FII REFERENCE #R 2003-26

Impacts of Mountain Pine Beetle Attack on Stand and Ecosystem Dynamics

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ABSTRACT

Mountain pine beetle (MPB) and fire are the two major natural disturbance agents for lodgepole pine in the IDF, SBS, SBPS, ESSF, and MS zones of BC. MPB-induced tree mortality strongly influences forest dynamics, both as a natural thinning agent, and by changing the fuel loading in stands, thus affecting fire behaviour. To accurately project impacts of MPB on lodgepole pine ecosystems, models of forest stand dynamics, MPB hazard, fuels succession, and fire behavior potential need to be linked together. Empirical data are needed on levels of mortality, growth of residual stands, fuel loading and regeneration to effectively calibrate and test the models in a variety of stands affected by MPB.

This report covers the second year of the study continuing the work of Dr. Terry Shore (CFS-PFC) who investigated the effects of the 1980ís MPB epidemic on lodgepole pine forests. In 1987/88, study sites were established in 30, 6, and 5 stands respectively in the Cariboo, Kamloops, and Nelson Forest Regions. Due to subsequent logging and wildfire, we were only able to resample 15 Cariboo stands, 4 in Kamloops and 1 in the Nelson Forest Regions in 2001. In the current reporting year of 2002, new study sites (10 and 5 respectively) have been established in stands in the current MPB outbreak in Tweedsmuir and Manning Provincial Parks.

Preliminary results have been used in determining the annual allowable cut currently being re-assessed for the timber supply area in the Williams Lake area. Initial results have been used to prioritize and schedule the remaining salvage of stands affected by the 1980ís MPB outbreak in the Cariboo Forest Region, and salvage of the current MPB outbreak. Lignum Ltd. and Riverside forest company staff have used our preliminary results to assist in understanding the role of fire and MPB disturbances and their interaction, particulary how past disturbances have created current stand structures. These results have also assisted determining appropriate forest harvest and silvicultural systems that will approximate natural stand level processes and structure, while minimizing mountain pine beetle and fire losses.

Upcoming extension activities for the current fiscal year of 2003-2204 will expand the range of applicability of our initial results. More complex analysis of the original data and stand changes since the end of the 80ís epidemic will reveal more information that will be invaluable to industry foresters, parks managers, Ministry of Forests planners and managers, and contribute to a growing pool of knowledge about the effects of MPB epidemics on future forest development.

Keywords:

mountain pine beetle, fire regime, stand dynamics, dendrochronology, succession, fuel loading, fire behavior, coarse woody debris, regeneration, fire scars, beetle scars, disturbance ecology, growth release

INTRODUCTION

Mountain pine beetle (*Dendroctonus ponderosae* Hopk.) is the largest natural disturbance agent affecting lodgepole pine (*Pinus contorta* var *latifolia* Dougl.) forests in BC. Lodgepole dominated stands comprise some 14 million hectares of forest land in British Columbia. Analysis of the cumulative outbreak area from Canadian Forest Service Forest Insect and Disease Survey annual aerial overview survey records show that approximately 4.7 million hectares of pine-leading stands have been affected by mountain pine beetle since 1959 (Canadian Forest Service, unpublished data). Although a variety of silvicultural tools and management strategies can be used to minimize timber losses to MPB (Safranyik *et al*, 1974; Maclauchlan and Brooks, 1994; McMullen *et al*., 1986; Whitehead *et al.*, 2001), effective control programs require early detection, rapid implementation, and continuous commitment. The long-term effects of these control strategies on the ecosystem are unknown (Hughes and Drever, 2001), and little is known about the long term post-epidemic development and growth of stands that have had no control measures used on them. A sound understanding of the impact of MPB outbreaks on the growth and yield of surviving trees in residual stands, regeneration, woody debris dynamics and fire potential is needed for managers to make better decisions regarding stand management in the face of MPB attacks.

