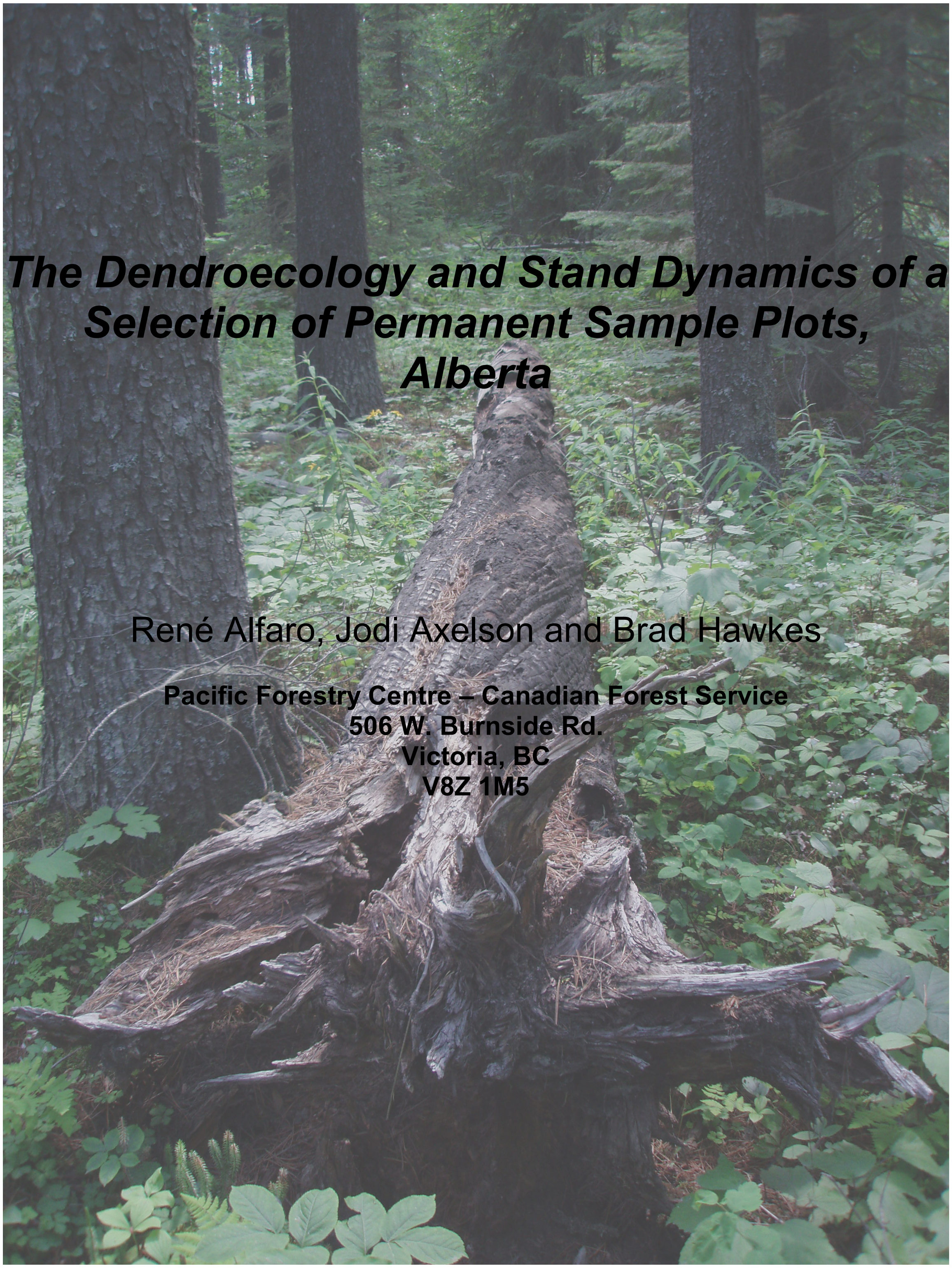
Decision Support for Forest Management in a Mountain Pine Beetle Environment



The Dendroecology and Stand Dynamics of a Selection of Permanent Sample Plots, Alberta

René Alfaro, Jodi Axelson and Brad Hawkes

Pacific Forestry Centre – Canadian Forest Service
506 W. Burnside Rd.
Victoria, BC
V8Z 1M5

Introduction

Historical ecology provides the long time sequence of observations needed to gain meaningful information on changes in ecosystem structures, disturbance frequencies and other dynamic processes (Swetnam et al., 1999). Dendroecology, a tool in historical ecology, is useful to clarify the dynamic processes of stand initiation, death and regeneration, as well as on the forest disturbances which have affected the forests under study; including damage caused by insects, disease, fire, and others. Such information is required to create growth and yield models capable of predicting future stand composition under different levels of disturbance intensity. Dendrochronology techniques are also particularly useful in establishing the relationship between tree growth and climatic variables. Dendroecological techniques have been used to evaluate forest disturbances, such as those caused by mountain pine beetle (Heath and Alfaro, 1990; Alfaro et al., 2004; Campbell et al., 2007; Alfaro et al., 2009; Axelson et al., 2009), spruce bark beetle (Veblen et al., 1991; Berg et al., 2006) and spruce budworm outbreaks (Swetnam and Lynch, 1993; Antos and Parish, 2002; Zhang and Alfaro, 2002; Campbell et al., 2006). One dendrochronological method used to date past beetle outbreaks is based on detection of periods of accelerated growth in annual rings of trees that survive outbreaks, which take advantage of the additional growing space, often referred to as a *release period* (Roe and Amman, 1970; Heath and Alfaro, 1990; Veblen et al., 1991; Berg et al. 2006).

The proposal titled “Decision Support for Forest Management in a Mountain Pine Beetle Environment”, included a dendroecology sub-component that aimed to establish the disturbance history of a sub-set of the of Permanent Sample Plots (PSPs) in the

Alberta Foothills, which were re-measured in the summer of 2008. The objectives of this research, as outlined in the full proposal, are to establish:

- disturbance history of selected stands, i.e., establish the occurrence, duration and intensity of previous fire an beetle disturbances in the sample stands,
- cycles of regeneration and mortality by dating fire scars, coarse woody debris and regeneration,
- and to establish growth rates before disturbance periods and to quantify growth releases occurring after canopy thinning by beetle.

This report presents our findings on the history of disturbances in PSPs located in the Lower and Upper Foothills ecosystems of the Northern Alberta Rockies, and provides insight on how this information can be used in modelling and decision support to forecast the future structure of the forests of this region. In depth stand reconstructions based on dendroecology are particularly useful to develop growth models that are sensitive to changes in disturbance regimes, such as those which may occur as a result of climate change.

Methods

PSP Selection

The full project, of which our study is part, included the re-measurement of 240 PSPs. The dendroecology sub-component outlined that a sub-sample of 5-10% of the total 240 PSPs (12-24 PSPs) would be intensively sampled to conduct in-depth stand reconstructions. Pre-screening of suitable PSPs for dendroecological reconstructions was performed by The Forestry Corp (Edmonton, Alberta); where the database of 240 PSPs was queried to meet a number of conditions. After consultation with The Forestry Corp, and other team members, candidate PSPs considered for dendroecological analysis were selected using the following criteria:

1) Located in the following natural sub-regions: Lower Foothills (LF), Upper Foothills (UF), and Sub-alpine (SA);
2) Be located in infested or high risk mountain pine beetle areas (SSI ≥ 61);
3) Composition >50% lodgepole pine and >80 years old;
4) Time since re-measurement ≤5 years;
5) Located between Grande Prairie and Hinton;
6) Road accessible.

We selected PSPs from Grande Prairie to Hinton in the LF and UF natural sub-regions, where the pine beetle outbreak is most intense. This strategy ensured sampling occurred in the regions with the highest stand susceptibility index (SSI) and/or mountain pine beetle infestation rate.

Field Methods

For stand reconstructions we collected increment core samples from PSP overstory trees, and disc samples of understory trees, and coarse woody debris (CWD) in the PSP buffer. In each PSP cluster 20 increment cores were collected from dominant lodgepole pine trees (Fig. 1a). If secondary canopy species were present (i.e., spruce or fir) we collected additional cores from those species. Increment cores were collected at stump height (~30 cm above forest floor). Destructive sampling of understory trees was performed in the PSP buffer (away from the plot boundary) to establish the date of establishment of these cohorts. We collected 50 disc samples at ground height from the understory, which was broken into a two categories: advance regeneration, defined as trees < 7 cm DBH and between 0.30 to 1.37 m in height; and regeneration (seedlings), defined as < 0.30 m in height (Fig. 1b).

To examine past disturbance history and to extend tree chronologies into the past, beyond the period recorded by the living trees, we obtained a targeted sampling (i.e., not random) of CWD and standing dead trees (Fig. 1c). Approximately 20 samples were collected in each PSP cluster buffer from a variety of decay classes for the CWD (≥7cm DBH).

Laboratory Methods

All wood samples were processed using standard dendrochronology methods (Stokes and Smiley, 1968). Once samples were dried, mounted and sanded (using progressively finer sandpaper: 120-600 grit) they were scanned and measured using WinDendro™ (v.2002a Regent Instruments Inc., 2003), with a measurement precision of 0.01 mm (Fig. 2).

Figure 1(a) Collection of an increment core at stump height; (b) Measuring height of an understory tree before conducting destructive sampling; (c) Collection of a disc from a charred standing snag in PSP buffer.

All the measured ring-width series were plotted and the patterns of wide and narrow rings were cross-dated among trees to identify possible errors in measurement due to false or locally absent rings. The program COFECHA (Holmes, 1983) was used to detect errors and verify cross-dating. Dated tree-ring series from each stand were used to cross-date dead trees and CWD. Scarred samples were compiled by stand, and scar type was identified. We used the scar characteristics outlined by Mitchell et al. (1983) and Stuart et al. (1983) to differentiate between fire and beetle scars. Scars that could not be identified as either fire or beetle origin, were classified as 'other' which encompass both unknown biotic and abiotic scarring agents (e.g., mammal damage, mechanical scarring).

The computer program ARSTAN (Cook, 1985; Cook and Holmes, 1986) was used to produce a mean standardized ring-width chronology for each species, using an arithmetic mean, standardized tree-ring series were averaged together to produce a mean chronology for each species in each stand. In addition to removing biological growth trends standardization transforms non-stationary ring-widths into a new series of stationary, relative tree-ring indices that have a defined mean of 1.0 and a relatively constant variance (Cook et al., 1990).

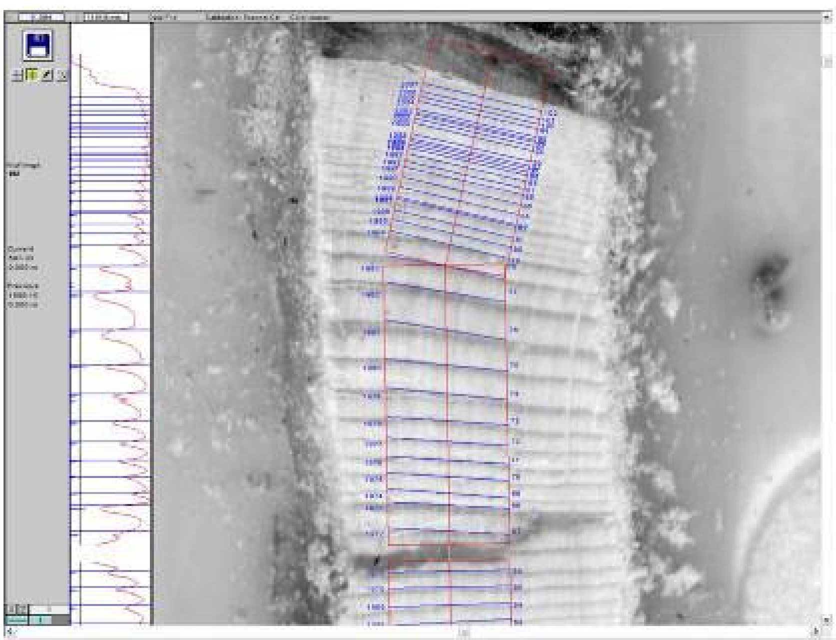


Figure 2. Example of an increment core being measured with WinDendro™

Tree-ring Analysis

Detection of canopy disturbances

The tree-ring program JOLTS (Holmes, 1999, University of Arizona, unpublished) was used to detect growth releases in individual trees, by computing a ratio of the forward and backward 10-year running means of ring-widths for each year. If this ratio exceeded 1.25 (i.e., a 25% increase in radial growth) for a given year, we counted a release for that year. Running means have been found to produce results that agree well with documented canopy disturbances (Rubino and McCarthy, 2004), and the 10-year window has been found to sufficiently smooth ring-width variability due to short-term climatic variation (Berg et al., 2006). The ratio of 1.25 has been used in previous studies to document growth releases and effectively identifies periods of canopy thinning due to mountain pine beetle outbreaks (Alfaro et al., 2004; Taylor et al., 2006; Campbell et al., 2007; Axelson et al., 2009).

Results

Permanent Sample Plots used for stand reconstructions

Screening of the 240 PSP database resulted in the selection of 55 candidate PSPs in the Lower and Upper Foothills (LF and UF) that met our criteria. Of this we selected 15 PSPs for dendroecological analysis. Six were Alberta Sustainable Resource Development (SRD) plots located in the LF, south of Grande Prairie (Fig. 3); 5 were Hinton Wood Product (HWP) plots located in the UF, around Hinton, and 3 were SRD plots located in the UF north of Nordegg (Fig. 3). Herein, we refer to PSPs as ‘stands’, and to overcome long PSP numbering system use our own CFS code (Fig. 3).

