important ecological benefits as well as a beautiful landscape which annually draws visitors to the park. Will management interfere with the process of meadow encroachment, which could mean destructive practices in order to save this dwindling ecosystem? Or will the meadow be allowed to fade into the surrounding forest?

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