Multiple-use, sustainable management of forest resources requires a sound understanding of stand dynamics resulting from MPB outbreaks. This knowledge is crucial to managing first and second-growth forests in a manner that approximates natural disturbance functions and patterns, while reducing future risks from MPB attacks. The literature cited in the introduction is a sample of research on issues regarding the interactions of fire and lodgepole pine stands and landscapes, and MPB effects on lodgepole pine stands. More complete literature reviews of the effects of MPB on ecosystems are given in Peterman (1978), Cole and Amman (1980), Mclauchlan and Brooks (1994), Hughes and Drever (2001), and in Appendix 4 of our year 1, 2001-2002 FRBC 02003-06 Annual Report. Given the depth of our knowledge of the ecology of both MPB and lodgepole pine, very little is known about how MPB and fire interact, and how MPB, lodgepole pine stand dynamics, and fire interact on the landscape to regulate the ecosystem as a whole.

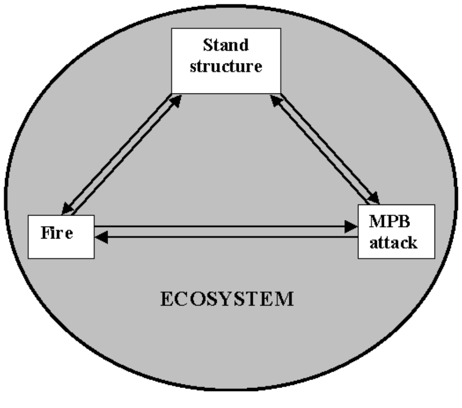


Figure 1: Conceptual model of feedbacks between MPB, fire and stand structure within the ecosystem

Lodgepole pine is an important timber resource in British Columbia, accounting for roughly 25% of the provincial timber supply (Canadian Forest Service, 2001). Research on this tree species has been extensive, and the importance of fire in maintaining lodgepole pine on the landscape is well documented (Agee, 1993). Due to the importance of lodgepole pine, both to the economy, and ecology of BC, substantial research efforts have focused on MPB.

Lodgepole pine is a seral species in many ecosystems, but can be a self-perpetuating climax species where climate, disturbance, and edaphic factors limit the regeneration of other species (Agee, 1993). Although lodgepole pine produces both serotinous and non-serotinous cones, permitting successful regeneration in either the presence or absence of fire, it is considered to be a fire dependent species (Lotan *et al.*, 1985). The landscape level age-class structure of lodgepole pine can be described as a mosaic of even-aged and uneven-aged patches intermingling in space and time (Agee, 1993). Whether a given patch or stand is even-aged or uneven-aged depends upon the disturbance history of the site: in the absence of fire, consecutive MPB attacks in the stand contribute to the conversion of an even-aged stand to an uneven-aged stand (Roe and Amman, 1970). Non-stand-replacement fires also lead to the creation of uneven-aged stands (Agee, 1993). The type of fire-regime that operates within a given stand or landscape has significant effects on stand structure. High-intensity fires stand-replacement fires create even-aged stands, whereas low-intensity surface-regime fires contribute to the development of uneven-aged stands.

It is evident that the mortality imposed on lodgepole pine forest stands by MPB attacks should influence fire behaviour: MPB kills trees, changing both the quantity and spatial distribution of fuels in the forest. What is lacking is a link between the mortality rate of trees in lodgepole pine forests under attack by MPB and the subsequent fuel loading of the stand. Mitchell and Preisler (1998) found that in unthinned lodgepole pine stands in southern Oregon, MPB-killed trees began to fall to the forest floor after 5 years, with 50% of trees falling within 9 years, and 90% fallen by 14 years post-attack. Johnson and Greene (1991) found that it is possible to make reasonable post-fire disturbance estimates of tree-fall rates by examining trees already on the ground using equations of decomposition rates. Given the mass density of downed trees, rough estimates of the actual time of fall could be determined. They did not examine mortality due to MPB attack.