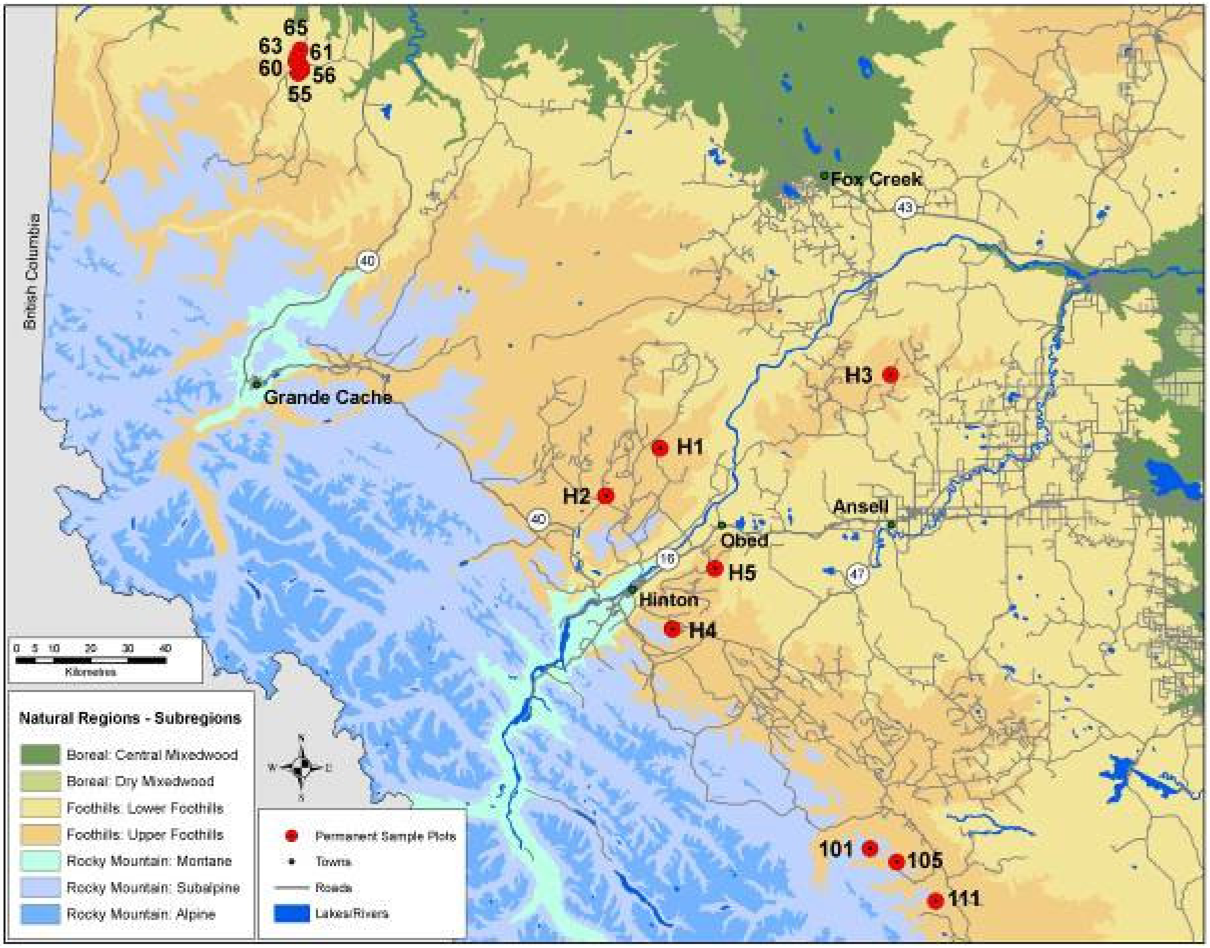


Figure 3. Locations of PSPs, labeled using CFS codes, selected for dendroecological analysis in the Lower and Upper Foothills natural sub-regions.

Properties of dated tree-ring data

In total 15 stands were sampled (Table 1) with over **1300** dendrochronological samples were collected during the summer and winter of 2008. Roughly 20 increment cores, 20 CWD and snag discs, and 50 understory discs were collected per stand (Table 2).

TABLE 1. PSPs selected for dendroecological analysis.

Agency	Sub-region	PSP No.	CFS code	Elevation m
SRD	**LF**	55	S55	1051
		56	S56	1041
		60	S60	1074
		61	S61	1078
		63	S63	1056
		65	S65	994
HWP	**UF**	1010214 1010215 1010216	H1	1128
		1010596 1010597	H2	-
		2010116	H3	-
		4010289 4010290 4010291	H4	-
		4010077 4010078	H5	1238
SRD		101	S101	1599
		105	S105	1433
		111	S111	1720

TABLE 2. Number of samples collected in the LF and UP natural sub-regions, Alberta.

Sub-region	No. of Cores	No. of CWD discs	No. of understory discs
LF	137	122	306
UF	250	158	400

Tree-ring series were developed for lodgepole pine (Pl) in each stand, and for white spruce (Sb), Engelmann spruce (Se), and amabilis fir (Ba) in stands which had sufficient numbers of canopy trees (Table 3). Cross-dating statistics were computed for each tree-ring series including: series range, number of cores collected, inter-series correlation, and mean sensitivity (Table 3).

The inter-series correlation measures the degree of agreement between a series and the master chronology, and represents how much common stand-level signal is recorded (Grissino-Mayer, 2001). The level of correlation among correctly cross-dated tree-ring series may differ with tree species, geographic area, site homogeneity, amount of stand competition, and degree of disturbance (Grissino-Mayer, 2001). The average inter-series correlation for lodgepole pine was 0.548, which is well above the minimum values of 0.328 ($p<0.001$), indicating that lodgepole pine trees within stands shared a common growth signal (Table 3). The lowest correlation was for white spruce in stand S60 (Table 3), likely a result of the low number of cores sampled in this stand, and the lack of series overlap in early portions of the series (i.e., only one tree dates to 1810, the remaining series date to the early 1900s).

Mean sensitivity, a statistic measuring the mean relative change between the adjacent ring widths (Fritts, 1976), is a metric of how complacent or sensitive a tree-ring series is, which is largely determined by how much tree growth is limited by environmental factors (Table 3).

Stand reconstructions

To unravel stand dynamics of a given stand we present all of the tree-ring data: timing of scarring, canopy establishment, growth releases sustained in the canopy, CWD origin and death, and establishment of advance regeneration in graph form. We present a graphical example of these processes for each natural sub-region; S60 in the LF (Fig. 4) and H1 in the UF (Fig. 5). Generalized stand dynamics information, such as that presented here, will be of use in the development of decision support growth models, with realistic growth dynamics.

TABLE 3. Cross-dating statistics for tree-ring series collected in the LF and UP natural sub-region.

Sub-region	PSP No.	Species	Range	No. of series	Inter-series correlation	Mean sensitivity
LF	S55	Pl	1897-2007	36	0.56	0.23
	S56	Pl	1894-2007	38	0.56	0.23
	S60	Pl	1895-2007	40	0.54	0.22
		Sb	1810-2007	7	0.38	0.20
	S61	Pl	1895-2007	20	0.54	0.24
		Sb	1902-2007	5	0.57	0.24
	S63	Pl	1897-2007	22	0.54	0.25
	S65	Pl	1897-2007	21	0.56	0.26
UF	H1	Pl	1874-2007	16	0.50	0.20
		Sb	1885-2007	9	0.49	0.16
	H2	Pl	1881-2007	21	0.56	0.22
		Sb	1898-2007	6	0.47	0.16
	H3	Pl	1742-2007	24	0.52	0.20
	H4	Pl	1878-2007	25	0.58	0.20
		Sb	1878-2007	9	0.47	0.20
		Ba	1876-2007	8	0.51	0.18
	H5	Pl	1902-2007	23	0.49	0.21
		Sb	1904-2007	9	0.51	0.20
	101*	Pl	1896-2008	51	0.58	0.17
		Sb	1906-2008	15	0.53	0.19
	105*	Pl	1896-2008	32	0.58	0.18
		Sb	1903-2008	27	0.52	0.16
	111*	Pl	1903-2008	22	0.54	0.20
		Sb	1910-2008	29	0.49	0.15
		Se	1921-2008	20	0.47	0.20

* Cores sampled in December 2008, range includes full growth year for 2008

Stand SRD60

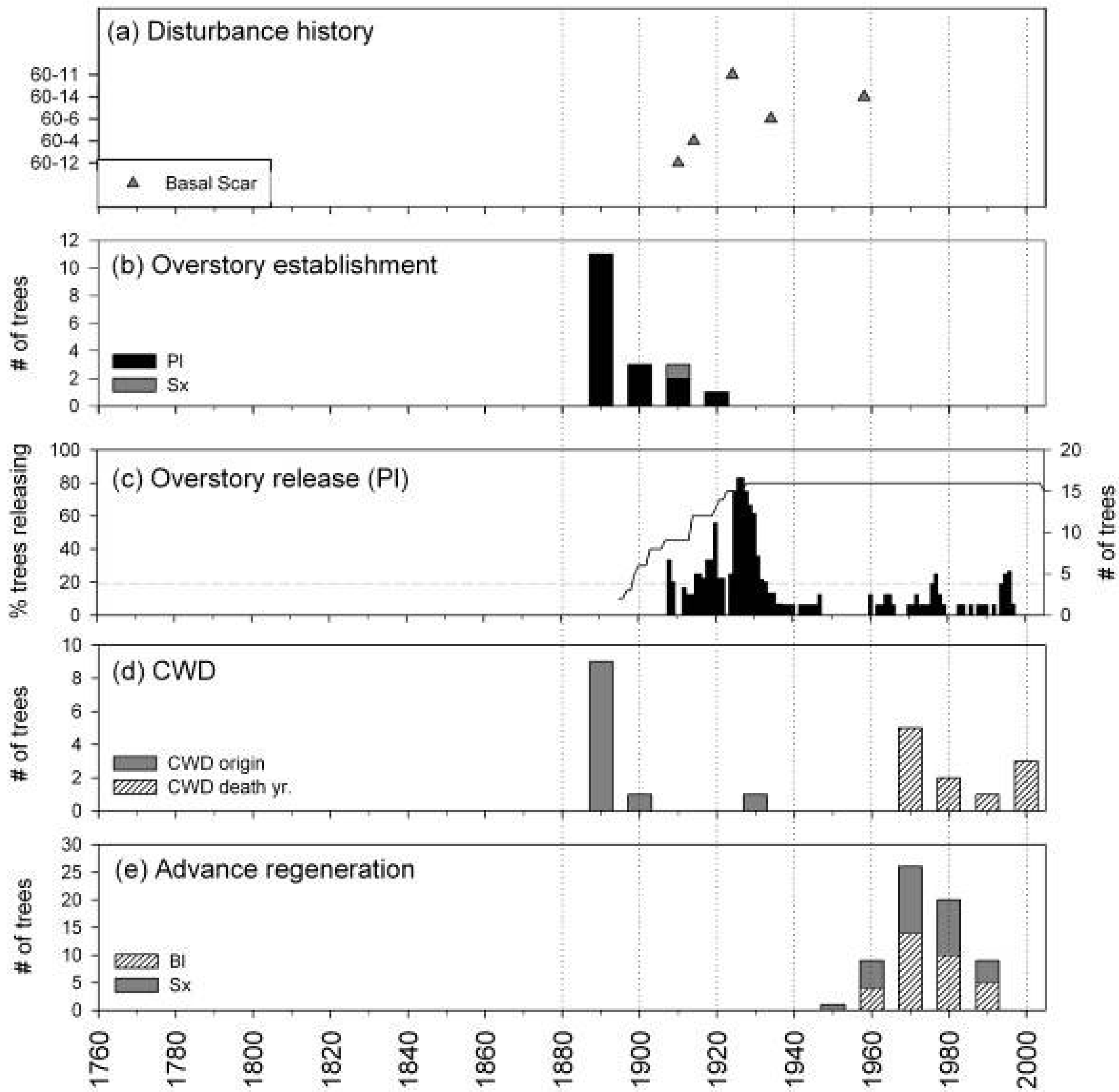


Figure 4. Reconstruction of disturbance history for S60: (a) Scar history from dated discs; (b) establishment date of the overstory; (c) Percent of lodgepole pine showing growth releases in a given year (left-axis), and sample depth (right-axis); (d) birth and death dates of the coarse woody debris (CWD); and (e) date of establishment of understory advance regeneration.

