Using Reconstructed Outbreak Histories of Mountain Pine Beetle, Fire and Climate to Predict the Risk of Future Outbreaks

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Mountain Pine Beetle Working Paper 2008-16

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MPBP Project # 8.44

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2008

Library and Archives Canada Cataloguing in Publication

Lewis, Kathy J.
Using reconstructed outbreak histories of mountain pine beetle, fire and climate to predict the risk of future outbreaks / Kathy Lewis and Kate Hrinkevich.

(Mountain Pine Beetle Initiative working paper 2008-16)
"MPBI Project # 8.44".
Includes bibliographical references: p.
Includes abstract in French.
ISBN 978-1-100-10640-3
Cat. no.: Fo143-3/2008-16E

1. Mountain pine beetle--Effect of forest management on--British Columbia--Bulkley-Nechako. 2. Mountain pine beetle--Climatic factors --British Columbia--Bulkley-Nechako. 3. Mountain pine beetle--Effect of fires on--British Columbia--Bulkley-Nechako. 4. Mountain pine beetle --Monitoring--British Columbia--Bulkley-Nechako. 5. Trees--Diseases and pests--Risk assessment--British Columbia--Bulkley-Nechako. 6. Trees --Diseases and pests--Monitoring--British Columbia--Bulkley-Nechako. 7. Dendroecology--British Columbia--Bulkley-Nechako. I. Hrinkevich, Kate II. Pacific Forestry Centre III. Title. IV. Series.

SB945.M78L48 2008 634.9'7516768 C2008-980328-0

Abstract

The mountain pine beetle (*Dendroctonus ponderosae*) is a native bark beetle of forests in BC, and there is documented evidence of outbreaks dating back to 1910. The current outbreak is substantially larger than past documented outbreaks, but the temporal scale of landscape-level forest change is much longer than the limited scope of recorded history. It is possible that the scale of management-induced changes to forest structure through fire suppression and forestry practices, and the mounting evidence of a changing climate, have contributed to an outbreak that is well outside the natural range of variation. The purpose of this project is to determine the magnitude and synchrony of historical beetle outbreaks in sub-boreal forests of central BC, and to relate those with climate factors and changes in fire regimes. Our focus is on the north-central part of BC, in areas that in the past have been less conducive to large scale mountain pine beetle outbreaks and less influenced by fire suppression, to determine whether or not the current outbreak in this area is due to the enormous population build-up alone, or whether changes in climate and/or fire regime have played a role. Using dendroecological methods, we have successfully reconstructed multiple mountain pine beetle outbreaks and calibrated our detection methods based on historical survey information. Our investigation of climate/outbreak relationships is underway and suggests that the timing of outbreaks in this area can be linked to periods of favourable climate for mountain pine beetle population growth.

Keywords: mountain pine beetle; dendroecology; climate change; fire suppression

Résumé

Le dendroctone du pin ponderosa (*Dendroctonus ponderosae*) est un scolyte indigène des forêts de la C.-B., et nous avons des documents sur des infestations remontant à 1910. L'infestation actuelle est bien plus importante que toutes les autres infestations à notre connaissance, mais l'échelle temporelle des changements forestiers à l'échelle du paysage est bien plus longue que la portée limitée de nos documents. Il est possible que l'échelle des modifications issues de l'aménagement de la structure des forêts par extinction des incendies et par pratiques forestières, ainsi que les indications de plus en plus nombreuses de changements climatiques, aient contribué à sortir l'infestation du cadre naturel de variation. L'objectif de ce projet est de déterminer la magnitude et le synchronisme des infestations du ravageur au cours de l'histoire dans les forêts sub-boréales du centre de la Colombie-Britannique, et de les lier aux facteurs climatiques et aux changements climatiques dans les régimes d'incendie. Nous nous concentrons sur le centre-nord de la C.-B., sur les régions qui ont été moins favorables à de grandes infestations de dendroctone du pin ponderosa et moins influencées par l'extinction des incendies, pour déterminer si l'infestation actuelle de cette région est attribuable à l'augmentation vertigineuse de la population uniquement, ou si les changements climatiques ou de régime d'incendie y jouent également un rôle. Au moyen de méthodes dendroécologiques, nous sommes parvenus à reconstruire de multiples infestations de dendroctones et à calibrer nos méthodes de détection en fonction des renseignements contenus dans les sondages antérieurs. Notre étude des liens existants entre le climat et les infestations est en cours et laisse penser que l'arrivée d'une infestation dans cette région peut être liée à des périodes de climat favorable à la croissance de la population du ravageur.