Turner *et al.* (1999) found that high severity MPB attacks (>50% of trees killed) increased crown fire probability, but intermediate or light levels of MPB severity reduced crown fire probability during the wildfires of 1988 in Yellowstone National Park. Lodgepole pine regeneration was more successful in severe-surface burned stands compared to stands experiencing crown fires. Stuart *et al.* (1989) noted that the structure of an Oregon lodgepole pine forest was uneven-aged, with distinct episodic pulses of regeneration strongly correlated to MPB outbreaks and fire. The magnitude of the regeneration pulse was a function of disturbance intensity. Delong and Kessler (2000) investigated the ecological characteristics of mature forest remnants left by wildfire in sub-boreal landscapes near Prince George, BC, and found some remnants had an uneven-aged, episodic pattern of lodgepole pine regeneration.

Stuart *et al.* (1989) also found that MPB outbreaks were preceded by a decrease in the mean annual increment of the stand. Heath and Alfaro (1990) examined a mixed Douglas-fir/lodgepole pine stand near Williamís lake, BC, where 76% of the pine was killed by MPB in the early 1970ís. In response to this natural thinning treatment (Peterman, 1978), the radial growth rate of residual fir was enhanced for 14 years after MPB attack, suggesting the possibility that stand volume lost by pine might be compensated for by increased fir growth by the time harvest rotation was reached. Release of remnant Douglas-fir and spruce post-epidemic was also observed in Wyoming and Idaho by Cole and Amman (1980). It is unknown whether there is release of surviving lodgepole pine in stands attacked by MPB.

Lundquist and Negron (2000) developed a conceptual model of stand development in ponderosa pine that linked stand structure with underlying tree-killing disturbances. Disturbance agents could be classified into two basic ecological functions. Firstly, new stands developed as a result of fire, wind, and epidemic populations of MPB killing trees over large areas. Secondly small-scale canopy gaps influenced stand development and structure due to a wide variety of factors killing small numbers of trees. Due to the complexity of interactions in both space and time between various disturbances, the authors indicated that direct effects of specific agents may be difficult to estimate.

Early growth and yield (GY) models used in forestry were based upon volume-over-age curves and knowledge of speciesí growth rates on different site types. These models lacked an assessment of the risk of losses due to disturbance. Recent models incorporate a broader array of disturbance agents and thinning regimes. Although a hazard rating model for MPB in lodgepole pine forests exists (Shore and Safranyik, 1992), an understanding of how fuels are altered by MPB is necessary to use fire behaviour prediction models in conjunction with GY models. We need to know how residual tree growth rates are affected by MPB attack, as the beetle effectively ìhigh-gradesî stands it infests. These linkages are critical to understand landscape level MPB impacts. This project is intended to extend the geographic and ecological range of BC adapted GY models like the Forest Vegetation Simulator (FVS) (Teck *et al*. 1996). The project will add a new evaluation of regeneration, coarse woody debris and fire potential in these forests impacted by MPB using a metric version (Taylor *et al*., 1998) of the Fuel Dynamics and Fire Effects Model extension of FVS (Beukema *et al*. 1998). Improving stand level GY models like FVS will allow managers to link stand-level silvicultural decisions to the whole forest in timber supply modeling in addition to issues regarding coarse woody debris retention and management. Knowledge of post-MPB attack stand dynamics will help forest managers make decisions to meet their long-term strategic plans. This knowledge will help them determine if release of other tree species maintains stand productivity through to the scheduled harvest, whether salvage of the pine component is necessary, and to forecast the structure and volume of the final harvest stand.

This project was established to assess the impact of MPB across a range of biogeoclimatic zones, varying stand conditions, and to investigate modeling techniques for projecting post-epidemic stand and ecosystem development, and in particular:

1. Effects of MPB on stand structure/composition and regeneration
2. Effects of MPB on growth of residual stems
3. Effects of MPB on coarse woody debris dynamics (standing trees and fall-down rates)
4. Effects of MPB on fuel loading, structure and fire hazard
5. Reevaluation of the Heath and Alfaro (1990) study of Douglas-fir release at Bull Mountain.
6. Establishment of new plots to extend ecological range of knowledge
7. Investigate modeling techniques to project stand, ecosystem, and CWD dynamics, and fire potential.

