COMPARISON OF CURRENT AND HISTORICAL STAND STRUCTURE IN TWO INTERIOR DOUGLAS-FIR SITES IN THE ROCKY MOUNTAIN TRENCH, BRITISH COLUMBIA, CANADA

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ABSTRACT

Contemporary stand characteristics in the dry Douglas-fir (*Pseudotsuga menziesii*) and ponderosa pine (*Pinus ponderosa*) types of western North America are very different than in the era that pre-dates European settlement. Historic stand structure consisted of well-spaced, large-diameter trees, sparse pockets of younger trees, and a highly diverse understory. Naturally occurring fires, on the order of every 2 to 15 years, created bare mineral soil seedbeds and reduced grass competition sufficiently to permit the regeneration of individual trees and clumps. Contemporary stands consist of dense thickets of sapling and pole-sized trees, occasional large-diameter overstory trees, and poorly developed understory communities. The incidence of insect, disease, and catastrophic fire disturbance is increasing in these forest types. The changes in stand structure and disturbance regime are due to a combination of livestock grazing, favorable climate for seed production and germination, and fire suppression. Restoration and management of these ecosystems is now considered to be the most effective strategy for preserving biodiversity, maintaining endangered species, and avoiding catastrophic disruption of ecosystem functions. The first step in ecosystem restoration is establishment of historic reference conditions utilizing methods to determine the historic range of variability for ecosystem structure, composition, and the dominant disturbance regime. Historical fire regime data were collected and analyzed from two sites in the Rocky Mountain Trench of British Columbia. The fire regime from both sites are characterized as frequent, with mean fire intervals of 14.1 and 18.9 years. Historic and contemporary stand structure and composition were determined from a series of sample plots located in the two sites. Plot data showed variability in tree regeneration in the past, significant stand density increases since the late 1800s, and a shift in tree species composition. Many structure and composition changes appear to be aspect dependent. The study results indicate a significant departure in ecosystem structure, composition, and disturbance regime from the historical reference condition. While much of the study data cannot be overly extrapolated across the Rocky Mountain Trench, some initial guidelines for restoration efforts can be derived.

keywords: British Columbia, dendrochronology, Douglas-fir, ecosystem restoration, historic fire regime, *Pseudotsuga menziesii*, Rocky Mountain Trench.

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INTRODUCTION

In western North America, contemporary stand characteristics in the dry forest types, specifically ponderosa pine and Douglas-fir, are very different today than they were before European settlement (Covington et al. 1994). In British Columbia, the only Canadian province containing ponderosa pine and the province containing the majority of interior Douglas-fir, this concept of changed conditions is recognized, but few studies specific to the problem have been conducted there. These ecosystems are currently well outside the historical range of variability for stand structure, species composition, and disturbance processes. Where ponderosa pine is the dominant species, studies have revealed that historical stand structure consisted of multi-aged, well-spaced, large-diameter trees, sparse pockets of younger trees, and a highly diverse understory (Cooper 1960, Agee 1993, Arno et al. 1995, Sackett et al. 1996, USDA 1997). Less intensive research has been conducted to determine historic stand structures in dry interior Douglas-fir-dominated forest types (Agee 1994). Where data have been collected, historical stands were found to be open and composed of large-diameter mature stems with few or no understory conifers (Keane et al. 1990, Agee 1993, Gray 2001).

In the northern part of the range for both ecosystems, which includes Washington, Idaho, Montana, and British Columbia, fires, either due to lightning or humans, occurred on the order of every 5 to 20 years (Agee 1994; Ohlson 1996; Wright 1996; Everett et al. 1997, 2000; Riccius 1998; Gray and Riccius 1999; Gray 2001; Schellhaas et al. 2000). These frequent fires were the dominant disturbance process that maintained historic stand structures (Biswell 1973, Weaver 1974, Harrington and Kelsey 1979, Habeck 1990, Arno et al. 1995, Wright 1996, Everett et al. 1997, Gray 2001).

Contemporary stands of ponderosa pine and Douglas-fir consist of dense thickets of sapling and pole-sized trees (Bonnor 1990), occasional large-diameter overstory trees, and poorly developed understory communities (Bonnor 1990, Mutch et al. 1993, Mutch 1994, Arno 1996, Covington et al. 1997). Insect- and disease-caused mortality is occurring at a higher rate today than in the past several centuries (Wickman and Swetnam 1996, USDA 1997), and in the past decade large areas of these ecosystems have been detrimentally affected by wildfire (Camp 1995, Camp et al. 1995, Camp and Everett 1996, Gaines et al. 1997, Sheppard and Farnsworth 1997). The changes in stand structure have been caused by a combination of intensive livestock grazing, favorable climate for seed production, and fire suppression (Barrett 1988, Covington and Moore 1994, Touchan et al. 1995).