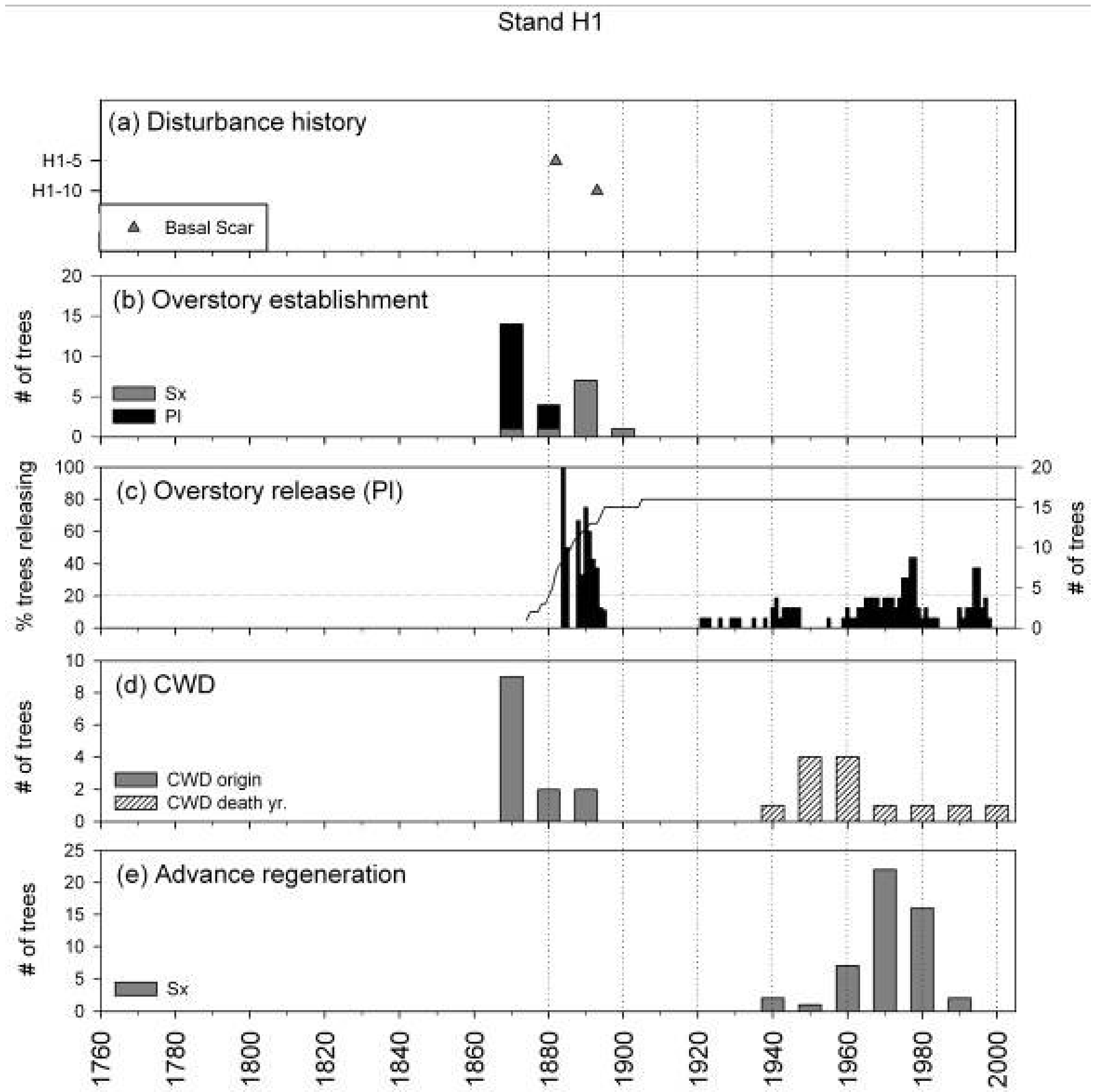


Figure 5. Reconstruction of disturbance history for H1 (HWP 1010214-216): (a) Scar history from dated discs; (b) establishment date of the overstory; (c) Percent of lodgepole pine showing growth releases in a given year (left-axis), and sample depth (right-axis); (d) birth and death dates of the coarse woody debris (CWD); and (e) date of establishment of understory advance regeneration.

Nearly all the scars identified appear to be biotic scars, probably caused by agents such as mammal damage (Fig. 4a and 5a). All stands originated from stand replacement fires, which created a distinct establishment pulse in 1890 in S60 and 1870 in H1 (Fig. 4b and 5a). In S60 lodgepole pine continued to establish (in small numbers) for two more decades after 1890, and a pulse small pulse of spruce establishment occurred in 1910 (Fig. 4b). In H1 spruce establishment occurred in small number from the 1870 to 1900, with a pulse establishing in 1890 (Fig. 5b).

Significant growth releases (>20% of trees releasing) were recorded in the lodgepole pine canopy in all stands (Fig. 4c and 5c). In S60 a sustained (>5 years) growth release occurred in around 80% of samples during the 1930s, and shorter release during the late 1970s and late 1990s (Fig. 4c). In H1 growth releases occurred in around 40-50% of the samples during the late 1970s and mid to late 1990s (Fig. 5c).

In all of the stands, with the exception of H3 and H4 (see Appendix), the CWD debris record originated from the same time period as the current canopy (Fig. 4d and 5d). In S60 and H1 the death dates of the CWD begin around the 1970s (Fig. 4d) and 1940s H1 (Fig. 5d) respectively. A pulse of CWD mortality occurring in the 1970s coincides with a small growth release in S60, and in H1 two decades of CWD death (1950-60) is followed by growth release of the live canopy.

The understory of the sampled stand was comprised almost entirely of shade tolerant species such as white spruce, Engelmann spruce, and amabilis fir (Fig. 4e and 5e). In both S60 and H1 there is a pulse of understory establishment in the 1970s and 1980s which coincides or follows death dates of the CWD.

Discussion

Stand reconstructions

Stands sampled in the Lower and Upper Foothills natural sub-regions indicate that fire has clearly played an important role in initiating the canopy in these stands, which currently maintain a fairly even-aged structure (Fig. 4b and 5b). In both sub-regions the origin of the canopy followed stand replacement fires as evidenced by strong pulses of establishment which occurred primarily in the 1890s. We speculate that the fire responsible for initiating the canopy was very intense, as fire scars pre-dating canopy establishment were not recorded on our samples. The scars that we do see occur post canopy initiation and appear to be mainly of a mechanical and biotic (e.g., mammal damage) nature. It is interesting to note that most of the CWD in the sampled stands was charred around the entire circumference, and that most of it established with the current canopy (Fig. 4d and 5d).

What caused the growth releases seen in the tree ring record? Growth release analysis indicates that some canopy disturbances occurred in some of the stands, but these were not severe enough to trigger large canopy mortality which would have been detected in the mortality dates of the CWD record. Also, canopy releases were not associated with regeneration episodes in the lower canopy in response to canopy disturbance (Fig 4 and 5). The only release period which resembles the responses seen in BC to documented canopy thinning by beetle outbreaks (release is accompanied by corresponding mortality dates of CWD and appearance of regeneration cohorts) was in the Lower Foothills Factor 1 chronologies (Fig. 6). For example: in S60 80% of the overstory pine underwent a growth release during the late 1920s and early 1930s (Fig 4c). This release is followed by a small regeneration establishment period (i.e., birth of CWD) (Fig. 4d).

There are several possible mechanisms to explain this landscape wide growth release, i.e., low severity ground fire in 1924, or an outbreak of a forest pest. In support of a previous mountain pine beetle outbreak argument is the fact that a very large mountain pine beetle outbreak occurred in across BC in the late 1920s and continued until the late 1930s. However, this release was not accompanied by corresponding dates of CWD death. Sampling lake sediments in the area of the Lower foothills where the chronologies were taken may yield additional evidence for a previous beetle outbreak in this area.

Conceptual model of stand dynamics

Comparing sample stands in Alberta with those in our BC studies (Alfaro et al., 2009; Axelson et al., 2009) indicate the possible to road ahead in a mountain pine beetle environment (Fig. 6). This conceptual model of the disturbance cycle indicates that with the interruption of the fire cycle, due to fire management, the mountain pine beetle has played a significant role in increasing the complexity of BC stands. In BC, the continued exclusion of fire and repeated mountain pine beetle outbreaks have resulted in multiple regeneration cohorts, adding a multistoried nature to these single storied stands (Fig. 7).

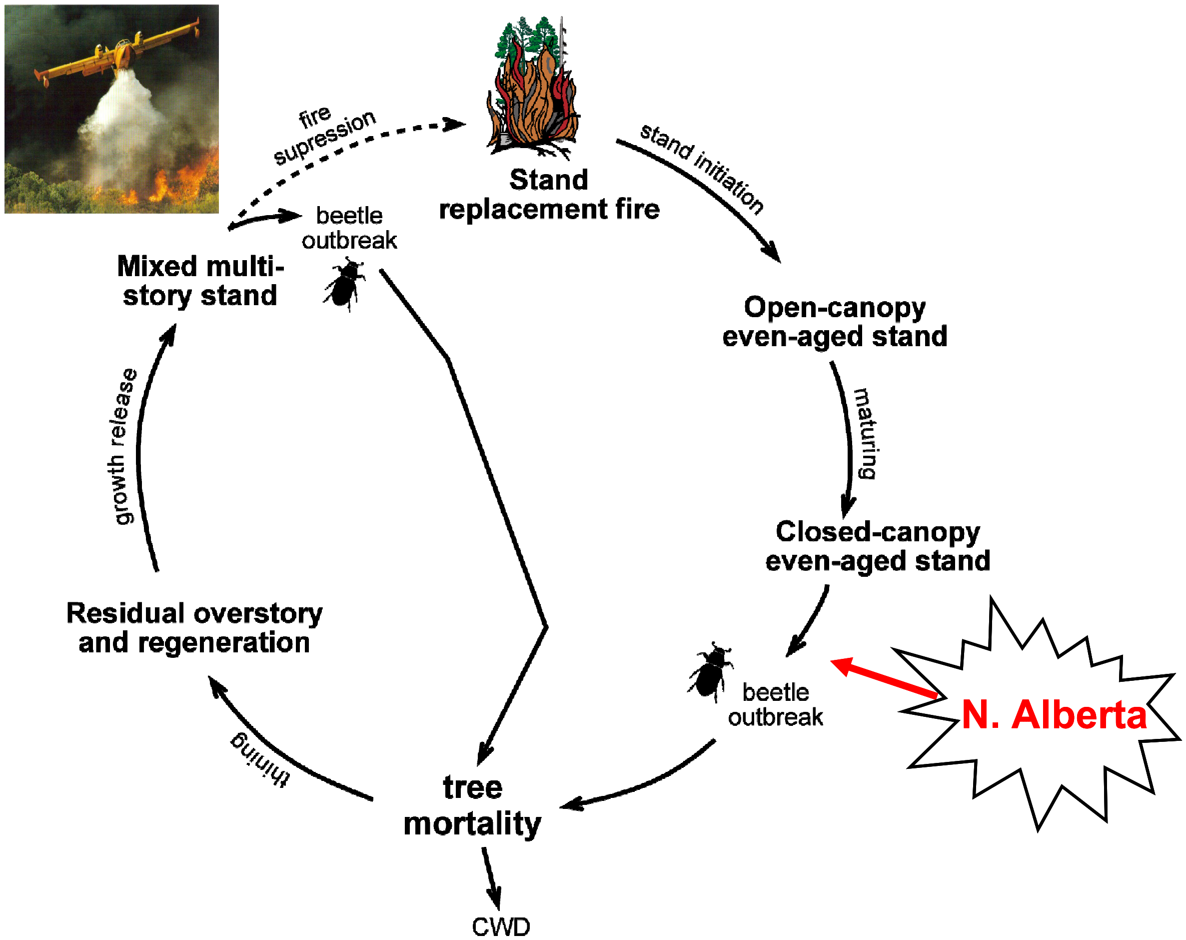


Figure 6. Stand dynamics cycle for lodgepole pine stands initiated by fire in British Columbia, and where sampled PSPs are located on this cycle.

We believe that using dynamic growth and yield models (e.g., TASS) to simulate beetle disturbance events of different intensities are needed to fully understand the potential effects of the mountain pine beetle in this ‘novel’ environment. In-depth instructions, based on stand data collected in this study and our stand reconstructions, can guide modelers in their efforts to realistically simulate lodgepole pine stands in the northern Foothills of Alberta.

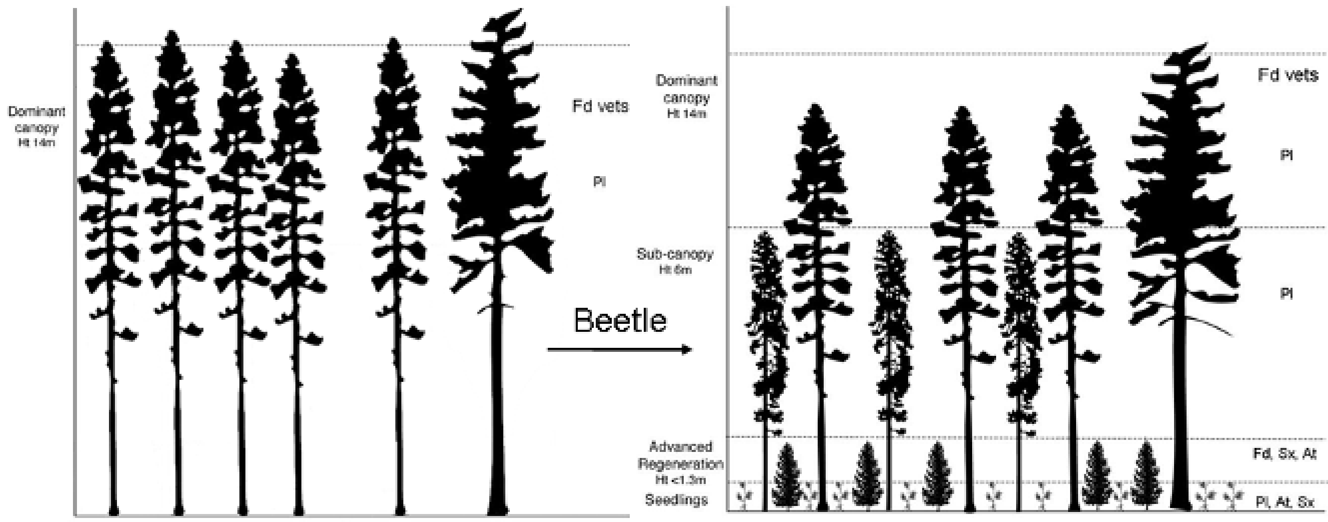


Figure 7. Diagrams showing how some lodgepole pine stands in BC have evolved from even-aged post-fire stands (left) to complex multi-storied stands (right) as a response to repeated mountain pine beetle thinning.