This project builds upon work done by Terry Shore and Les Safranyik in 1987/88,and was designed to be completed over a period of three years, as outlined in the Gant chart below. We have now completed Phase 1 (year 2001 activities), Phase 2 (year 2002 activities) to date. The work for Phase 3 (year 2003) is underway.

Schedule of Project Research and Development Activities 2001-2003.

Activity	Year / Quarter											
	2	0	0	1	2	0	0	2	2	0	0	3
		2	3	4	1	2	3	4	1	2	3	4
1.1 Plot remeasurement		▨	▨									
1.2 Lab analysis & data entry				▨	▨							
2.1 Establish current outbreak plots						▨	▨					
2.2 Data entry								▨				
3.1-3 Data analysis and model calibration and publications							▨	▨	▨	▨		

This reporting period

METHODS

This study was initiated in 1987/88 by Terry Shore and Les Safranyik**.** Study plots were established in 30 stands in the Cariboo Forest Region, 5 stands in the Kamloops Forest Region and 6 stands in the Nelson Forest Region. Field data was collected and entered into a database, and some graphs were constructed to illustrate volume losses. In early 2001 the study was revived. In the early summer of 2001, 20 of the original 41 stands were relocated that had not been heavily disturbed by logging or wildfire. The field methods of the original study and sampling activities in 2001 are described in full detail in the FRBC Reference #PAR 02003-06 *Impacts of Mountain Pine Beetle Attack on Stand and Ecosystem Dynamics* report summarizing Phase 1 activities of this project. Below is a full description of site selection and methodology used in Phase 2 activities.

2002 Stand Location

Due to logging and natural fire losses of more than half of the study stands initiated by Shore *et al.* in the mid 1980ís, it was determined that new study stands within the current outbreak needed to be in protected areas to ensure they could be resampled into the future. Maps were constructed from Ministry of Forests current MPB infestation GIS coverages, roads and provincial parks and other protected areas throughout the Prince George and Prince Rupert Forest Regions. In July 2002, Steve Taylor and Chris Stockdale spent 5 days visiting potential sites in these regions, and discovered very few heavily infested areas were road-accessible in protected areas. Tweedsmuir and Manning Provincial Parks were chosen to represent the current outbreak. Five (5) study stands were established in Manning Provincial Park, and ten (10) study stands were in protected areas either in or adjacent to Tweedsmuir Park on Tetachuk Lake. Figure 1 shows the locations of all study stands: resampled stands in 2001 (15 stands in the Cariboo Forest Region, 4 stands in the Kamloops Forest Region and 1 in the Nelson Forest Region), new stands established in Tweedsmuir Park, and Manning Park, as well as stands relocated in Waterton National Park, and Kootenay National Park (these stands relate to FII R03-

0111, but data gathered from those stands will also be used within this study as well).