The restoration and management of these ecosystems, consistent with conditions present during their evolutionary history, is now considered to be the most effective strategy for preserving diversity, maintaining endangered species, and avoiding catastrophic disruption of ecosystem functions (Covington et al. 1994, Covington 1995). In order to begin the process of ecosystem restoration, reference conditions for these ecosystems need to be determined (Fulé et al. 1997). Several approaches have been taken to determine reference conditions in these ecosystems throughout the western United States (Arno et al. 1995, Camp 1995, Fulé et al. 1997, Harrod et al. 1999). In each case the researchers were attempting to determine the historical range of variability (Morgan et al. 1994, Swanson et al. 1994, Swetnam et al. 1999) for ecosystem structure, composition, and fire regime. Comparisons can then be made with contemporary conditions. The data could be used to estimate departure of current vegetation conditions from those during the pre-settlement era, to predict potential changes in forest composition and structure, and to develop objectives or targets for restoring forest composition, structure, and spatial pattern (Harrod et al. 1999). In British Columbia, the data can be used to refine ecosystem management guidelines and implementation plans such as those developed for the Rocky Mountain Trench in the Kootenay/Boundary Land Use Plan.

STUDY AREA

This study was conducted in the Cranbrook Forest District of the Nelson Forest Region in southeastern British Columbia. Climate in the study area is continental: Mean temperatures range from a low of –9 °C in January to a high of 18 °C in July, and mean annual precipitation is 438 mm with 59% occurring as rainfall (Chilton 1981). Plots were established on two study sites: Lewis Ridge (lat 50°45′30″N, long 115°37′30″W), 37 km to the northeast of Cranbrook; and Isidore Canyon (lat 49°28′00″N, long 115°44′00″W), 12 km to the southeast of Cranbrook.

The Lewis Ridge plots ranged from 1,030 m elevation to 1,100 m, and from 110° to 180° aspect. Slopes were moderately steep ranging from 45% to 54%. In the ecological classification system for British Columbia (Krajina 1965), the biogeoclimatic classification for the Lewis Ridge site was Interior Douglas-fir dry mild 2 (IDFdm2) site series 02 (Braumandl and Curran 1992). The combination of xeric soil moisture and medium-to-poor soil nutrient characteristics signifies a designation of 02 as the site series with characteristic vegetation consisting of Douglas-fir and ponderosa pine in the overstory, and Rocky Mountain juniper (*Juniperus scopulorum*), common juniper (*J. communis)*, arrowleaf balsamroot (*Balsamorhiza sagittata*), and antelope bitterbrush (*Purshia tridentata*) in the understory.

The Isidore Canyon site was located at 1,158 m elevation, 57° aspect, 12% slope, and on an IDFdm2 01 site series. This plot was markedly different from the Lewis Ridge plots in both topographic characteristics and site series. The Isidore Canyon plot was higher in elevation, on a northeast aspect versus the southeast-to-south aspects at Lewis, and on a very shallow slope gradient. Overstory species on this site included Douglas-fir, ponderosa pine, and western larch (*Larix occidentalis*). The understory comprised primarily pinegrass (*Calamagrostis rubescens*), although scattered individuals of antelope bitterbrush and bluebunch wheatgrass (*Agropyron spicatum*) could be found in openings. The effects of topography and plant species composition are reflected in the IDFdm2 01 designation, which indicates a more mesic soil moisture and nutrient-rich regime (Braumandl and Curran 1992).

Study site selection was based on a previous project in 1997 (R.W. Gray, British Columbia Ministry of Forests, unpublished data). Both sites met the criteria of having a limited history of harvest or catastrophic fire impacts and being close enough to town to be used for educational purposes. Budget and timing allowed for more intensive sampling in Lewis Ridge where four plots were established in addition to fire history sampling. The Isidore Canyon site fell within the Cranbrook Forest District Demonstration Forest. A single plot was established here for comparison with Lewis Ridge and for public education. Historical fire regime sampling also took place at the Isidore Canyon site.

METHODS

Plot Locations

Plots were randomly located on the Lewis Ridge site by creating a 100 × 100-m map grid over the 21.9 ha study area and assigning a number to each square. Study plots were 50 m^2 and anchored with the northwest corner of the plot in the northwest corner of the grid. Potential study plots were chosen by picking random numbers and locating them on the grid. A set of criteria were established ahead of time as minimum acceptable conditions for plot placement. Because the objective behind the study was to establish pre-settlement forest stand structure, the strictest criteria were that stands must not show evidence of timber harvest or catastrophic wildfire. Another criterion was that the plot could not have significant topographic (>30% slope) or aspect (>45°) changes. We had difficulty locating intact areas for the plots because of the long history of resource management activities in this portion of the Trench and the 50-m^2 plot size. Four plots were established in the Lewis Ridge study area and one in the 41.3-ha Isidore Canyon study area. The Isidore Canyon plot was selected because: 1) it was in the Cranbrook Forest District's Demonstration Forest; 2) the area was accessible by a 4-wheel-drive vehicle; and 3) the area was highly disturbed, which made random plot location prohibitively time consuming.

Sampling

Once the plots were randomly located three 50-m plastic tapes were laid out to mark the sides and bottom boundaries of the plot. All plots were oriented perpendicular to the slope with side measurements corrected to horizontal distance. A fourth tape was used to mark off a 10-m strip parallel to the bottom tape. Each tree >5 cm diameter at breast height (dbh) and all snags and downed logs were recorded by coordinates between the four tapes. As each strip was completed, the tape was moved an additional 10 m up slope to mark the next strip.