Mots-clés : dendroctone du pin ponderosa, dendroécologie, changements climatiques, extinction des incendies

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1 Introduction

The mountain pine beetle (mpb) (*Dendroctonus ponderosae*) is a native bark beetle of forests in BC, and there is documented evidence of outbreaks dating back to 1910. Province-wide aerial surveys for bark beetles and other forest pests have been carried out since 1959. The current outbreak is substantially larger than past documented outbreaks, but the temporal scale of landscape-level forest change is much longer than the limited scope of recorded history. We don't know if there were past outbreaks of this magnitude. It is possible that the scale of management-induced changes to forest structure through fire suppression and forestry practices, and a changing climate, have contributed to an outbreak that is well outside the natural range of variation.

We face continued uncertainty around the effects of climate change on forest dynamics, and the accelerated harvest rates that will influence stand composition and age class structure of future landscapes. Reconstructing outbreak history and climate, in relation to changes in fire frequency brought about by forest management, will enable us to better predict the future effects of climate and management interactions on beetle outbreaks. The purpose of this project is to determine the magnitude and synchrony of historical beetle outbreaks in the sub-boreal forests of central BC, and to relate those with climate factors and changes in fire regimes.

Mountain pine beetle outbreaks have, in the past, been most significant in the south-central part of BC (Safranyik et al. 1974). The current outbreak is dominating much of the Sub-boreal Spruce (SBS) zone which has a cooler and wetter climate and consequently longer fire return intervals. The fire regime, and the relative role of fire (and fire suppression) on stand dynamics in the central part of BC is different than in regions such as the Interior Douglas-fir zone. We are therefore interested in examining the outbreak history in the sub-boreal ecosystems, and the factors that have contributed to past outbreaks in comparison with the current outbreak. For example, we have observed that many trees in the SBS zone have experienced a significant reduction in ring-width that was initiated well before the beetle outbreak, and that can't be explained by inter-tree competition (unpublished data).

Moore et al. (2005) investigated climate-related influences on the likelihood of mountain pine beetle outbreaks. They examined annual local-scale climate variables and larger-scale climatic phenomena (e.g., Pacific Decadal Oscillation, PDO) as they relate to climatic suitability for mpb spread. They found that the probability of a day with temperatures below the cold-mortality threshold was lower in neutral and positive phases of PDO. They speculate that the climate associated with the PDO shift may explain more recently favourable winter climate, and that the PDO shift itself is a manifestation of larger-scale climatic change.

Alfaro et al. (2004) have reconstructed some of the outbreak history for mpb in the south-central part of BC using tree ring analysis. They used growth releases evident in ring series to identify three synchronous large-scale disturbance events, presumed to be caused by mpb, in the Chilcotin Plateau since the 1860s. Other researchers have used similar approaches to document outbreak history of other forest insects such as spruce beetle (Veblen et al. 1991), spruce budworm (Swetnam and Lynch 1989), and pandora moth (Speer et al. 2001). Our intent is to focus on the central and north-central part of BC, in areas that in the past have been less conducive to large scale mpb outbreaks, and less influenced by fire suppression, to determine whether or not the current outbreak in this area is due to the enormous population build-up alone, or whether changes in climate and/or fire regime have played a role in these sub-boreal forests.

1.1 Objectives

Specific objectives of this project are to:

1. Reconstruct mountain pine beetle outbreak history in the sub-boreal forests of the north-central interior using several dendroecological approaches.
2. Reconstruct fire history and past climate in the same areas sampled for mountain pine beetle outbreaks.
3. Examine the spatio-temporal synchrony of past outbreaks.
4. Determine if outbreak history is related to fire frequency.
5. Determine if outbreak history is related to changes in local climate variables that can be identified as signals in tree rings.
6. Determine if outbreak history is related to indices of interannual and interdecadal climate variation over large scales, such as the El Niño – Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), and Northern Oscillation Index (NOI).
7. Predict the risk of future mountain pine beetle outbreaks given current management practices and climate projections.