Future work

We would like to repeat this study in the southern Foothills (Nordegg to Waterton Lakes) to determine the impacts of known beetle outbreaks in southern latitudes of the Foothills, on the overstory tree growth, CWD dynamics and understory regeneration dynamics. Of particular interest, is to establish large scale climatic drivers of growth which can be utilized in growth models capable of simulating the impacts of global warming of forests of Alberta.

Acknowledgements

We wish to acknowledge the enormous contribution of Andrew Copeland who was involved extensively in this project, from planning fieldwork logistics to cross-dating all 1300 samples and graphing dendroecology results. Thanks go to Lauren Bergman and Peter Sprague for their assistance in the field. We wish to thank the help of many people in Alberta who made this project a success including: John Stadt and Dave Morgan from SRD; Marianne Kennedy from the Forestry Corp who ran our dendrochronology criteria through the PSP database; Glenn Buckmaster and the folks at the West Fraser in Hinton for consultation on HWP PSPs, maps and access information; and to Bruce Nielsen and his crew who collected samples for us in December and did a great job coring frozen trees. Funding for this project was made available by the Foothills Research Institute, Mountain Pine Beetle Program, and special thanks go to Don Podlubny for field assistance in our last PSP.

References

Alfaro, R. Axelson, J. and Hawkes, B., 2009. Mountain pine beetle increases the complexity of fire-origin lodgepole pine stands in British Columbia, Canada. BC Journal of Ecosystems and Management 9 (3), 85-89.

Alfaro, R., Campbell, E., Hawkes, B., 2004. Historical frequency, intensity and extent of mountain pine beetle disturbance in landscapes of British Columbia. Pacific Forestry Centre, Canadian Forest Service, Victoria, BC, MPBI Project # 2.05.

Axelson, J., Alfaro, R., Hawkes, B. 2009. Influence of fire and mountain pine beetle on the dynamics of lodgepole pine stands in British Columbia, Canada. Forest Ecology and Management, Vol.257, Issue 9: 1874-1882. doi: 10.1016/j.foreco.2009.01.047.

Antos, J., Parish, R., 2002. Dynamics of an old-growth, fire initiated subalpine forest in southern interior of British Columbia: tree size, age and spatial structure. Can. J. For. Res. 32, 1935-1946.

Berg, E., Henry, D., Fastie, C., De Volder, A., Matsuoka, S., 2006. Spruce beetle outbreaks on the Kenai Peninsula, Alaska, and Kluane National Park and Reserve, Yukon Territory: Relationship to summer temperatures and regional differences in disturbance regimes. For. Ecol. Manage. 227, 219-232.

Campbell, E., Alfaro, R., Hawkes, B., 2007. Spatial distribution of mountain pine beetle outbreaks in relation to climate and stand characteristics: A dendroecological analysis. J. Integ. Plant Bio. 49 (2), 168-178.

Campbell, R., Smith, D., Arsenault, A., 2006. Multicentury history of western spruce budworm outbreaks in interior Douglas-fir forests near Kamloops, British Columbia. Can. J. For. Res. 36, 1758-1769.

Cook, E., 1985. A time-series analysis approach to tree-ring standardization. PhD dissertation, University of Arizona, Tucson, AZ. 104pp.

Cook, E., Holmes, R., 1986. User's manual for program ARSTAN. *In*: Holmes, R., Adams, R., Fritts, H. (Eds.), Tree-ring chronologies of western North America: California, eastern Oregon and northern Great Basin. University of Arizona, Tucson, AZ. Chrono. Ser. 6, 50-56.

Cook, E., Briffa, K., Shiyatov, S., Mazepa, V., 1990. Tree-ring standardization and growth-trend estimation. *In* Cook, E.R. and Kairiukstis, L.A. (Eds). Methods of Dendrochronology: Applications in the Environmental Sciences, Klumer Academic Publishers, Dordrecht, 104-123.

Eisenhart, K., Veblen, T., 2000.Dendroecological detection of spruce bark beetle outbreaks in northwestern Colorado. J. For. Res. 30, 1788-1798.

Fritts, H.C. 1976. Tree Rings and Climate. Academic Press, London, 567 p.

Grissino-Mayer, H. 2001. Evaluating cross-dating accuracy: A manual and tutorial for the computer program COFECHA. Tree-Ring Research, 57 (2), 205-221.

Heath, R., Alfaro, R., 1990. Growth response of a Douglas-fir/lodgepole pine stand after thinning of lodgepole pine by the mountain pine beetle. J. Entomol. Soc. of B.C. 87, 16-21.

Holmes, R., 1983. Computer assisted quality control in tree-ring dating and measurement. Tree-Ring Bull. 43, 69-78.

Mitchell, R., Martin, R., Stuart, J., 1983. Catfaces on lodgepole pine – fire scars or strip kills by the mountain pine beetle? J. For. 81, 589-601.

Regent Instruments, 2003. http://www.regentinstruments.com/

Rubino, D., McCarthy, B., 2004. Comparative analysis of dendroecological methods used to assess disturbance events. Dendrochronologia, 21(3), 97-115.

Stokes, M., Smiley, T., 1968. An introduction to tree-ring dating. University of Chicago Press, Chicago.

Stuart, J., Geiszler, D., Gara, R., Agee, J., 1983. Mountain pine beetle scarring of lodgepole pine in south-central Oregon. For. Ecol. Manage. 5, 207-214.

Swetnam, T., Allen, C., Betancourt, J., 1999. Applied historical ecology: using the past to manage the future. Ecological Applications 9 (4), 1189-1206.

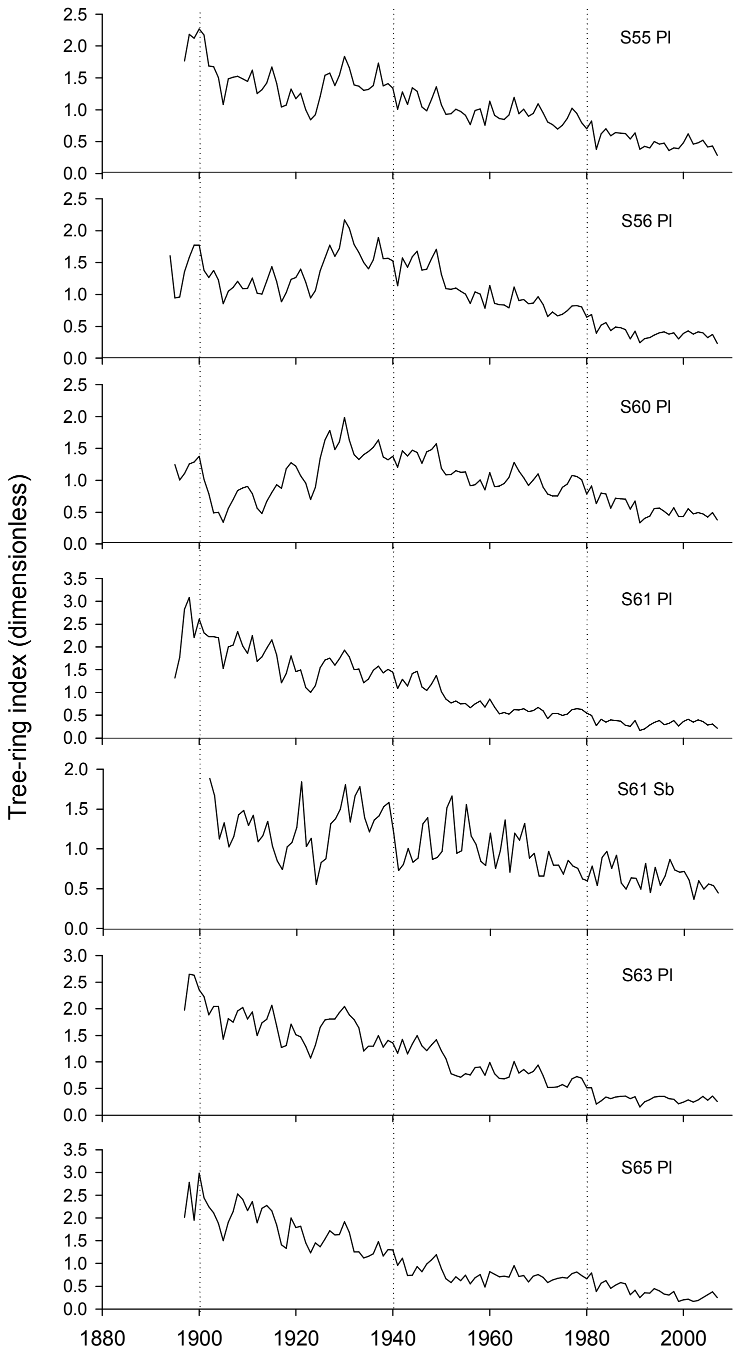
Swetnam, T., Lynch, A., 1993. Multicentury, regional-scale patterns of western spruce budworm outbreaks. Ecol. Mono. 63 (4), 399-424.

Taylor, S., Carroll, A., Alfaro, R., Safranyik, L., 2006. Forest, climate and mountain pine beetle outbreak dynamics in western Canada. In: Safranyik, L., Wilson, B. (Eds.). The Mountain Pine Beetle A Synthesis of Biology, Management and Impacts on Lodgepole Pine. Natural Resources Canada, Canadian Forest Service, Pac. For. Centre, Victoria, BC, Canada, pp. 67-94.

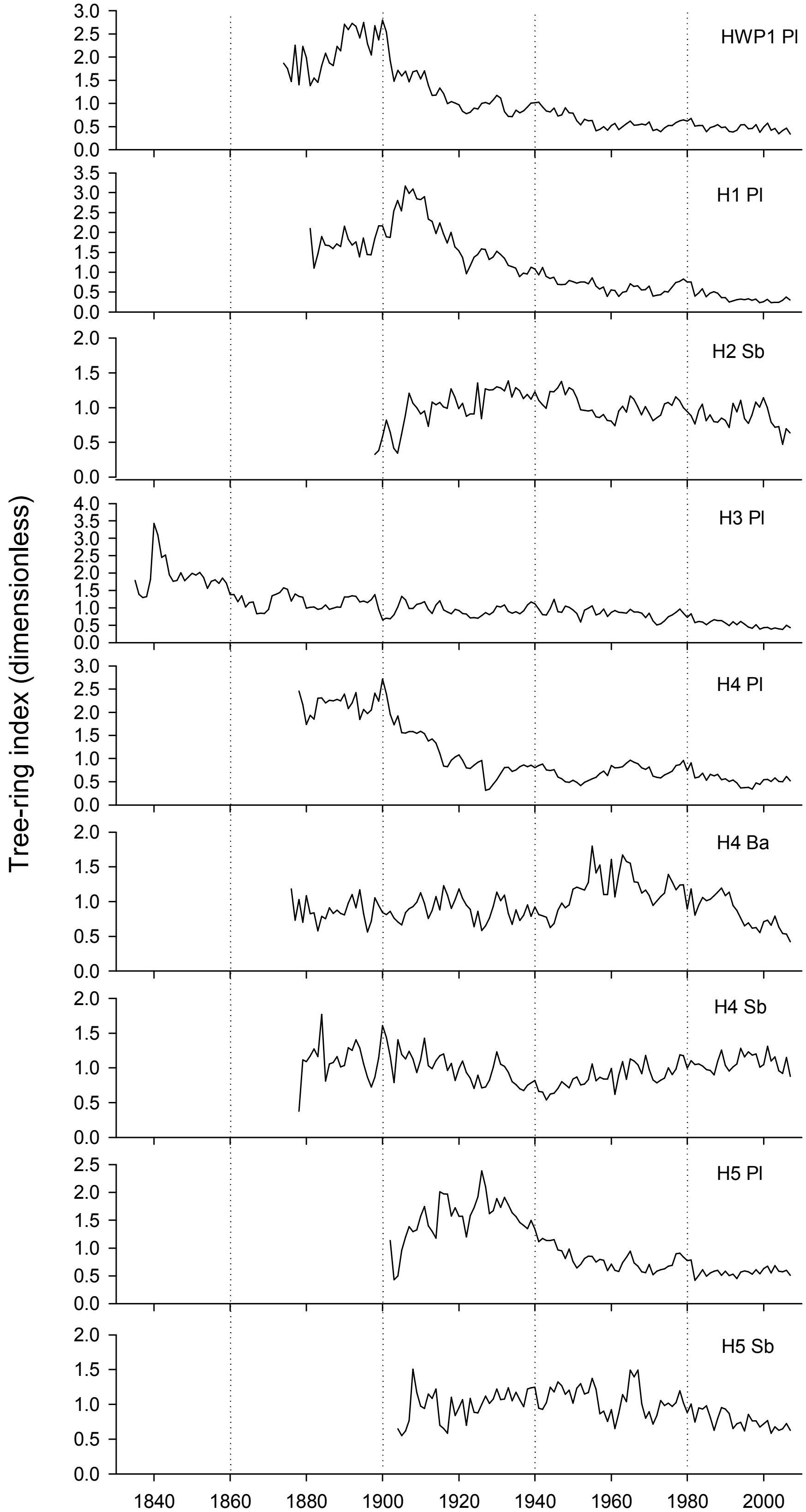
Veblen, T., Hadley, K., Ried, M., Rebertus, A., 1991. The response of subalpine forests to spruce beetle outbreak in Colorado. Ecology 71 (1), 213-231.