All trees >20 cm dbh were cored at the base until the pith was extracted or until a near-complete core (in the case of heart-rot) was collected. Diameter at breast height, as well as height and species were also recorded for these trees. Trees in the 5–10-cm and 10–20-cm dbh size classes were treated separately because a potentially high proportion of them were post-settlement-era trees. Under this assumption every third tree in each size class was cored, but every tree was located by coordinates with dbh, height, and species recorded.

In addition to the increment cores of trees in the plots, 10 increment cores from Douglas-fir, ponderosa pine, and larch trees that were likely to express the climate signal for the region were also collected. Of these 10 cores, only 2 expressed a strong climate signal and were used in the master chronology. These 2 cores along with 8 increment cores exhibiting the climate signal from the plots were combined to create the master chronology, an essential tool for dendroecological work (Stokes and Smiley 1968, Fritts 1976, Fritts and Swetnam 1989). Using the common pattern of "marker" years (either extremely narrow or wide rings) from the master chronology, we crossdated both the increment cores and fire scar samples to ensure accurate dates for tree ages and past fires (Madany et al. 1982, Dietrich and Swetnam 1984, Brown and Swetnam 1994, Grissino-Mayer 1995).

Field sampling methodology for determining the fire regime of the two sites follows Arno and Sneck (1977) and Gray and Riccius (1999). The collection of fire-scar samples from a small area (<40 ha) in order to determine the historical fire regime (Martin and Sapsis 1992) in short-interval fire-return ecosystems is a widely accepted methodology (Madany et al. 1982; Covington and Moore 1994; Arno et al. 1995, 1997; Grissino-Mayer 1995; Agee 1996; Swetnam and Baisan 1996; Wright 1996; Gray and Riccius 1999).

Fire-scarred trees were sampled throughout the study area on both Lewis Ridge and Isidore Canyon but not in any of the plots. We obtained nine samples each from the two study sites. Where possible, dead–downed material was used; however, the quality of this material was generally poor owing to advanced decay. Large-diameter live trees were sectioned, a large piece of wood or rock was placed in the wound, and flagging was placed on the tree to identify it as a potential danger. Small-diameter live trees were felled, sectioned to determine the best sample, and bucked up and scattered to reduce the potential for a build-up of Douglas-fir beetles (*Dendroctonus pseudotsugae*).

Laboratory Analysis

Fire History

The fire-scarred samples were left to dry for approximately 3 weeks. Once dry, the samples were cut into manageable cross-sections (usually about 3 to 5 cm) with a band saw and mounted on 100-mm ranger board. Each section was sanded with progressively finer sandpaper.

We were able to use all nine samples from Lewis Ridge, but only seven of the nine samples from Isidore Canyon because two of the samples were too rotten to crossdate. We crossdated the fire scars from live tree samples with the aid of a binocular dissecting microscope using methods outlined in Yamaguchi (1991) from the bark year to the pith. For samples obtained from dead material (logs and snags), we measured the ring widths using a Velmex-Acurite measuring stage and MEDIR software (Grissino-Mayer et al. 1996). The undated ring width series from the sample was compared with the ring width series of the master chronology using COFECHA (Grissino-Mayer et al. 1996) to determine the pith or inside date of the sample. We then visually crossdated the sample to confirm the inside date and to obtain the fire dates. Only distinct fire scars were dated, resulting in a potentially conservative population of fire dates for each site.

We used the software package FHX2 (Grissino-Mayer 1995) for graphical and statistical analyses of the fire history data. Statistics included mean, minimum, and maximum fire intervals over a specified time period for each of the sites. This time period or period of reliability (defined by the researcher) ensures consistency in the fire history data (Grissino-Mayer 1995). For both sites, we defined the beginning and end of the period of reliability by the earliest and latest fires when a minimum number of trees had the ability to record fire. For Lewis Ridge we used the criterion that at least three trees had the ability to record fire, while we only required two trees to have the ability to record fire at Isidore Canyon because there were fewer samples. This corresponds to a time period from 1694 to 1883 for Lewis Ridge and from 1683 to 1894 for Isidore Canyon. For a more detailed discussion of the period of reliability see Grissino-Mayer (1995) and Riccius (1998).

Stand Structure

The increment cores were left to dry and then mounted on wooden core mounts with wood glue. We sanded the cores with progressively finer sandpaper beginning with 80 grit and ending with 320 or 400 grit. We crossdated the increment cores using methods outlined in Yamaguchi (1991) to ensure accuracy in the inside or pith date. In cases where the increment cores lacked a pith, we estimated the number of rings to the pith using transparent overlays of concentric circles with various widths. We chose the set of circles that most approximated the ring widths near the pith on the increment core and counted the number of circles to the estimated pith. While this