2 Material and Methods

Study Area

The study area is located in the northwest corner of the SBS biogeoclimatic zone (excluding the Skeena and Nass River valleys extending further north) and is bounded by Babine Lake to the west and south, Takla Lake to the north, and Stuart Lake to the east. This region, northwest of Fort St. James, represents the most active area for documented historic mpb infestations in north-central BC (Safranyik et al. 1974; Wood and Unger 1996). It also falls just south of the historical -40°C isotherm which represents a biological limit for the northern boundary of the beetle’s range and is therefore a climatically-sensitive zone for outbreak dynamics and regime changes over the past century (Carroll et al. 2004). Historical documented outbreaks throughout the study area have occurred primarily as numerous small and spatially separate infestations covering in total between 100-6000 ha, with some stands being classified as chronically infested (Wood and Unger 1996).

In general, these SBS forests occur at low to mid-elevations (500-1300 m) and are characterized by cold, snowy winters and relatively warm, moist, and short summers, with moderate annual precipitation (415-1650 mm). Upland coniferous forests dominate the landscape, with hybrid white spruce (*Picea engelmannii* x *glauca*) and subalpine fir as the primary climax tree species, and lodgepole pine and trembling aspen as the most common seral species. Other tree species found in the SBS zone include paper birch, Douglas-fir, and black spruce. The mixed composition of tree species in these forests provides an important indicator for distinguishing between species-specific disturbance agents such as mountain pine beetle, and less selective events such as fire. Patches of Englemann Spruce Subalpine Fir forest types occur at higher elevations throughout the study area; however, sampling will be concentrated in SBS stands where lodgepole pine plays a more important role.

Outbreak reconstruction

The mountain pine beetle outbreak reconstruction used a combination of tree-ring dating techniques designed to identify outbreak periods in the site chronologies and also to distinguish between mpb events and other disturbance agents. The first involved the development of non-host and survivor-host release criteria representative of individual tree responses to beetle-related canopy tree mortality. The second method is based on development of standardized chronologies that emphasize coarse to intermediate-scale disturbance events, enabling us to determine stand initiation dates and growth patterns during periods of full or partial canopy removal. The third method used age class distributions in combination with fire-scar dating, charcoal evidence, and the site mean chronologies to differentiate between fire and beetle-related cohort establishment. Both disturbance agents can cause stand-replacing events that result in relatively rapid stand initiation. By dating fire scars in trees older than the main cohort and looking for evidence of burned wood, it should be possible to distinguish between initiation events caused by mpb and those caused by fire. By working in primarily mixed-species stands, specific disturbance agents should be evident based on species compositional changes over time and temporal mortality patterns.

Canopy trees (>10cm diameter at breast height (dbh) were sampled in 20 × 20 m rectangular plots, within which all living trees were cored at 30 cm from the ground and inventoried for species, dbh, and canopy position. Dead standing trees >10 cm diameter were also inventoried and cored to determine date of death. Any evidence of specific mortality agents were noted. All downed trees >10 cm diameter and originating from within the plot were inventoried according to species, dbh, and a decay class rating on a scale of 1-4 used to estimate time since death and previous canopy structure of the stand. Discs were cut from all downed trees with wood intact enough to determine mortality dates using dendroecological methods. Where possible, cause of death was noted to distinguish between mpb-related canopy disturbance and other mortality agents. Four .01 hectare subplots, centered at each corner of the rectangular plot, were used to sample all woody species <10 cm dbh. Inventories included diameter and species information for all living subcanopy trees 4-10 cm diameter, and species and height class data for all stems <4 cm dbh.

All cores and discs were mounted and sanded using standard dendrochronological techniques (Stokes and Smiley 1968). Annual rings were measured using a Velmex measuring system and the program COFECHA used to assist in crossdating samples. Within each plot, mean standardized chronologies were developed for each species using a horizontal line standardization in the program ARSTAN (e.g., Veblen et al. 1991). Individual trees were also analyzed for growth releases indicative of canopy disturbances that may not show up in the combined chronologies. Historical outbreak records, pine mortality dates, and results of earlier studies describing survivor responses (e.g., Veblen et al. 1991; Alfaro et al. 2004) were used to calibrate growth release detection criteria. Plot age (at coring height), diameter, and vertical canopy structures aided in the development of disturbance histories, as did fire dates derived from fire-scarred discs.