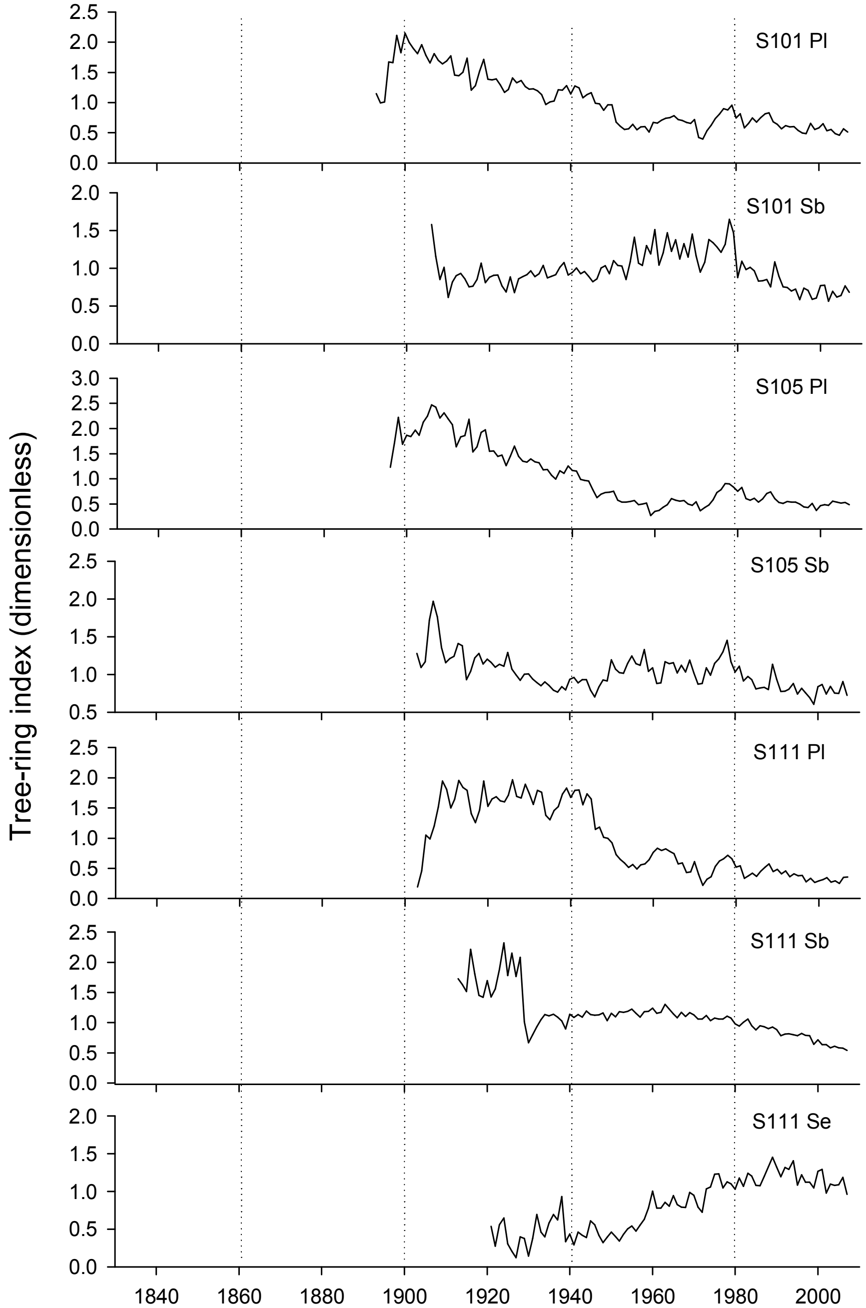
Zhang, Q., Alfaro, R., 2002. Periodicity of two-year cycle spruce budworm outbreaks in central British Columbia: A dendro-ecological analysis. For. Sci. 48 (4), 722-73.

Appendix



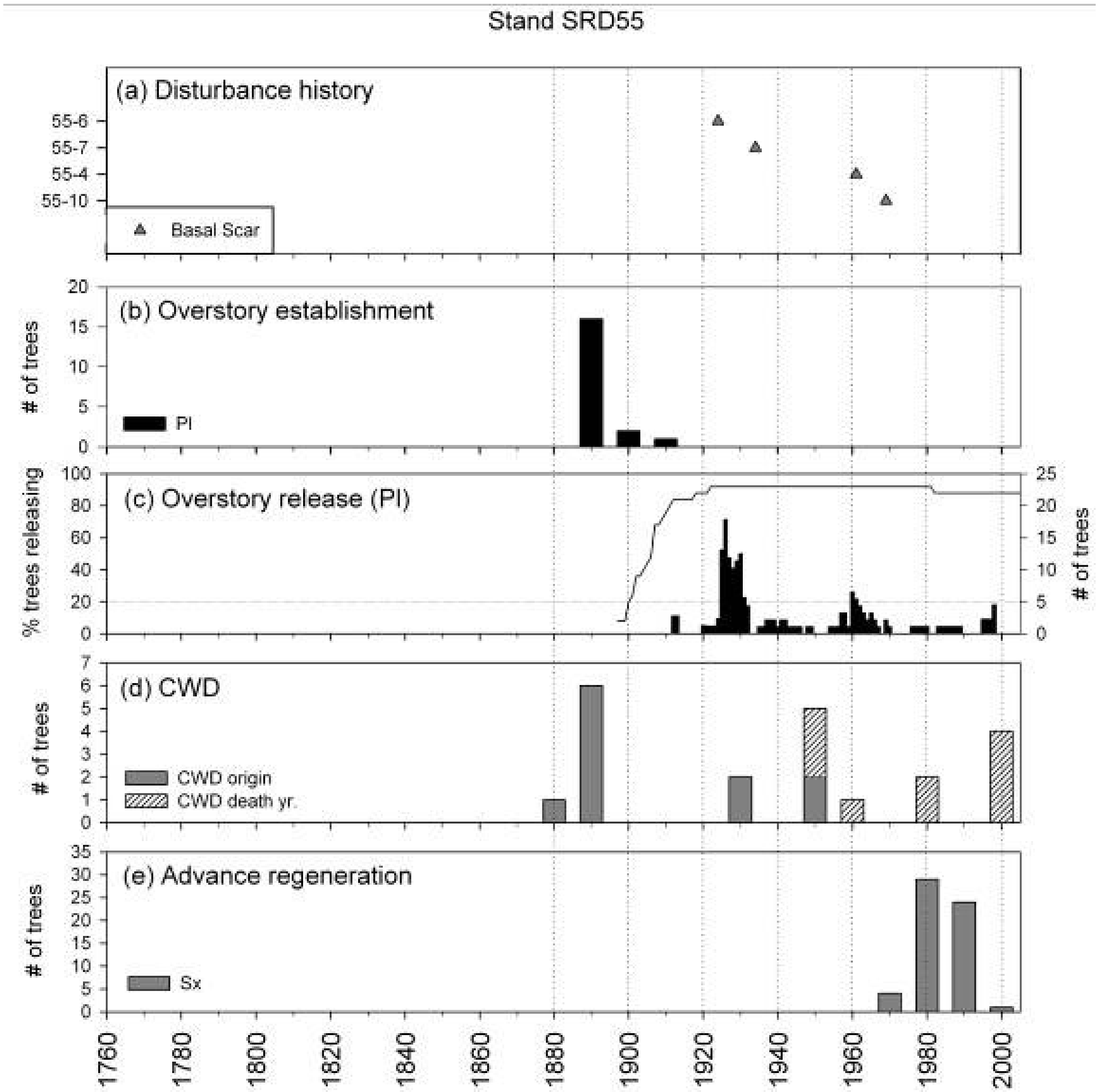
Standardized chronologies for Lower Foothills stands using horizontal line through the mean.


HWP1 Pl
H1 Pl
H2 Sb
H3 Pl
H4 Pl
H4 Ba
H4 Sb
H5 Pl
H5 Sb
Tree-ring index (dimensionless)
1840
1860
1880
1900
1920
1940
1960
1980
2000



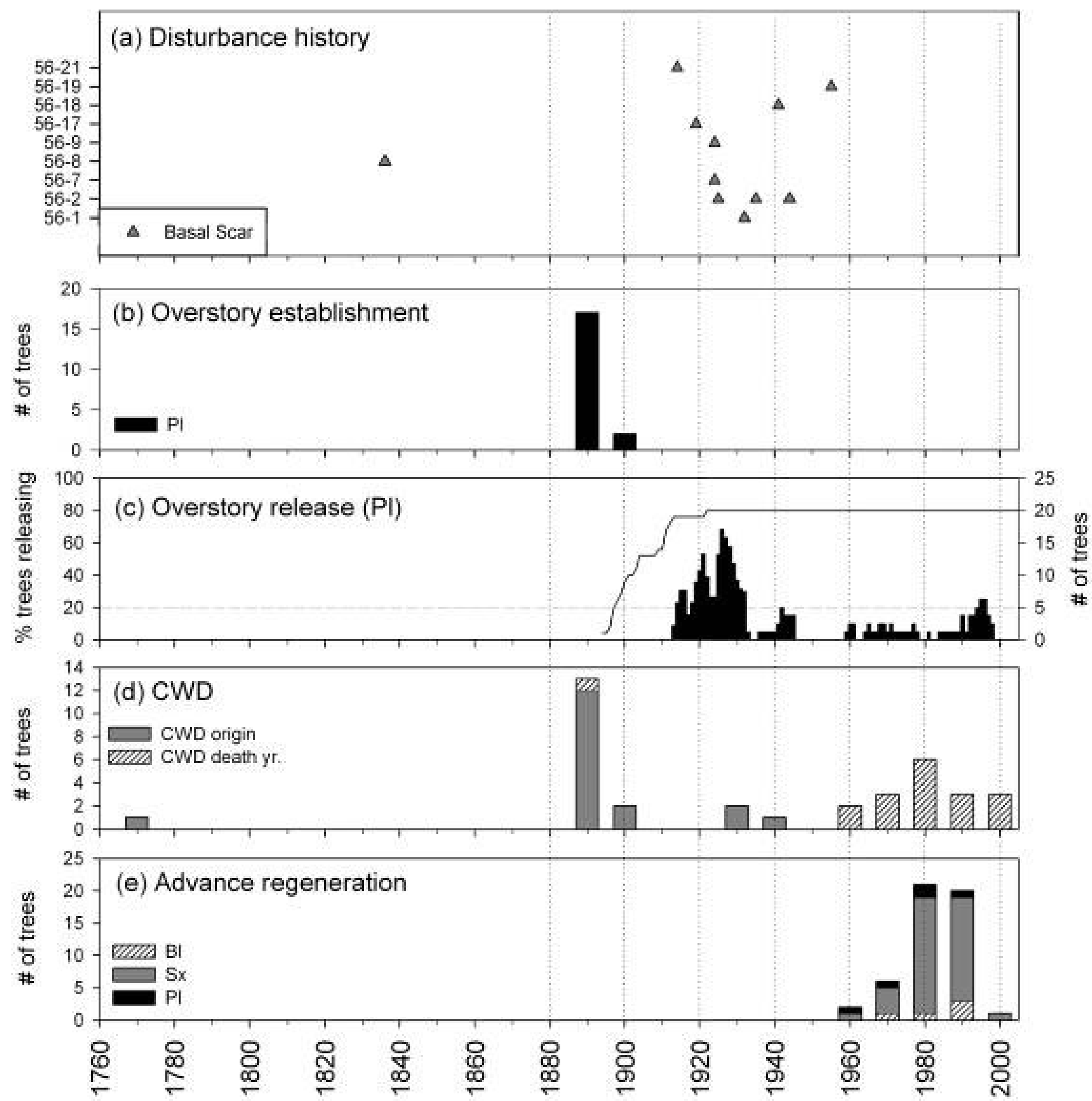
Standardized chronologies for Upper Foothills stands using a horizontal line through the mean.