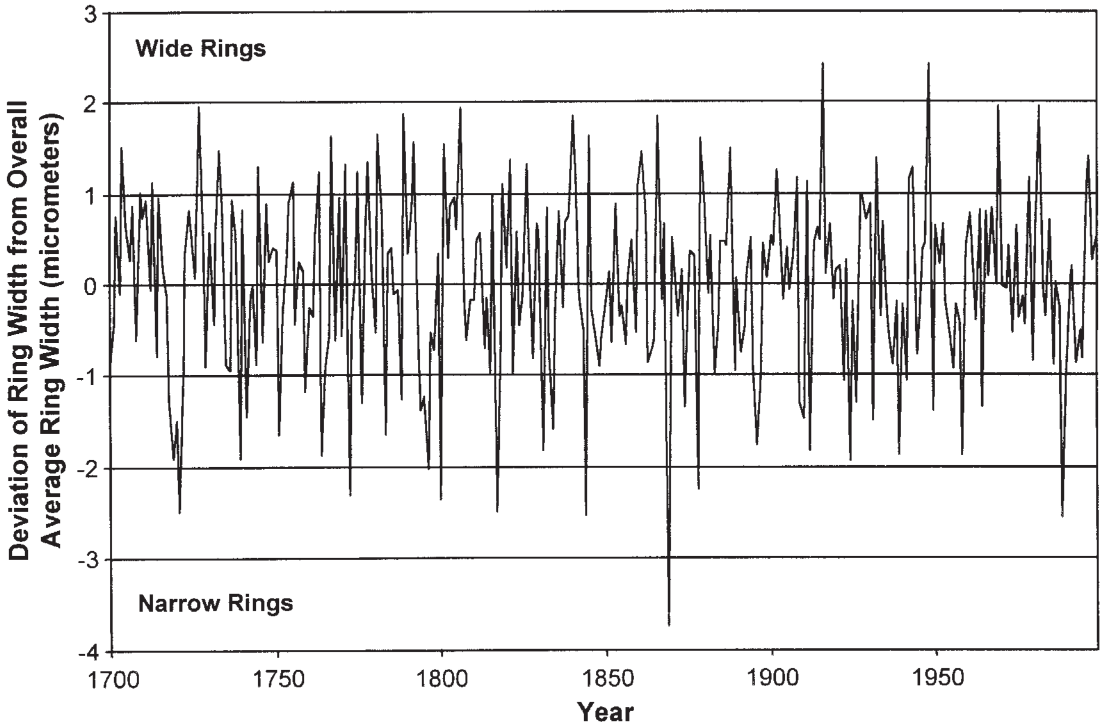


Figure 1. Master chronology for Lewis Ridge study site, British Columbia.

method does provide an estimation of age at the pith, it is important to acknowledge the potential associated error (Wong and Lertzman 2001). The error is related to our lack of knowledge of the actual ring widths (which can vary greatly) of the missing portion of the increment core. The final age of each increment core was entered into an Excel® (Microsoft 1993–1994) spreadsheet for graphical and statistical analyses. It should also be noted that even though trees were cored at the base and the pith may have been obtained, the true germination date of trees can still be off by as much as 20 years (Savage et al. 1996).

RESULTS

Master Chronology

The master chronology for Lewis Ridge from 1700 to 1998 contained a large number of marker years, either very narrow or very wide rings (Figure 1). The sensitivity of ring widths in the master chronology made crossdating relatively easy.

Fire History

The fire history from our samples for Lewis Ridge spans a period of 430 years with the earliest recorded fire occurring in 1586 and the most recent recorded fire occurring in 1883 (Figure 2). This corresponds to 14 years with fires recorded on samples from this site. Thirty-two fire scars occurred on the nine samples with an average number of four scars per sample. The species mix for Lewis Ridge was four ponderosa pine and five Douglas-fir.

Using the period of reliability from 1694 to 1883, we found a mean fire interval (MFI) of 18.9 years. The minimum fire interval was 3 years and the maximum was 52 years. In the present era, outside the POR, there has been a fire-free interval of 115 years, from the last fire to the present.

The fire history from the Isidore Canyon samples spans a period of 403 years with the earliest fire occurring in 1595 and the last fire occurring in 1894 (Figure 3). For this time period we identified 19 years with fires. A total of 38 fire scars occurred on the seven samples which corresponds to an average of about five scars per sample. The species mix from Isidore Canyon was four western larch, two ponderosa pine, and one Douglas-fir.

For the period of reliability from 1683 to 1894 the mean fire interval was 14.1 years. The minimum interval between fires was 1 year, while the maximum interval was 29 years. A fire was not recorded on any of our samples in the last 104 years.