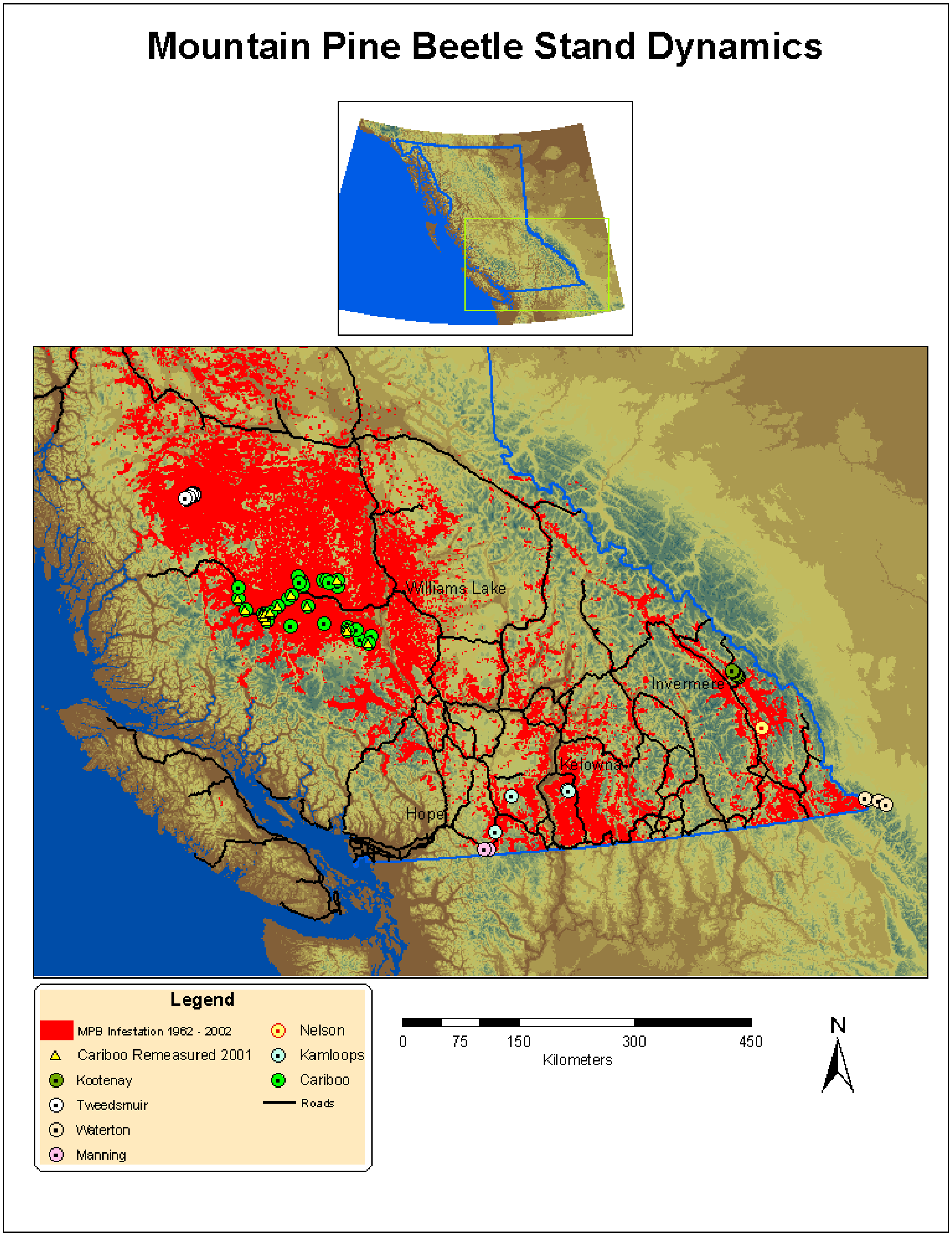


Figure 1: MPB Stand Dynamics study stand locations

2002 Field methods

Manning Provincial Park

Five sites (stands) were located in areas having recently experienced severe levels of MPB activity. A tie point was established by taking a GPS measurement, and recording the area on a digital video camera. Each stand consists of ten (10) variable radius (prism) plots in two parallel lines of 5 plots each, spaced at approximately 100m intervals. Plot centers were marked as inconspicuously as possible with a piece of angle aluminum pounded into the ground, and GPS coordinates were recorded. Stand locations are shown in Figure 2**,** and GPS coordinates for each stand are shown in Appendix 1, Table 1**.**