Stand histories for each PSP



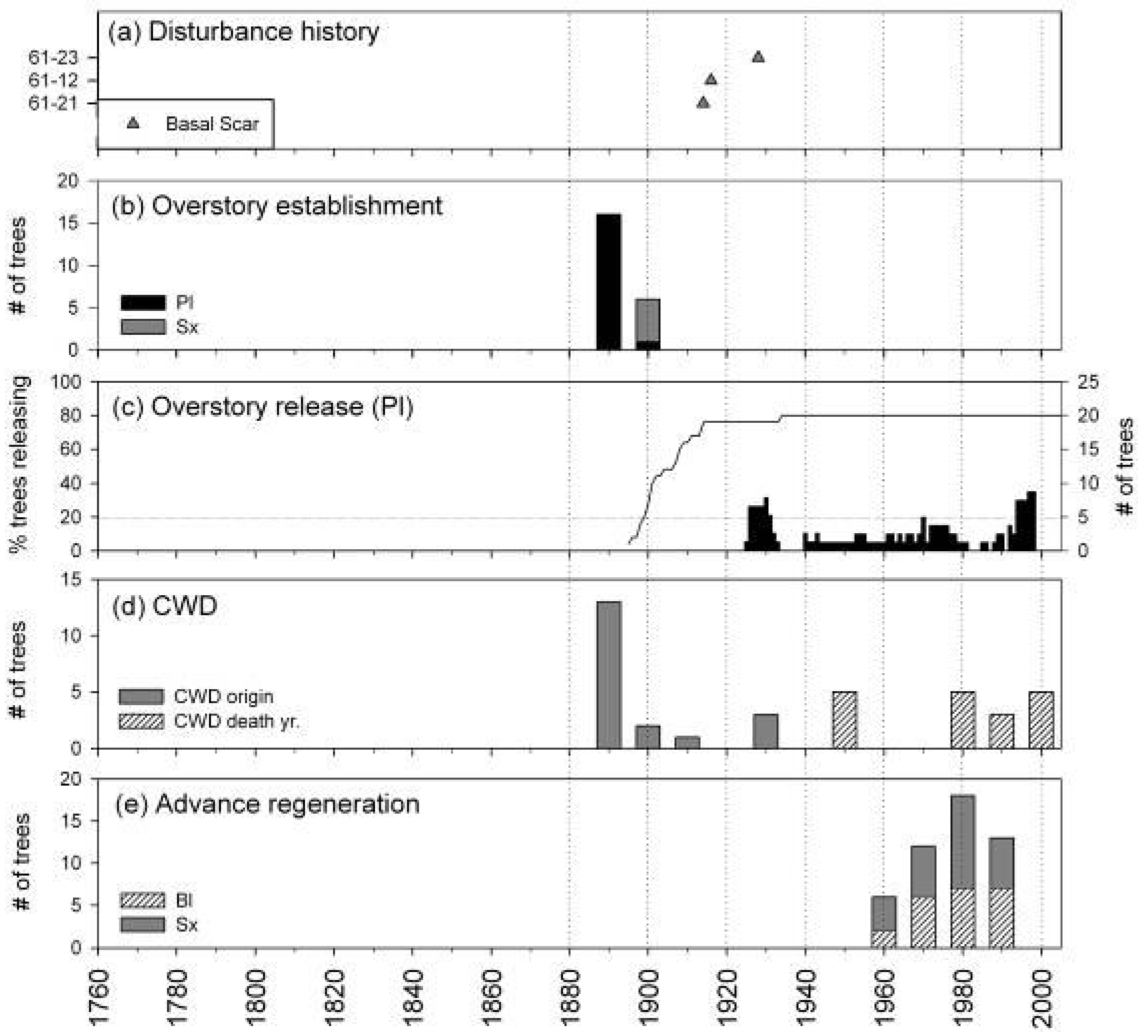
Reconstruction of disturbance history for SRD55: (a) Scar history from dated discs; (b) establishment date of the overstory; (c) Percent of lodgepole pine showing growth releases in a given year (left-axis), and sample depth (right-axis); (d) birth and death dates of the coarse woody debris (CWD); and (e) date of establishment of understory advance regeneration.

Stand SRD56



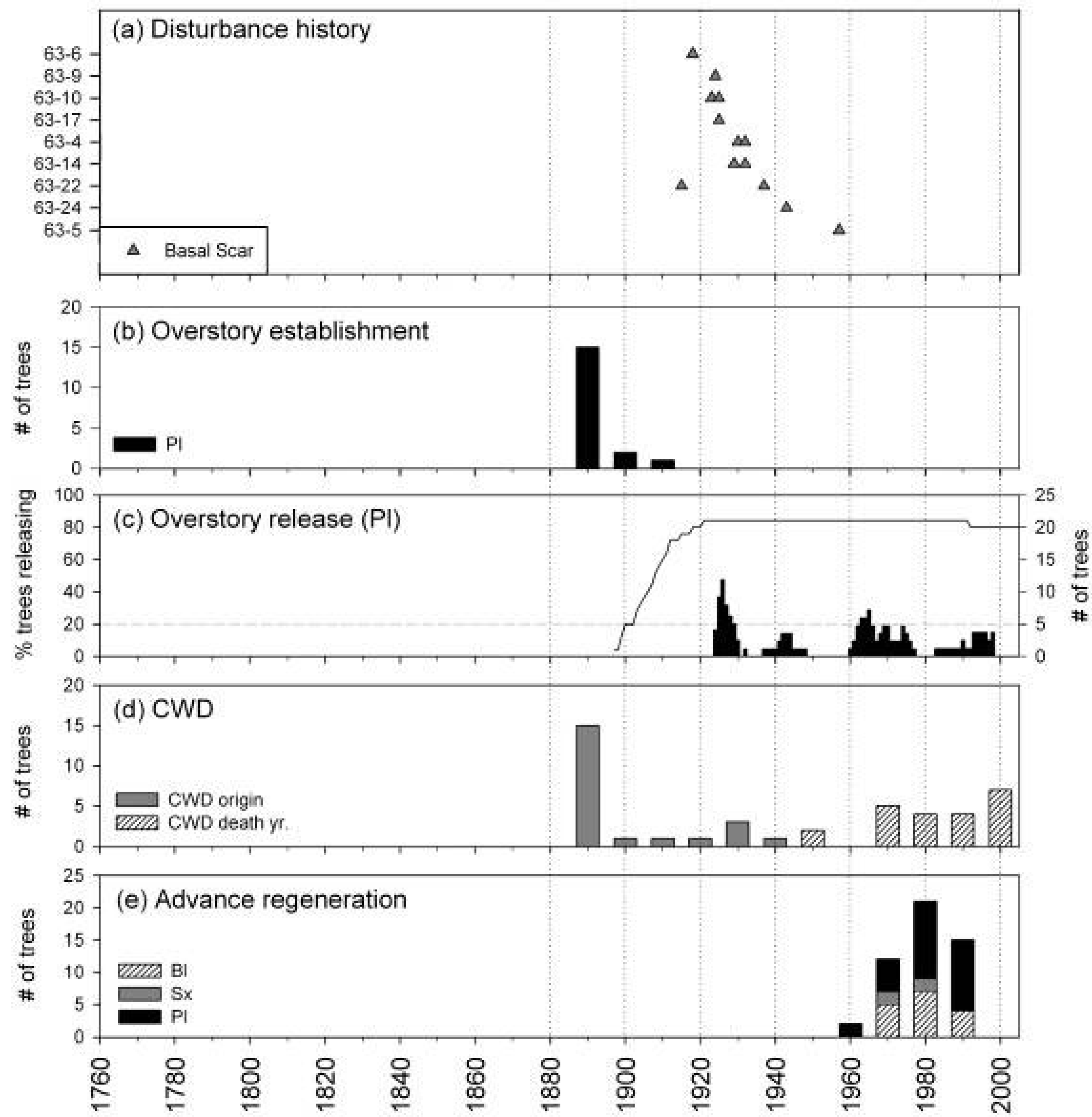
Reconstruction of disturbance history for SRD56: (a) Scar history from dated discs; (b) establishment date of the overstory; (c) Percent of lodgepole pine showing growth releases in a given year (left-axis), and sample depth (right-axis); (d) birth and death dates of the coarse woody debris (CWD); and (e) date of establishment of understory advance regeneration.

Stand SRD61



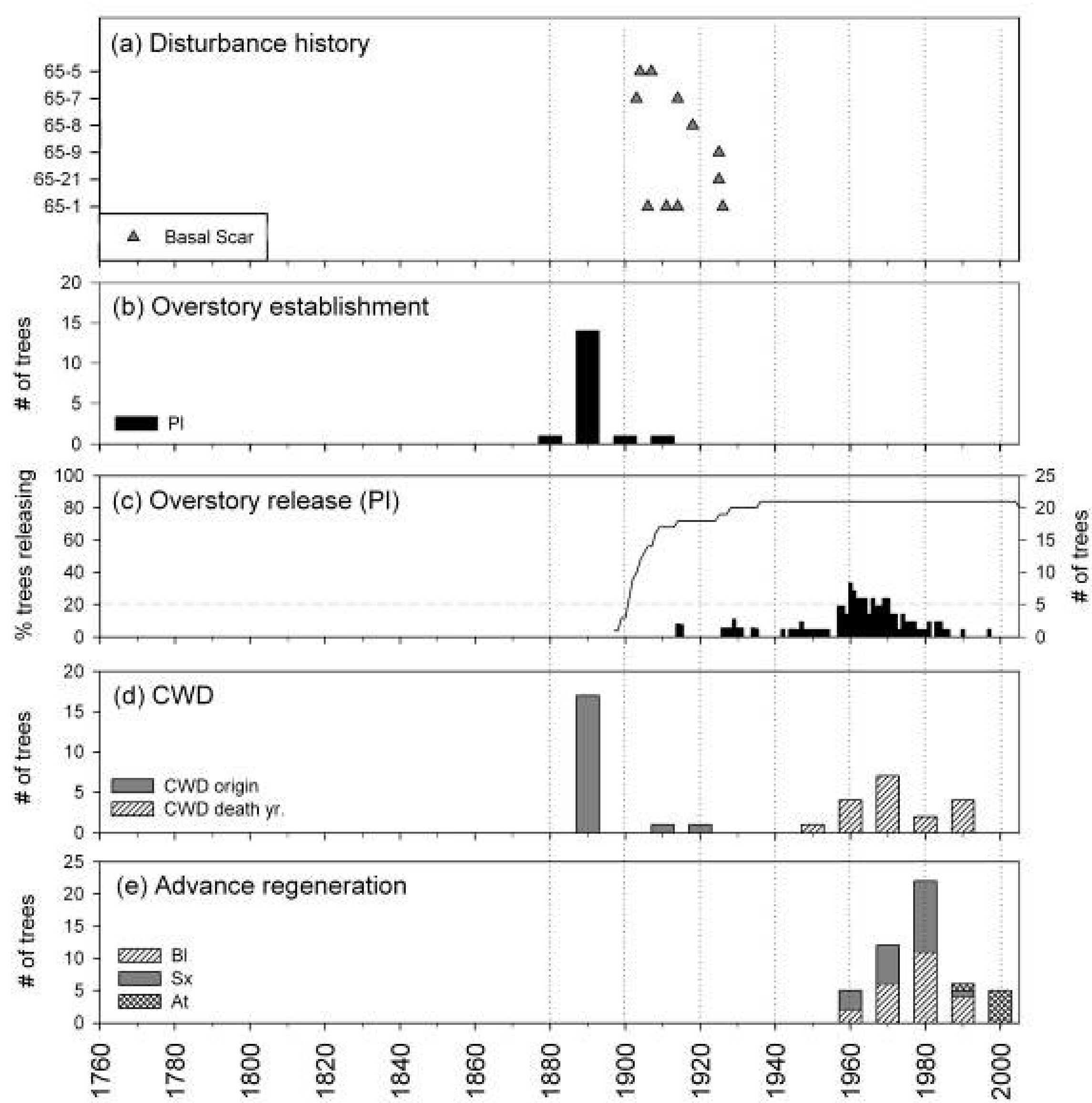
Reconstruction of disturbance history for SRD61: (a) Scar history from dated discs; (b) establishment date of the overstory; (c) Percent of lodgepole pine showing growth releases in a given year (left-axis), and sample depth (right-axis); (d) birth and death dates of the coarse woody debris (CWD); and (e) date of establishment of understory advance regeneration.

Stand SRD63



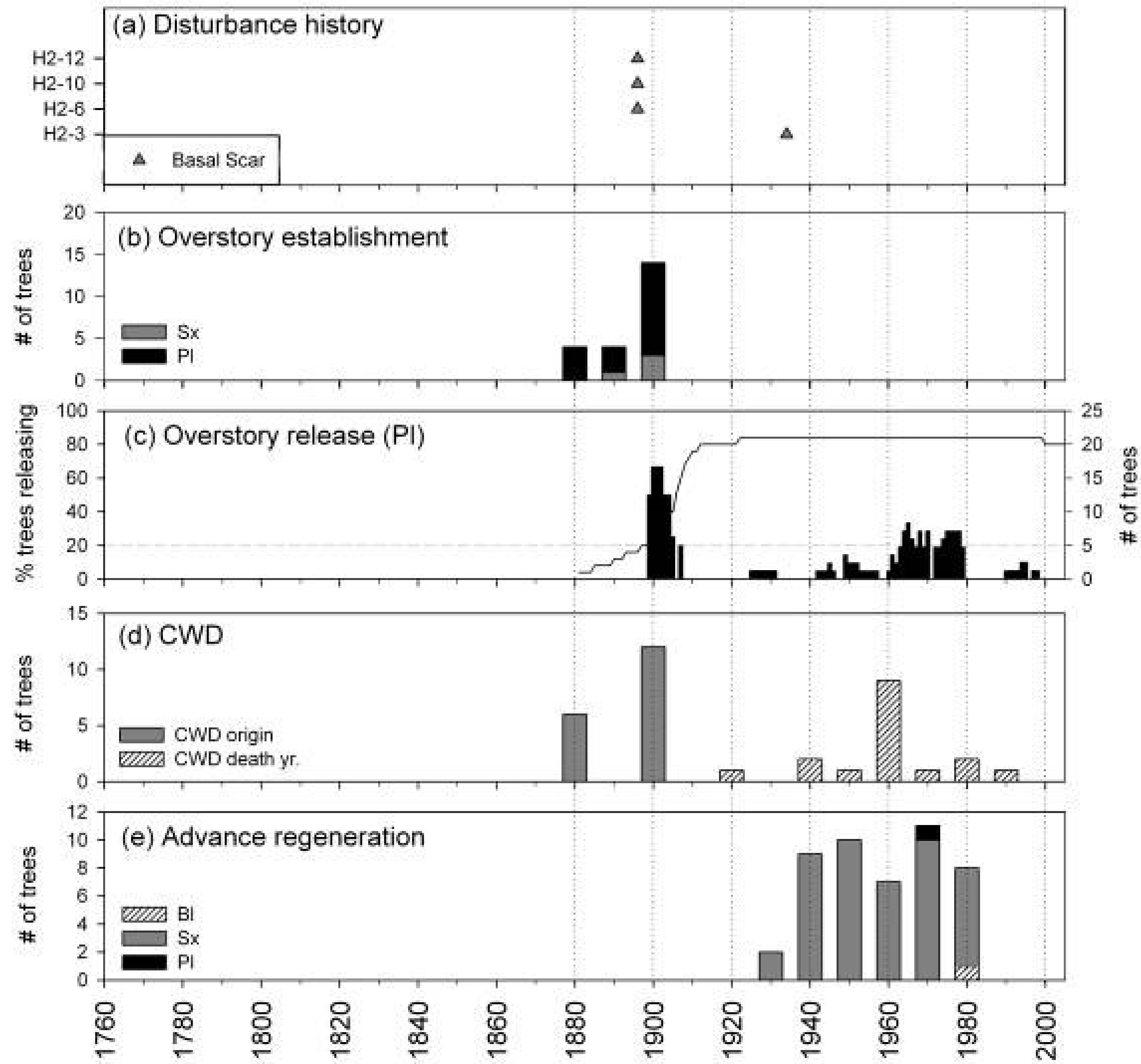
Reconstruction of disturbance history for SRD63: (a) Scar history from dated discs; (b) establishment date of the overstory; (c) Percent of lodgepole pine showing growth releases in a given year (left-axis), and sample depth (right-axis); (d) birth and death dates of the coarse woody debris (CWD); and (e) date of establishment of understory advance regeneration.