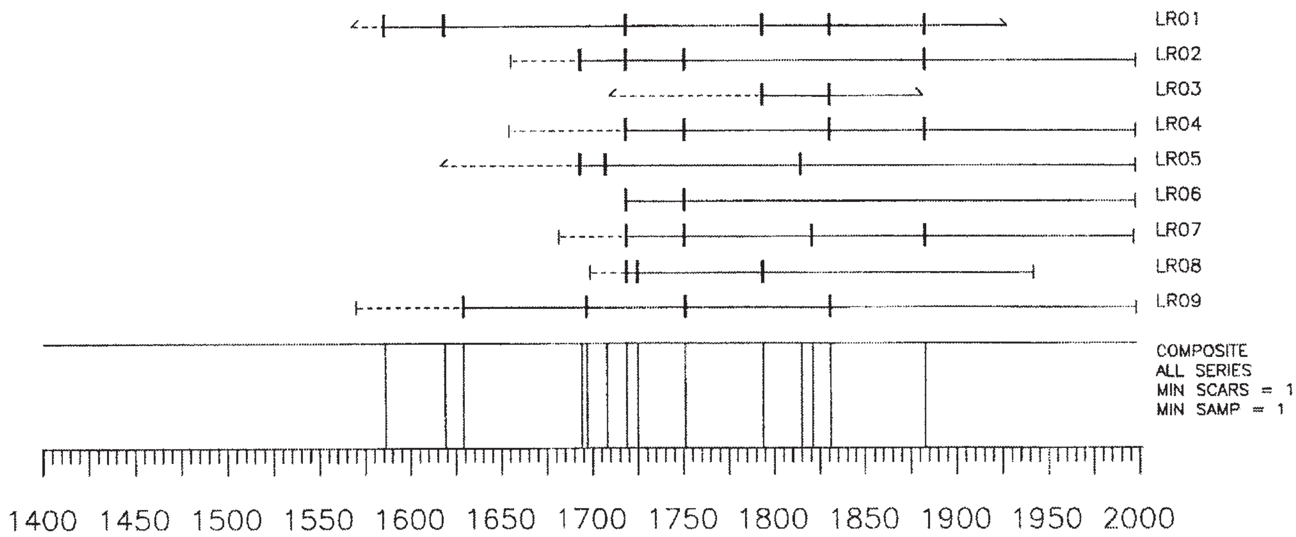


Figure 2. Fire-scar chronology for Lewis Ridge study site, British Columbia. Horizontal bars represent the life spans of individual trees, while the fire-scar events are indicated by short vertical bars. At the bottom of the chronology is the composite of all fire-scar events for the study site.

Stand Structure

To estimate the ages of trees <20 cm dbh that we did not core, we examined the relationship between age and dbh for Douglas-fir and ponderosa pine in each plot. The data from each plot were fit with linear and loglinear least squares regressions. Loglinear models were chosen over linear models if they produced a more uniform distribution of residuals. Regressions using solely this small-diameter tree data, however, were very weak ($R^2 < 0.1$). This suggests past radial growth of trees <20 cm dbh in these plots was quite variable and thus any estimate of age incorporates a large amount of uncertainty. Indeed, using all tree data, dbh at best explains 62% of the variation in age in Douglas-fir (Figure 4A). The strength of the relationship between age and dbh varies from plot to plot and species to species.

We analyzed the sensitivity of the estimated ages of trees <20 cm dbh to the parameters of the regres-

