EVALUATING THE POTENTIAL FOR SNOWPACK RECONSTRUCTION IN INTERIOR BRITISH COLUMBIA AND THE NORTHERN U.S. ROCKIES USING *LARIX LYALLII* (SUBALPINE LARCH)

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INTRODUCTION

Precipitation sensitive tree-ring width chronologies (primarily from *Pseudotsuga menziesii* and *Pinus ponderosa*) have been developed for the northern U.S. and Canadian Rockies and the interior ranges of British Columbia. These chronologies have been invaluable for exploring historic precipitation and drought variability at local and regional scales, however their moisture sensitivity is related primarily to growing season (or summer) conditions. In the mountainous west, the delayed melt of winter snowpack is an important contributor to summer flows for many rivers of importance for hydroelectric power generation, urban water resources and downstream irrigation in key agricultural regions (e.g. the Canadian Prairies and Columbia River Basin). Snowpack is also a critical control of net glacier mass balance both directly and through its influence on the amount and timing of summer ablation. Snowpack conditions over the 20th century are generally decoupled from moisture received over the summer season. To reconstruct the range of past fluctuations in streamflow and glacier mass balance in the intermountain West realistically it is vital to identify tree-ring chronologies containing a strong and temporally stable winter precipitation signal. We describe initial investigations of the potential for developing snowpack reconstructions from *Larix lyallii* (subalpine larch).

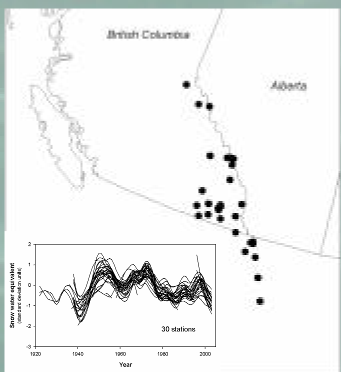


Fig. 1. Location of snow course and snowpack telemetry sensors (SNOTEL; majority of U.S. data) from which snow water equivalent (SWE) records used in this study were obtained (35 records from 38 sites). Inset diagram: Plots of April 1st standardized SWE records (May 1st for the U.S. stations) over the 20th century at 30 stations (those that start at or before 1951) smoothed with a 10-year spline. Note the strong coherence across the region. The SWE data are presented in standard deviation units from their 1951-2003 means (several station records end before 2003). Canadian SWE data were obtained from the 2004 version of the Canadian Snow Data CD-ROM (Meteorological Service of Canada, 2000). The records for Montana were obtained from the National Resources Conservations Service anonymous ftp server (ftp.wcc.nrcs.usda.gov).

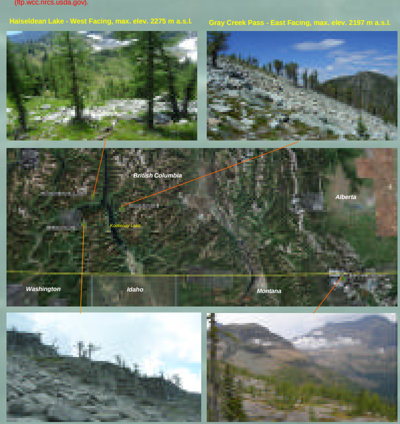


Fig. 2. Location of the four sites sampled in this study along with site photographs and characteristics.

SAMPLE SITES AND CLIMATE RECORDS

Subalpine larch grows near timberline in high alpine areas (generally >2000m) often on granite or quartzite talus with limited soil development. Its distribution in Canada is limited to the southern reaches of the Rocky Mountains, Purcells and Selkirks and a small pocket in the central, southern interior of B.C. (Arno and Habeck, 1972). Exploratory correlation analyses between 38 snowpack records (see Fig. 1 for details) and subalpine larch chronologies from near treeline sites primarily in the Rocky Mountains (Colenutt, 2000) have been conducted. Several of the most western chronologies in this network exhibit significant negative correlations with April 1st snowpack records. The strongest relationships are with a chronology from Gray Creek Pass, B.C. To evaluate the regional representativeness and replicabiltiy of this signal the Gray Creek Pass chronology was updated, and three additional high-elevation larch chronologies were collected at sites in the Purcell and Selkirk Mountains (i.e. west of the Rocky Mountains) in July 2006 (Fig. 2). A subalpine larch chronology from Boulder Pass Glacier National Park, Montana (Fig. 2) is used to evaluate the regional synchroneity of the growth variations.