Stand SRD65



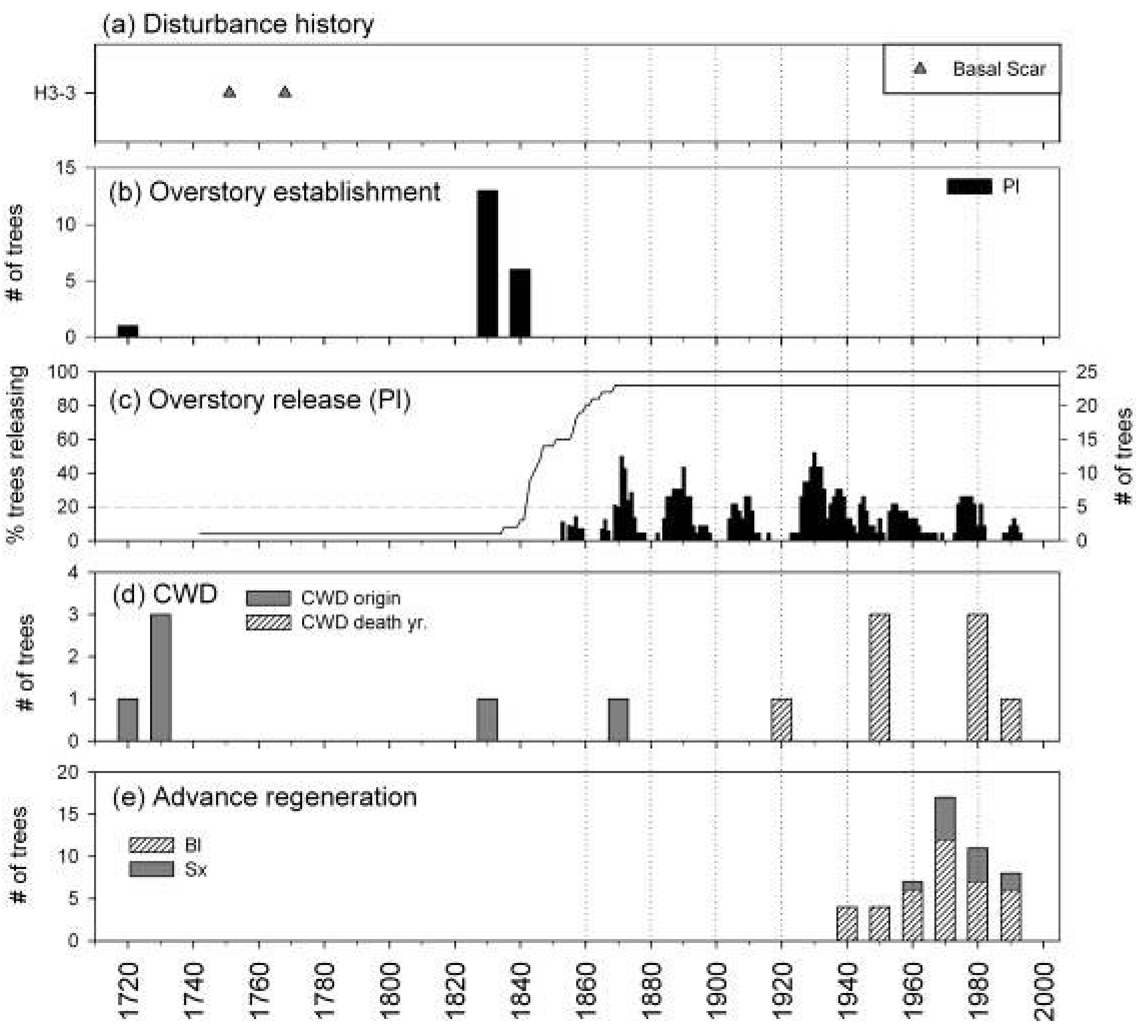
Reconstruction of disturbance history for SRD65: (a) Scar history from dated discs; (b) establishment date of the overstory; (c) Percent of lodgepole pine showing growth releases in a given year (left-axis), and sample depth (right-axis); (d) birth and death dates of the coarse woody debris (CWD); and (e) date of establishment of understory advance regeneration.

Stand H2

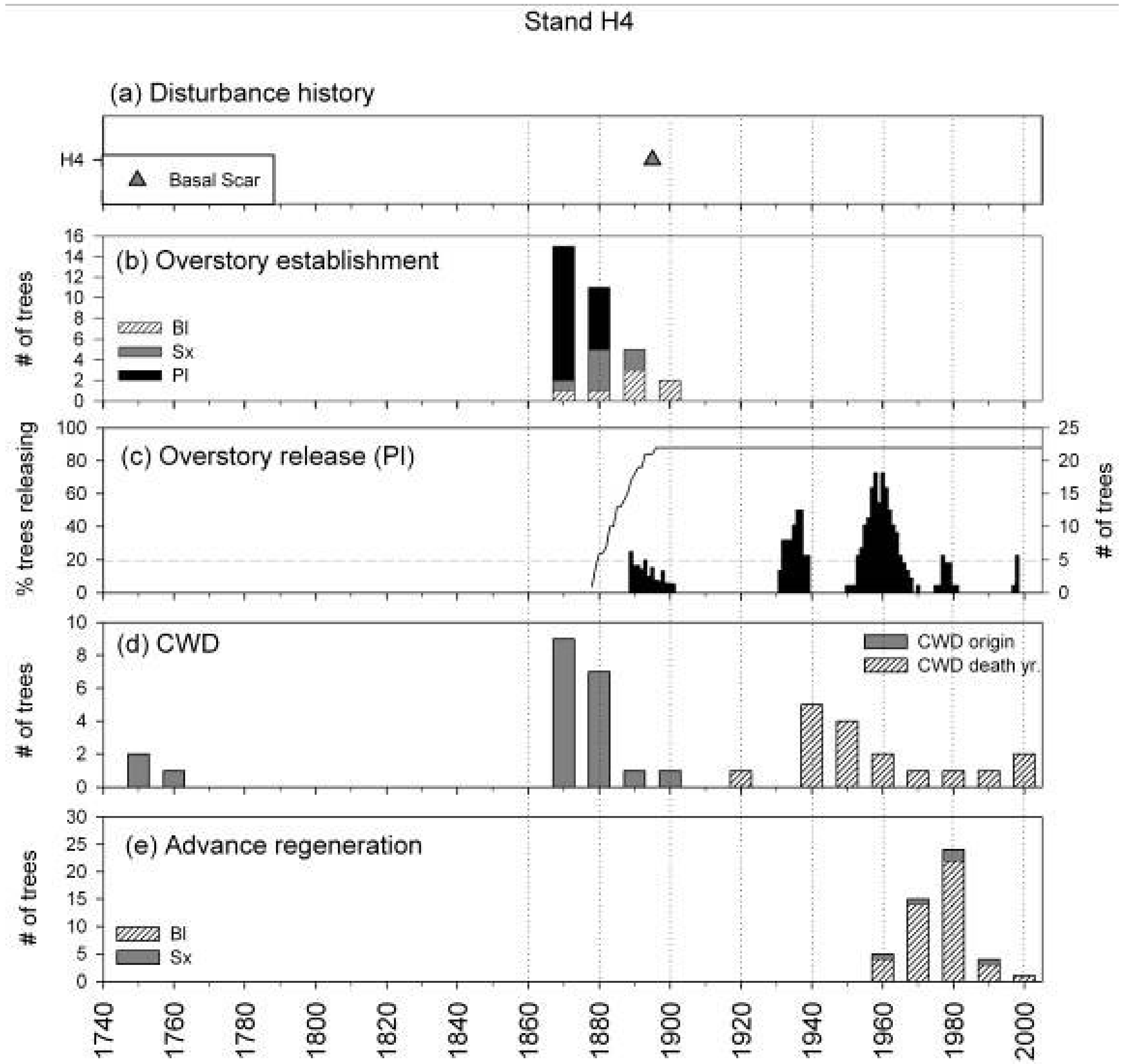


Reconstruction of disturbance history for H2 (HWP 1010596-97): (a) Scar history from dated discs; (b) establishment date of the overstory; (c) Percent of lodgepole pine showing growth releases in a given year (left-axis), and sample depth (right-axis); (d) birth and death dates of the coarse woody debris (CWD); and (e) date of establishment of understory advance regeneration.

Stand H3

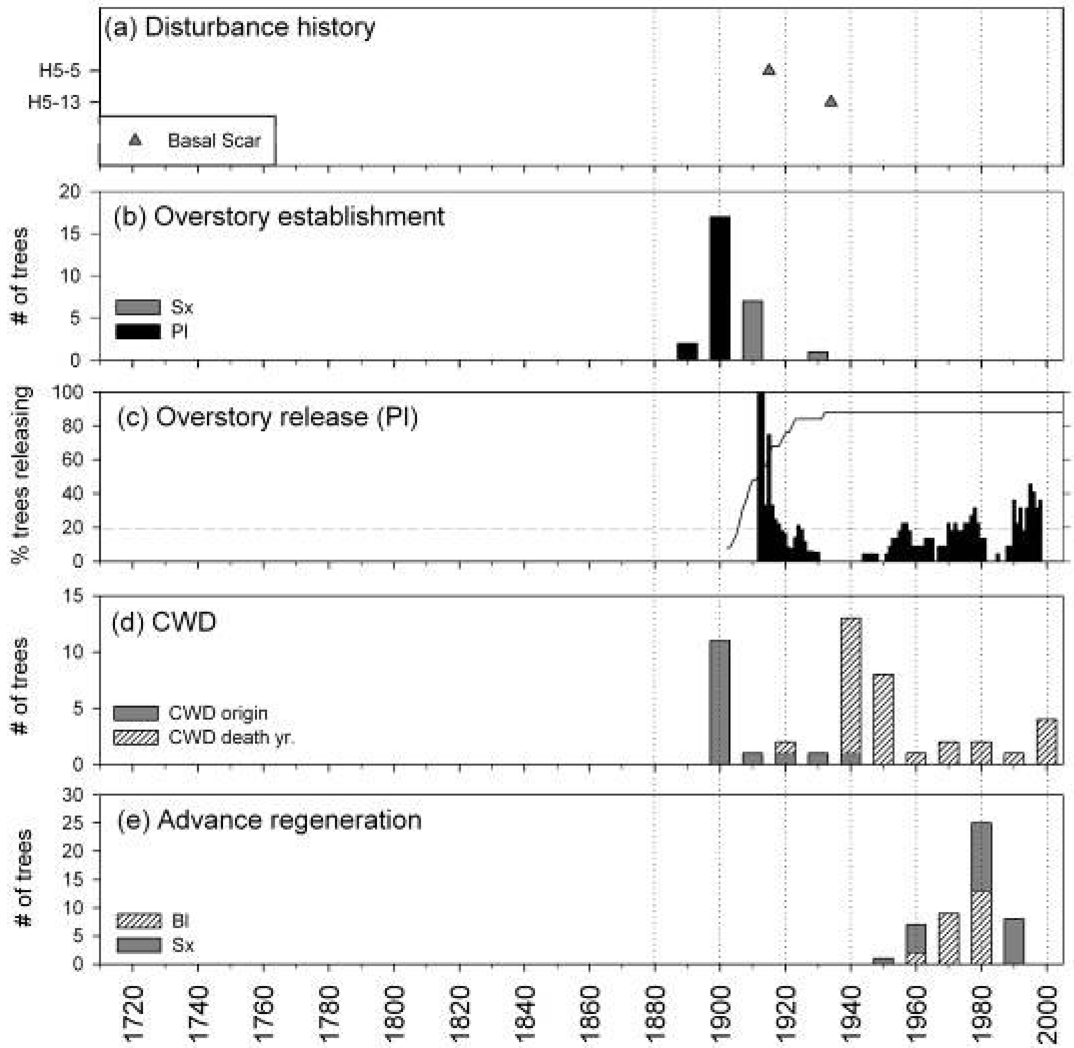


Reconstruction of disturbance history for H3 (HWP 2010116): (a) Scar history from dated discs; (b) establishment date of the overstory; (c) Percent of lodgepole pine showing growth releases in a given year (left-axis), and sample depth (right-axis); (d) birth and death dates of the coarse woody debris (CWD); and (e) date of establishment of understory advance regeneration.