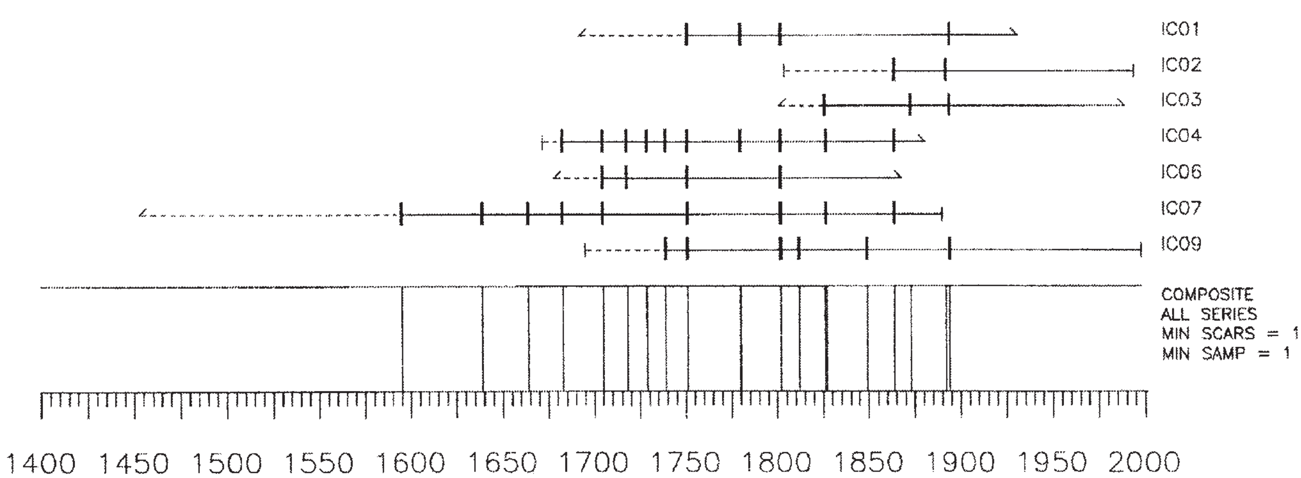
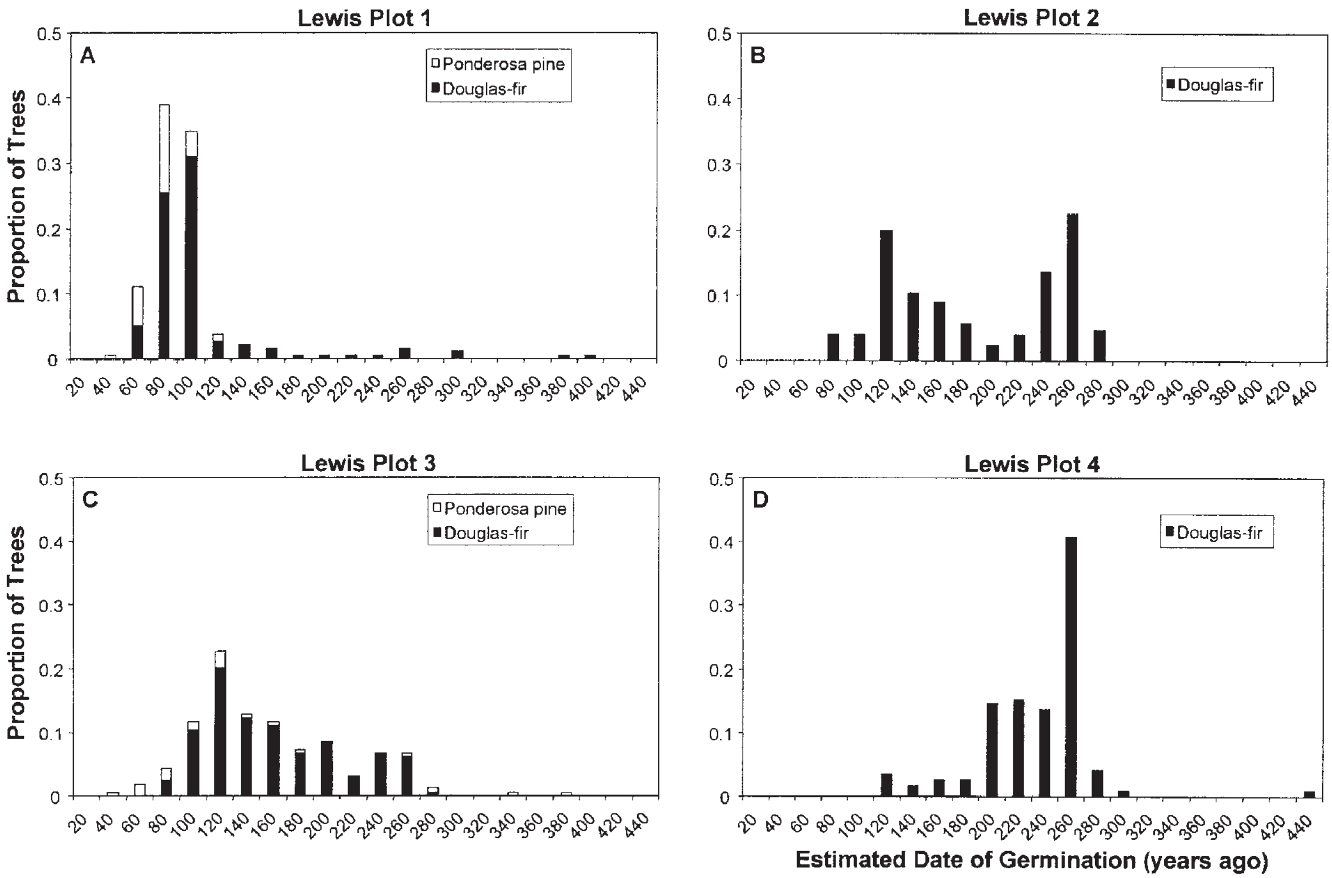


Figure 3. Fire-scar chronology for Isidore Canyon study site, British Columbia. Horizontal bars represent the life spans of individual trees, while the fire-scar events are indicated by short vertical bars. At the bottom of the chronology is the composite of all fire-scar events for the study site.



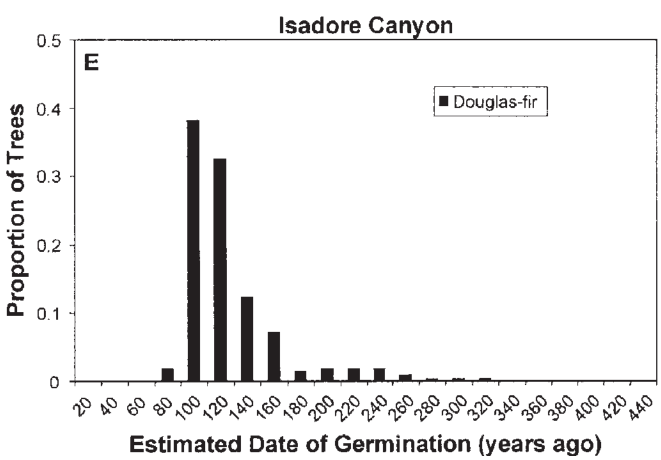


Figure 4. Regeneration frequency graphs for four Lewis Ridge plots (A–D) and one Isidore Canyon plot (E), British Columbia. The *x*-axis indicates the estimated date of germination prior to the 1998 sampling date.

sions; ages were re-estimated using the 95% upper and lower confidence limits of the regressions' parameters to determine how this affects the proportion of trees estimated to be of pre-settlement establishment (i.e., >150 years old). In Lewis Plot 1 and Isidore Plot (Figure 4A,E) estimates of Douglas-fir ages were not sensitive to uncertainty in the parameters of our regressions. In both plots we are confident that very few trees <20 cm dbh are of pre-settlement origin. The age of trees <20 cm dbh is more uncertain in plots 2 and 3. The regressions estimate 25% and 8.5% of trees <20 cm dbh (plots 2 and 3, respectively) to be >150 years. However, because of the wide 95% confidence intervals around the parameters of these two regressions, it is possible for 6%–67% and 0%–100% of trees <20 cm dbh to be of pre-settlement origin. In plot 4 all 35 Douglas-fir trees <20 cm dbh were estimated to be greater than 150 years. Very few ponderosa pine trees <20 cm dbh were estimated to be of pre-settlement origin.