RESULTS

Chronology Comparisons

Measurements from the new sites sampled in 2006 and the update to the Gray Creek chronology are still in progress and are not yet available. Instead we focus here on comparing the existing Gray Creek Pass chronology (ends in 1993) with the chronology from Boulder Pass, Montana (Fig. 3). Despite the distance between the chronologies (~200 km), correspondence between them is high (Fig. 3c) with a correlation coefficient of 0.56 over the period 1600-1993. The two chronologies show periods of above average (1600-1993 mean) growth during the 1650-60s, 1800-1820s, 1850-80s and the 1920s-40s. Common periods of below mean growth occur during the early 1700s, from the late 1740s-50s (<2 sd from the mean), the 1830s-40s and part of the 1890s. Correlations calculated over a shorter window reveal that there are periods when the relationship between the two chronologies deteriorates particularly post-1950. The sharp growth reduction from about 1958-1968 in the Gray Creek larch chronology is absent from the Boulder Pass record and, though not necessarily related, it does overlap with a known period of larch sawfly outbreak in the East Kootenays (1964-7). It is also absent from chronologies developed from three other species (Engelmann spruce, mountain hemlock, and subalpine fir) sampled near the Gray Creek site. Evidence of needle disease (red needles; possibly needle blight or cast) was also present at the site when we sampled (July 23, 2006). Colenutt (2000) identified the Gray Creek Pass chronology as unique in her larch dataset (i.e. it loaded on its own principal component) and further work will be required to determine the nature of this and past growth reductions.

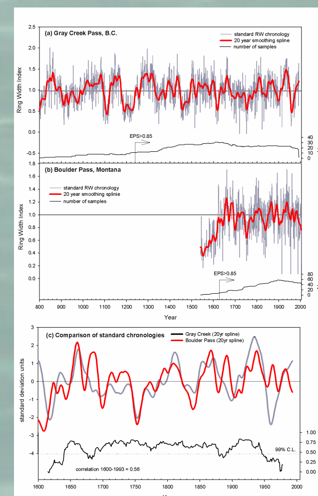
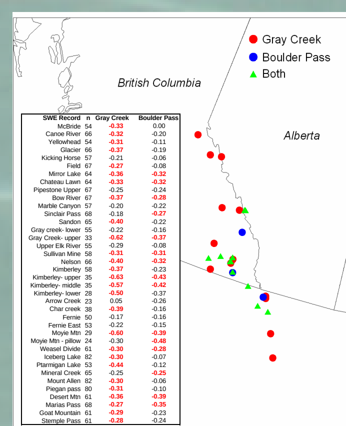


Fig. 3. Standard ring-width chronologies and sample depth (with approximate 0.85 EPS cutoff) from (a) Gray Creek Pass, B.C. and (b) Boulder Pass, Montana. For comparison 20 yr smoothed versions of the chronologies are shown in standard deviation units from the 1600-1993 mean in (c). The bottom plot in (c) shows moving correlations (31yr window, 29 yr overlap, plotted 16th yr) between the unsmoothed standard chronologies and the 99% significance level.



SWE Record	n	Gray Creek	Boulder Pass
McBride	54	-0.33	0.00
Canoe River	66	-0.32	-0.20
Yellowhead	54	-0.31	-0.11
Glacier	66	-0.37	-0.19
Kicking Horse	57	-0.21	-0.06
Field	67	-0.27	-0.08
Mirror Lake	64	-0.36	-0.32
Chateau Lawn	64	-0.33	-0.32
Pipestone Upper	67	-0.25	-0.24
Bow River	67	-0.37	-0.28
Marble Canyon	57	-0.20	-0.22
Sinclair Pass	68	-0.18	-0.27
Sandon	65	-0.40	-0.22
Gray creek- lower	55	-0.22	-0.16
Gray Creek- upper	33	-0.62	-0.37
Upper Elk River	55	-0.29	-0.08
Sullivan Mine	58	-0.31	-0.31
Nelson	66	-0.40	-0.32
Kimberley	58	-0.37	-0.23
Kimberley- upper	35	-0.63	-0.43
Kimberley- middle	35	-0.57	-0.42
Kimberley- lower	28	-0.50	-0.37
Arrow Creek	23	0.05	-0.26
Char creek	38	-0.39	-0.16
Fernie	50	-0.17	-0.16
Fernie East	53	-0.22	-0.15
Moyie Mtn	29	-0.60	-0.39
Moyie Mtn - pillow	24	-0.30	-0.48
Weasel Divide	61	-0.30	-0.28
Iceberg Lake	82	-0.30	-0.07
Ptarmigan Lake	53	-0.44	-0.12
Mineral Creek	65	-0.25	-0.25
Mount Allen	82	-0.30	-0.06
Piegan pass	80	-0.31	-0.10
Desert Mtn	61	-0.36	-0.39
Marias Pass	68	-0.27	-0.35
Goat Mountain	61	-0.29	-0.23
Stemple Pass	61	-0.28	-0.24