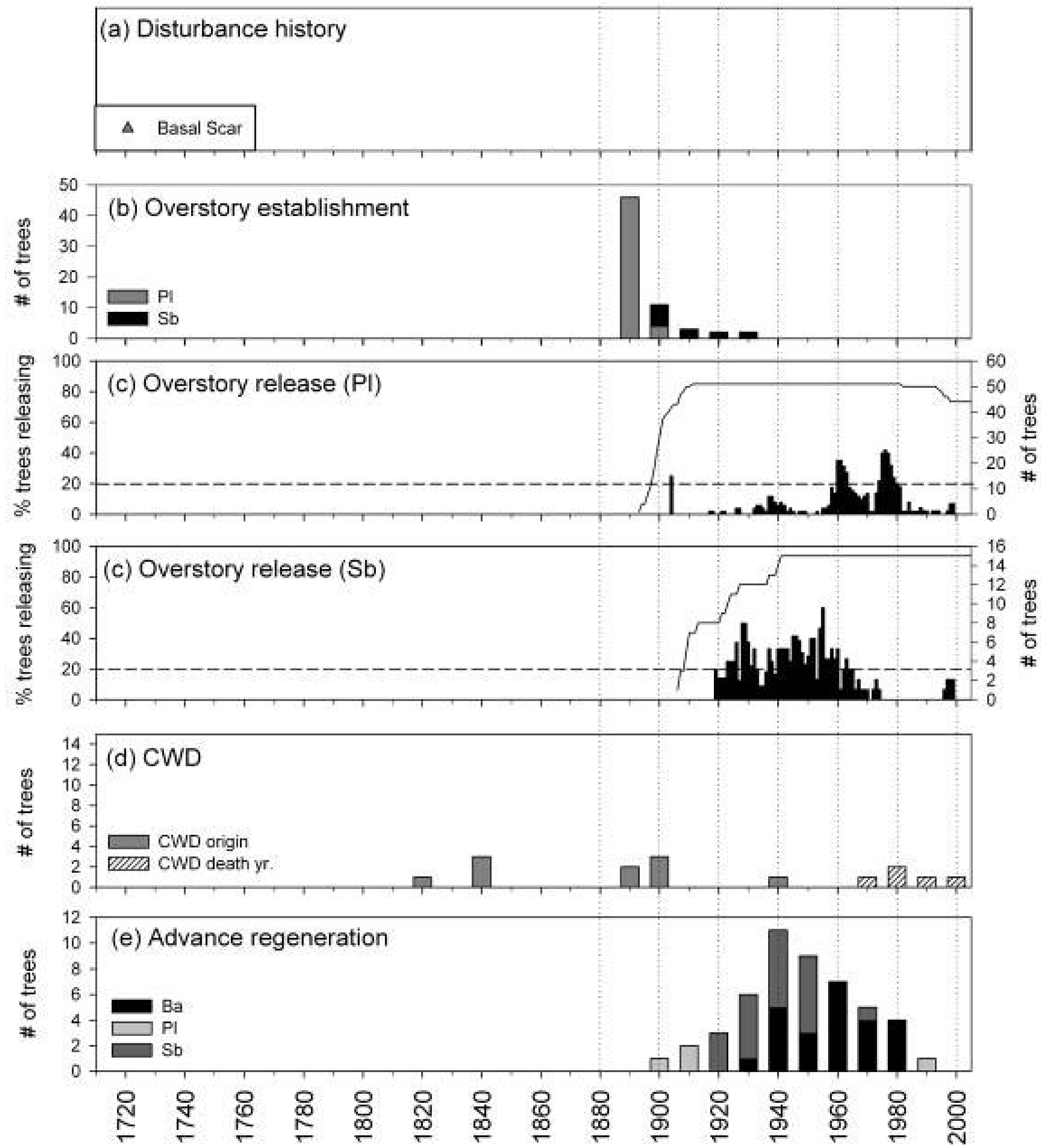
Reconstruction of disturbance history for H4 (HWP 4010289-291): (a) Scar history from dated discs; (b) establishment date of the overstory; (c) Percent of lodgepole pine showing growth releases in a given year (left-axis), and sample depth (right-axis); (d) birth and death dates of the coarse woody debris (CWD); and (e) date of establishment of understory advance regeneration.

Stand H5

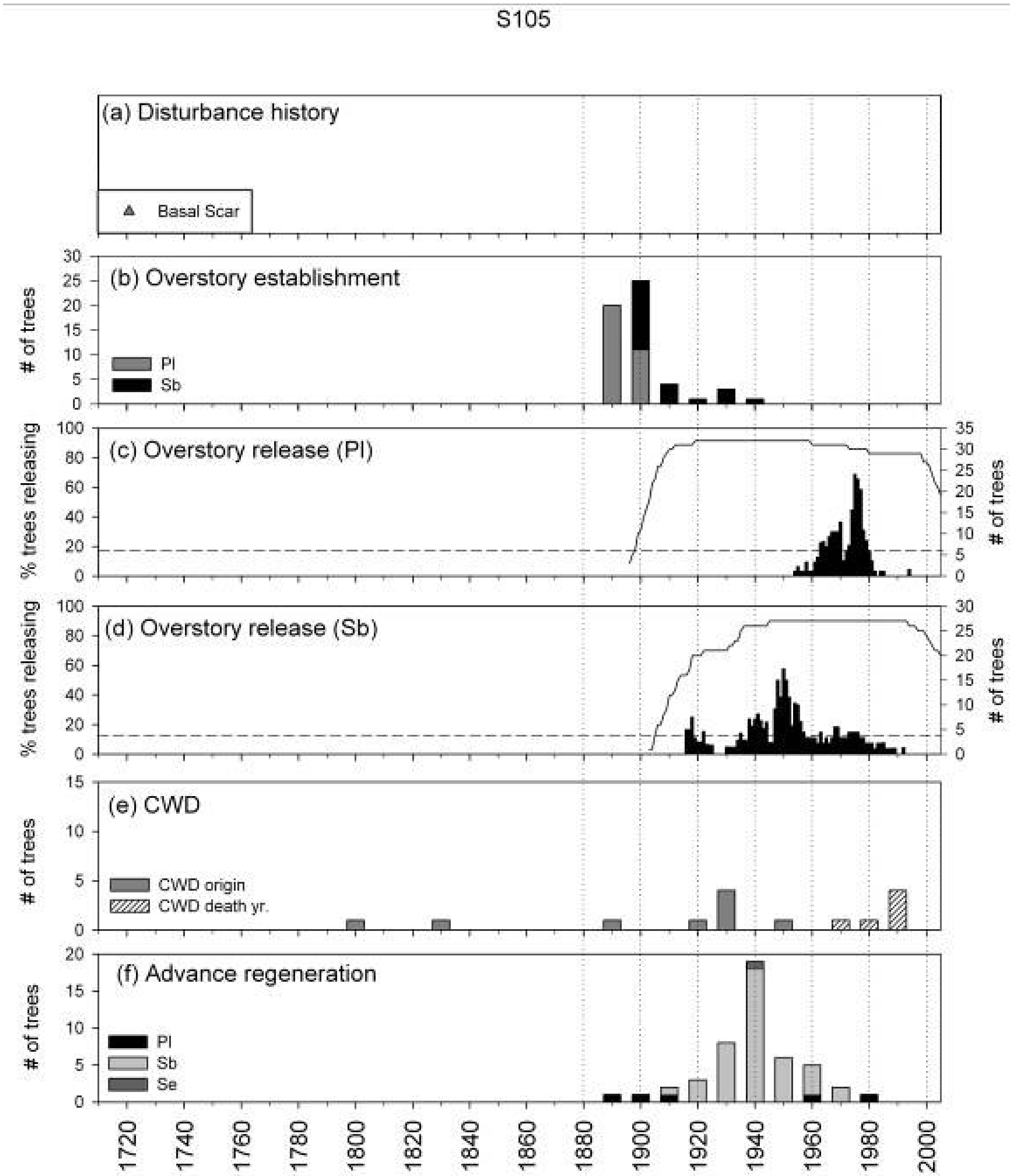


Reconstruction of disturbance history for H5 (HWP 4010077-78): (a) Scar history from dated discs; (b) establishment date of the overstory; (c) Percent of lodgepole pine showing growth releases in a given year (left-axis), and sample depth (right-axis); (d) birth and death dates of the coarse woody debris (CWD); and (e) date of establishment of understory advance regeneration.

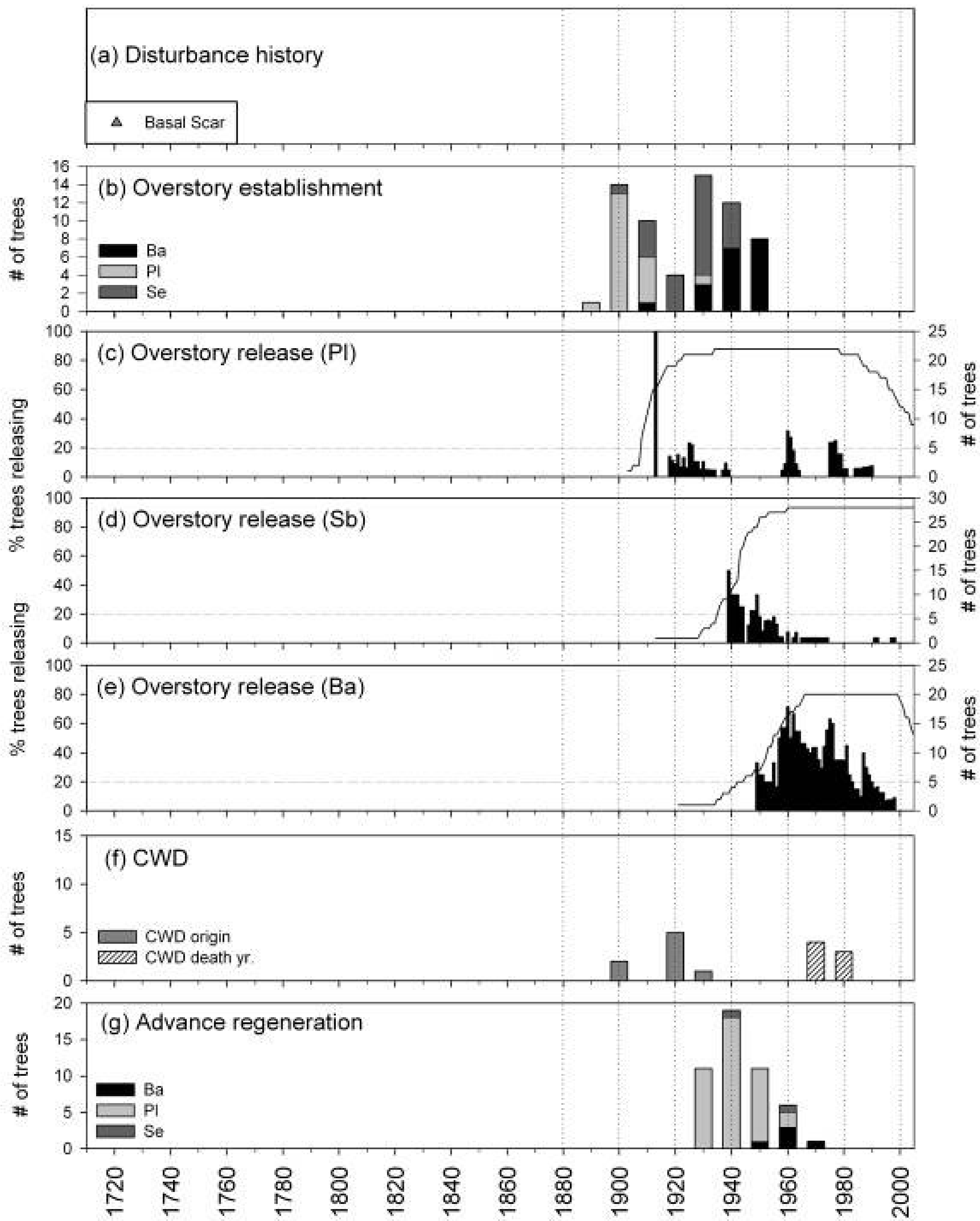
S101



Reconstruction of disturbance history for SRD101: (a) Scar history from dated discs; (b) establishment date of the overstory; (c) Percent of lodgepole pine showing growth releases in a given year (left-axis), and sample depth (right-axis); (d) birth and death dates of the coarse woody debris (CWD); and (e) date of establishment of understory advance regeneration.



Reconstruction of disturbance history for SRD105: (a) Scar history from dated discs; (b) establishment date of the overstory; (c) Percent of lodgepole pine showing growth releases in a given year (left-axis), and sample depth (right-axis); (d) birth and death dates of the coarse woody debris (CWD); and (e) date of establishment of understory advance regeneration.



Reconstruction of disturbance history for SRD111: (a) Scar history from dated discs; (b) establishment date of the overstory; (c) Percent of lodgepole pine showing growth releases in a given year (left-axis), and sample depth (right-axis); (d) birth and death dates of the coarse woody debris (CWD); and (e) date of establishment of understory advance regeneration.