Even with a conservative analysis of the data the trend in stand structure change over time is readily

Table 1. Current and historic stand density (trees/ha) for all trees >5 cm diameter at breast height for Lewis Ridge and Isidore Canyon, British Columbia.

	1998			1850		
Plot	Douglas-fir	Ponderosa pine	All species	Douglas-fir	Ponderosa pine	All species
Lewis 1	536	184	720	44	0	44
Lewis 2	500	16	516	292	16	308
Lewis 3	572	80	652	228	24	252
Lewis 4	472	20	492	440	20	460
Isidore 1	1360	0	1368	180	0	180

apparent. Regeneration frequency, stand density, and species composition all show significant changes in the 148-year interval.

Regeneration Frequency

Regeneration frequency (Figure 4A–E) was highly variable among all plots. Lewis plot 1 (Figure 4A) indicates a pulse of regeneration occurring in the late 1800s and early 1900s with scattered, low frequency regeneration (survival) occurring as far back as the early 1600s. Ponderosa pine begins to be detected in the late 1800s. Lewis plot 2 (Figure 4B) is perhaps the most interesting in that it exhibits a very obvious bimodal regeneration pattern. The first occurs in the early 1700s followed by a gradual slowing of regeneration, then an increase up to the late 1800s when it abruptly slows. The pattern in Lewis plot 3 (Figure 4C) is similar to plot 1 except the pulse peaks earlier than in plot 1. Lewis plot 3 (Figure 4C) also contains a fairly low but consistent rate of ponderosa pine regeneration which is dissimilar from all other plots. Lewis plot 4 (Figure 4D) is different in that it indicates a single pulse in the early 1700s. This pulse correlates well with the early pulse in Lewis plot 2, but unlike plot 2 a second, later pulse does not materialize.

The regeneration frequency exhibited on the Isidore Canyon site (Figure 4E) is similar to Lewis plot 1 (Figure 4A) with the pulse building up to the turn of the century then drastically ending in the early part of this century. The greatest similarity between all sites is the noticeable lack of significant regeneration since the 1920s. None of the five plots contained a high density of <5 cm dbh trees, which are cited as a common structural element in contemporary stands throughout the West (Bonnor 1990, Covington and Moore 1994, USDA 1997).

Stand Density

In all cases stand density has increased (Table 1), on some plots by as little as 7% (Figure 4D), and others by as much as 1,640% (Figure 4A). The average condition for the five plots is a 540% increase in stand density.

Ponderosa pine shows the highest level of variability in density over time. The species exhibits a dramatic increase in density in Lewis plots 1 and 3 (Figure 4A,C) but no change over time on Lewis plots 2 and 4 (Figure 4B,D). No ponderosa pines were recorded on the Isidore Canyon plot (Figure 4E); however, large old pines, including a 400-year-old fire scar sample tree, were located in the stand. Density of Douglas-fir shows an increase on all plots except Lewis plot 4 (Figure 4D) where the increase was only 32 trees/ha.

DISCUSSION

The historic fire regime appears to have had a significant and varied effect on stand structure. Stand structure has changed appreciably on several of the five sites between the baseline date of 1850 and 1998. Causal factors are likely numerous; however, the most critical factor, and the only one that can be reasonably measured, is fire. The frequency of fire activity on the two sites, 19 years at Lewis Ridge and 14 years in Isidore Canyon, lie well within the range of mean fire intervals for similar ecosystems in the western U.S. and Canada (Arno 1976, 1980; Agee 1993, 1994; Arno et al. 1995; Gray and Riccius 1999; Everett et al. 2000; Gray 2001; Schellhaas et al. 2000). Site characteristics estimated at Lewis Ridge—steep southeast-to-south aspects with an understory dominated by grasses—indicate that the mean fire interval may be overestimated. Not only were fire-scarred trees rare, but scarring episodes appeared to be highly random. In one location two large >350-year-old ponderosa pine stood no more than 20 m apart, yet one was scarred and the other was not. With a historical stand structure consisting of well-spaced trees and an understory of fine grass fuels and litter, even head fires coming up the slope would result in little direct heat damage to tree boles.

There are many subtle indicators of a historic high-frequency, low-intensity fire regime in Isidore Canyon that are not overly obvious in the current landscape. The presence of numerous fire-scarred trees, especially on the slope directly below the plot, and scattered plants such as antelope bitterbrush and bluebunch wheatgrass in small niches, indicate a historic stand structure that is very different from the contemporary one. Fire-scarred trees were not only more numerous in Isidore Canyon but also consisted mostly of western larch and ponderosa pine, neither of which occur significantly in the contemporary stand structure.