Climate reconstruction and climate/mpb interactions

Two increment cores were extracted from 20 trees in a climate-sensitive site within the study area. Cores were processed and crossdated using the same techniques described above. Standardization procedures were chosen to preserve high frequency variation in the ring width series and to remove age-related growth trends using the program ARSTAN. Standardized chronologies were calibrated and verified against historic climate station data from the Fort St James weather station, and reconstructions extended back in time beyond the documented period for all possible relevant climate parameters defined by Carroll et al. (2004). Principle components analysis and multiple regression techniques were used to identify and model the tree-ring derived climate variables of interest for the reconstruction.

Reconstructed climatic parameters were then analyzed relative to the timing of mpb events to evaluate the relationships between the two using a combination of techniques, including logistic regression and superposed epoch analysis. Direct annual relationships as well as autocorrelations for climatic parameters preceding mpb events were considered.

3 Results and Discussion

Results to date are based on methodologies developed in the first phase of a two phase approach for accomplishing the proposed reconstructions. We are currently in the second year of a three year project for which we received two years of funding from the Mountain Pine Beetle Initiative. During the first phase of the project we redefined our study area and streamlined the sampling strategy to improve the outbreak reconstruction. As part of phase two, twelve outbreak sites and one climate site were sampled during the summer of 2007. A total of 565 increment cores and 75 partial cross-sections were collected. All samples were mounted and sanded, of which half have been measured and cross-dated and analysis is currently underway. Preliminary results include confirmation of one outbreak consistent with the historical record, and at least two others that either predate surveys or were not reported in the surveys. The climate reconstruction is still in progress; however, we have are confident in our ability to identify climatic drivers and extend the climate record to events that pre-date our weather station data.

There were four key outcomes identified within the approved work plan to be delivered during the 2007/2008 fiscal year:

1. The detailed work plan for Phase II will be part of the PhD proposal defence and will involve all research group members. The outcome of the defence will be used to develop the final 2007/2008 work plan.
2. Documented outbreak locations will be used to calibrate the detection methods and these methods will be applied to all sites.
3. Fire scar sampling will be used to rule out fire as a cause of regionally synchronous disturbance.
4. Historic climate records and climate reconstructions for the study area will be used to test for relationships between climate and mountain pine beetle.

In fulfillment of these key outcomes, the PhD proposal defence was completed and the work plan approved by all research group members. Documented outbreak locations were sampled, and we have successfully identified these outbreaks in the tree-ring record. Detection methods have been calibrated for similar sites that experienced unreported or pre-survey outbreaks. A small number of fire-scarred discs (n=5) were collected in 2007; however, the sample size is not large enough yet to evaluate fire/mountain pine beetle interactions. Some evidence for regionally synchronous stand-replacing fires in the late 1700s have been identified in the mean site chronologies of at least four of our outbreak sites; however, further data analysis is necessary to confirm this. We anticipate that additional sampling of fire scarred discs will allow us to identify a number of smaller, low-intensity fire events and to relate their timing with that of our outbreak reconstructions. Lastly, we have obtained historical climate data for the study area and have begun looking for possible relationships between climate and known outbreaks. Preliminary work suggests that there is a correlation between outbreak timing and periods of favourable climate for mountain pine beetle development; however, we are unable to begin statistically modelling these relationships until more outbreaks have been identified.

4 Conclusions

Preliminary conclusions are that reconstruction of mountain pine beetle outbreaks in the northern range of the beetle are possible, and based on reconstructions to date, appear to have been on temporally and spatially small scales relative to the current outbreak. Limitation in spread of the beetle during past outbreaks are most likely due to greater tree species diversity that results from longer fire return intervals in this area, and successional processes that result in a greater incidence of shade tolerant tree species that are non-hosts.

5 Acknowledgements

This project was funded by the Government of Canada through the Mountain Pine Beetle Program, a three-year, $100 million program administered by Natural Resources Canada, Canadian Forest Service. Publication does not necessarily signify that the contents of this report reflect the views or policies of Natural Resources Canada – Canadian Forest Service.