Fig. 4. The location of SWE records (see Fig. 1 for full dataset) that exhibit statistically significant correlations ($p<0.05$) with the Gray Creek Pass alone (red), Boulder Pass alone (blue) and both (green) chronologies are plotted. The inset table gives an indication of the strength of these relationships: stations are listed north-south (n is given) and significant correlations are given in red.

Relationships with snowpack

Correlations between the two larch chronologies and SWE records are summarized in Fig. 4. Both chronologies correlate negatively ($p<0.05$) with records from stations covering a broad area along the continental divide and west into southern interior B.C. The n values vary considerably for the SWE records (23-82); mean correlations are -0.33 with Gray Creek (27 significant, mean of significant correlations -0.38) and -0.23 with Boulder Pass (15 significant, mean of significant correlations -0.35). The Gray Creek chronology exhibits a greater number of significant correlations over a broader geographic range. To investigate these differences further the chronologies are plotted against the mean SWE time series in Fig. 5 (based on 30 stations, see Fig. 1). The Gray Creek Pass chronology shows less decadal variability and generally exhibits three distinct periods of growth: above mean until about 1950, below mean from 1950 to the mid-1970s and above mean after this period. This lower frequency pattern appears to correlate better with snowpack over a broader area. The Boulder Pass chronology is actually in phase with mean SWE until the mid-1940s and out of phase (i.e. negatively correlated; Fig. 5) afterwards. The period of positive growth in the 1960s in the Boulder Pass chronology, which is in contrast to the Gray Creek Pass chronology, matches the higher frequency variability in the mean SWE record. It is unfortunate that one of the most striking differences between the two chronologies occurs over the calibration period. It would appear that the Gray Creek Pass chronology may best capture lower frequency variability which is not ideal for reconstruction work.

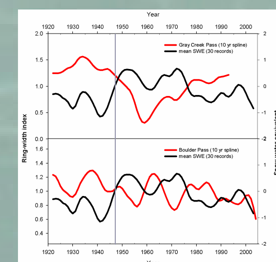


Fig. 5. Mean standardized SWE (30 records, see Fig. 1) plotted against the Gray Creek Pass and Boulder Pass subalpine larch chronologies. All series are smoothed with a 10 year filter to emphasize common variations. The vertical bar highlights the period before and after which the mean SWE and Boulder Pass relationship changes sign.

DISCUSSION AND CONCLUSIONS

The subalpine larch and Gray Creek Pass chronologies correlate well with each other exhibiting periods of common above and below normal growth. The chronologies correlate negatively with snow water equivalent records from a broad area suggesting potential for recovering pre-instrumental snowpack information for the area from these species. However, the relationship between the two chronologies deteriorates over the 20th century complicating analysis of the climate signal in these series. Future measurement of the new samples from Gray Creek, Haiseldean Lake and Whitewater as well as comparisons with the Rockies larch network (Colenutt, 2000) may elucidate causes of variability. If the new chronologies prove to have a snowpack signal, sampling of dead wood at the sites (not sampled given time constraints) may extend these records. Additional subalpine larch sites can also be sampled in the Purcells (e.g. Jumbo Pass) and Selkirks. Mountain hemlock is also found in these ranges and previous work in the Coast Ranges (Dan Smith *et al.* at the University of Victoria) has demonstrated that it has a negative response to winter snowpack.

REFERENCES

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Colenutt, M.E. 2000. Climate reconstruction in the southern Canadian Rockies using tree-ring data from Alpine Larch. Unpublished Ph.D. Thesis, University of Western Ontario, London, Ontario, Canada.