Understory species recorded on Lewis Ridge exhibit a high level of adaptability to a short-interval fire regime. Arrowleaf balsamroot is reported to be either undamaged or slightly damaged by fire, but rarely killed. The species regenerates from a thick caudex located below the soil surface (McWilliams 2002), making it safe from all but the most intense fires. Antelope bitterbrush responds similarly but resprouts from the root-crown. In areas of high fuel build-up the plant can be killed (Zlatnik 1999); however, historic fuel accumulations on Lewis Ridge were not likely to be very high. Both species could be in decline on the site due to overstory stem density and high crown closure.

Any speculation on how fire has historically affected stand structure over the four sample plots on Lewis Ridge and the single plot in Isidore should be tempered with a discussion of local topography and its effect on fire behavior. The four Lewis Ridge plots were arrayed across the slope from east to west with a gradual convex ridge and plateau above them and a wide talus field below them. Plot 1 was situated to the west of the talus field and was fully exposed to fire spread coming directly upslope from below as well as diagonal headfire spread from the southwest. The remaining plots were not exposed to upslope fire spread due to the talus field below them and were separated from each other by a series of small-scale undulating ridges and draws. These plots would likely only be exposed to low-intensity flanking or backing fire. The historic frequency of fire, therefore, would be similar for all plots, with samples collected from across the study area. Potential fire behavior, and its effect on stand structure, would be different for each plot however. The Isidore Canyon plot was located on a gently rolling convex ridge directly above the valley bottom. There were no natural fire or fuel breaks between the valley bottom and the plot location. Head fires of moderate intensity coming up slope would have been common on this site.

Stand density has increased substantially since the last recorded fire on Lewis plot 1 and the Isidore Canyon plot. Both show a large pulse of regeneration occurring at the turn of the 20th century. This pattern is significant considering the type of historical fire behavior to which these two sites would have been exposed. The remaining three plots on Lewis Ridge reflect the high level of variability in stand structure expected from a highly variable, but consistently low-intensity fire regime. These three sites contain higher levels of historic stocking than many other stands with similar fire regimes in similar ecosystems (Harrod et al. 1999, Everett et al. 2000, Gray 2001).

Historic stand density on the remaining three Lewis Ridge plots could also be a function of regeneration patterns and low-intensity fire. One conclusion that can be drawn from the data is the episodic nature of regeneration on the three plots. Figures on regeneration pulses are fairly rare in the literature with most research focusing on the "epoch-making" ponderosa pine regeneration pulse in 1919 in the Southwest (Arnold 1950, Savage et al. 1996, Mast et al. 1999). Regeneration associated with that particular event became established in a single year when an excellent seed year in 1918 was followed by high summer precipitation in 1919 (Savage et al. 1996).

The pulses observed on Lewis Ridge in particular are episodic over decades rather than single years. Clues to understanding the processes involved in these regeneration episodes likely lie in the climate record. Dendrochronological studies in high-elevation sites in the southern Canadian Rockies indicate general trends of narrow ring-widths in both the early 1700s and mid-1800s (Luckman 1997). Narrow ring-widths are correlated with periods of below-normal precipitation. The environment immediately following these drought-stress periods may be conducive to regeneration events. Additional studies to determine climate history are underway in parts of the Trench (E. Watson, University of Western Ontario, personal communication). Historic regeneration pulses on sites such as Lewis Ridge plot 1 and the Isidore Canyon plot likely did not survive the type of fire behavior common on these sites and would therefore not be recognized as a distinct regeneration pattern. The much cooler burning conditions common to Lewis Ridge plots 2, 3, and 4 would enable these patterns to emerge.

MANAGEMENT IMPLICATIONS

The high degree of stand structure variability exhibited between the five plots makes it difficult to prescribe restoration treatments with specific density, species composition, and inter-tree spacing targets. The study results have a limited geographical range and the data should not be overly extrapolated. Additional plots should be established in the Trench in order to gain a more comprehensive picture of the historical range of variability in stand structure. Stand structure trends from the study indicate a relationship between historic stand density and potential fire behavior. The lowest potential historic fire intensity, linked to the effect of topography on fire behavior, appears to result in higher levels of historic stocking.

This trend has significant management implications. The large and coarse scale of Trench-wide restoration planning has identified four broad ecosystem types. The four types—grassland, shrubland, open forest, and managed forest—are further described by biogeoclimatic subzone and site series. Target forest structure (i.e., stand density), while loosely based on research, is being uniformly prescribed across large areas depending on this land-use designation. These target stand structures are not considering 1) the historical range of variability in stand density, 2) the ability to operationally treat certain stand structures on varied topography with prescribed fire, and 3) the long-term wildfire resilience of these stands depending on where they are located. The objective of long-term ecosystem restoration and management is to maintain resilient, diverse, and sustainable ecosystems. Recognizing that fire was, and will be, the most prevalent disturbance process means that resource managers must incorporate not only the high probability of fires occurring, but the worst-case scenario of fire behavior into restoration planning and operations.

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