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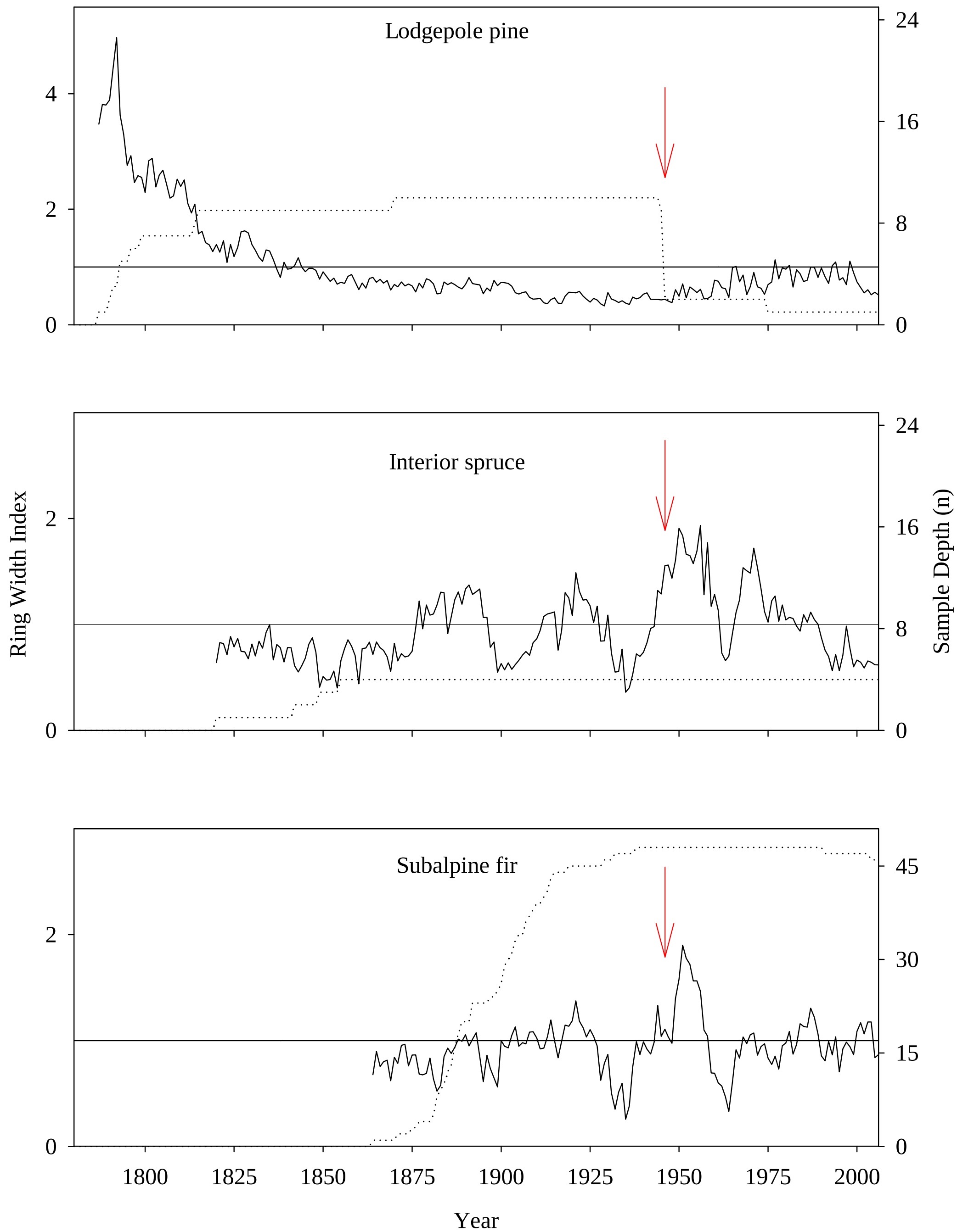
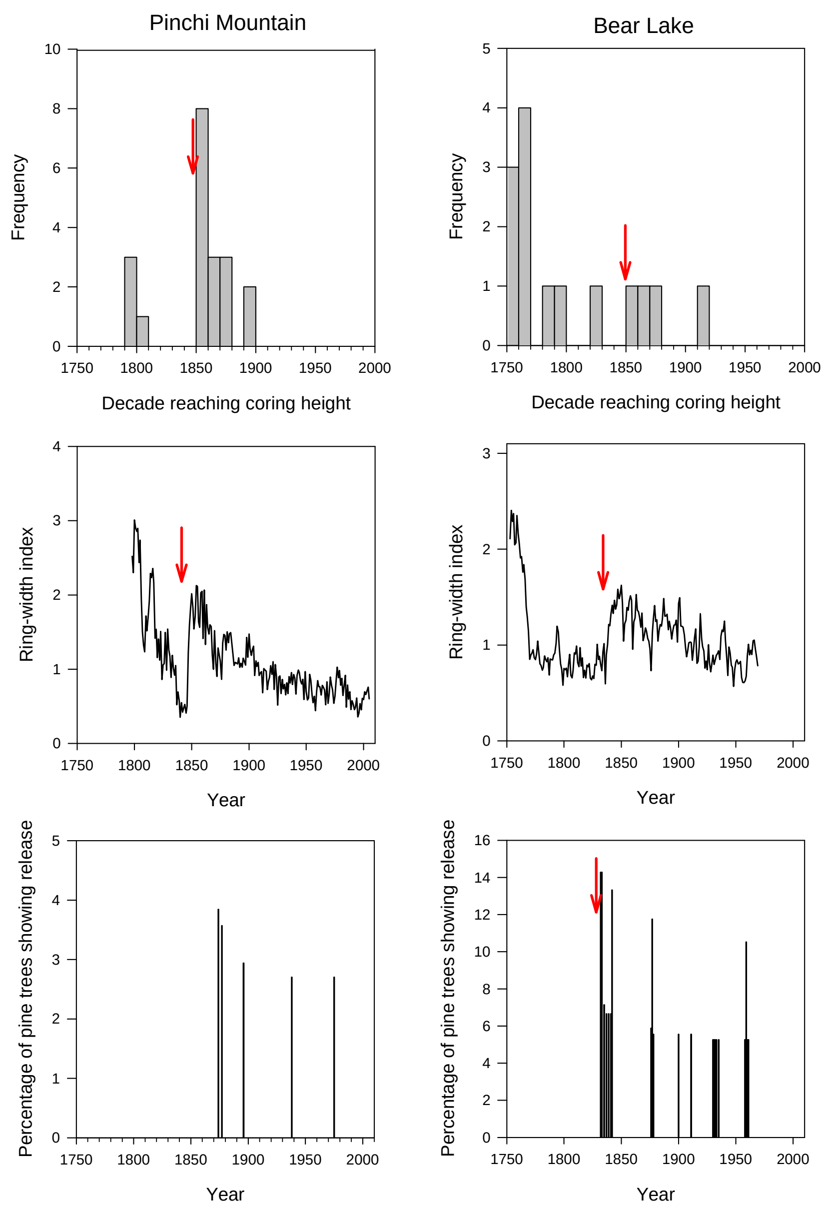
Appendix 1. Mean ring width chronologies from a mixed composition stand located south of Takla Lake. Historical records indicate a mountain pine beetle outbreak occurred in this area in 1946. Pine mortality dates (1945-1946) confirm the historical information found in the survey records, while growth releases in non-host spruce and fir provide calibration data for detecting non-host response to earlier infestations in mixed stands.



Appendix 2. Disturbance histories for the Pinchi Mountain and Bear Lake study sites. Top plots identify establishment of unique cohorts, middle plots identify average stand-level growth conditions, and bottom plots identify the percentage of trees releasing from suppression per year. Arrows indicate a synchronous canopy disturbance that predates mountain pine beetle survey records. Both stands are pure lodgepole pine, suggesting that cohort establishment and growth releases are the direct result of regional pine mortality around 1850. These effects will be compared with stand responses to known outbreaks identified in other pure lodgepole pine stands to support our identification of this pre-survey record outbreak.



Appendix 3. Historical climate data from the Fort St. James (FSJ) weather station (1895-2004). Shown here are winter and summer mean annual temperatures, with reconstructed outbreak (Appendix 1) shown. After additional outbreaks are identified, climate characteristics for these particular years will be isolated and analyzed for characteristics relevant to outbreak development. We hypothesize that the sites in our study area are particularly sensitive to climate variation, resulting in a significant correlation between mountain pine beetle outbreaks and climate suitability. Outbreaks that predate the climate record (Appendix 2) will be analyzed against reconstructed climate chronologies evident in the tree-ring record.