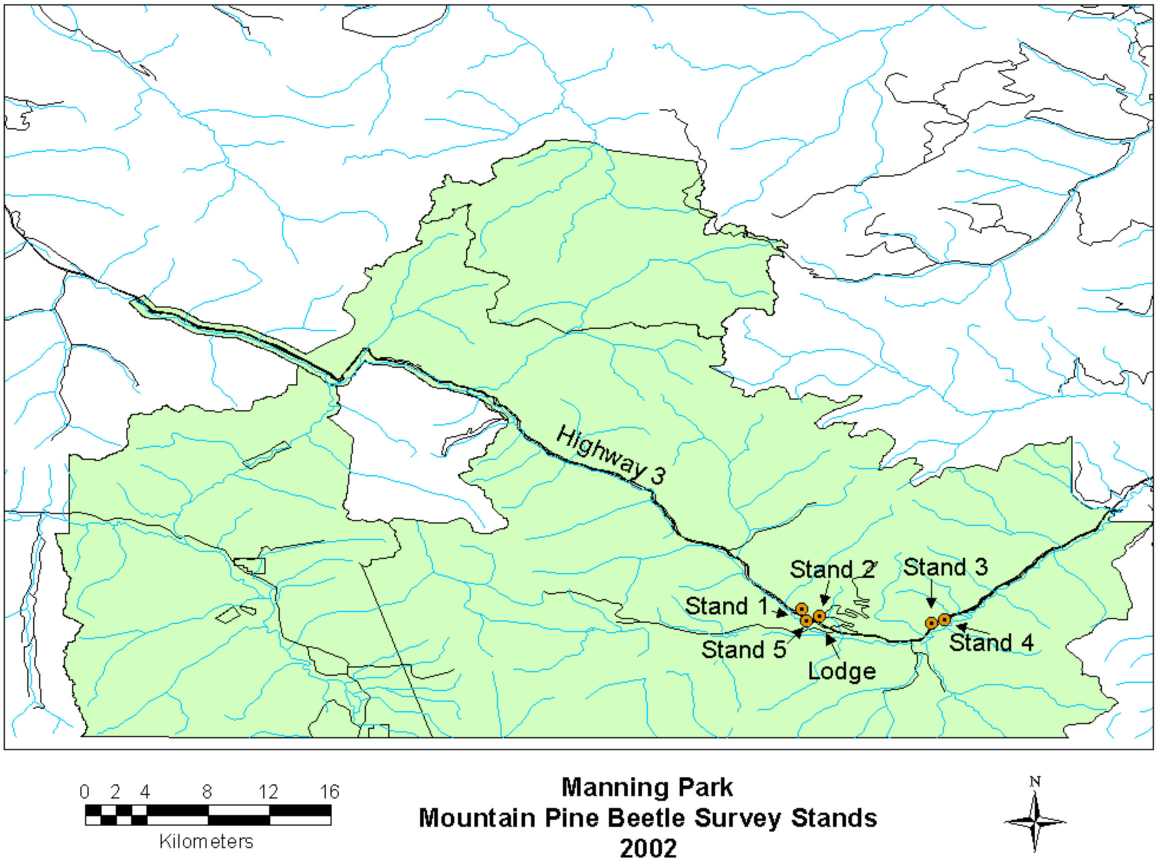


Figure 2: Manning Provincial Park survey stands, 2002

Tweedsmuir Provincial Park

Low water levels in the Redfern rapids at the time of sampling prevented access from Tetachuk Lake to Eutsuk Lake inside the park. Ten (10) stands were selected along Tetachuk Lake. Nine of the ten stands had to be placed outside the park boundary, but were in other protected areas. Four of the ten stands on Tetachuk Lake were on the south shore of the lake, in the Entiako Protected Area, and the other six stands were on the north shore of the lake (5 in the

Very High Caribou Migration Corridor to the east of Tweedsmuir Park, and 1 just inside the park). The 9 stands outside the park boundary were all accessed by boat from Tetachuk Lake, and therefore the tie-points for these stands are on the shore of the lake. The stand located inside the park boundary was accessed from a hiking trail from the Nature Trails Wilderness Lodge**.** GPS points were recorded for each tie point, and the stands have also been located on aerial photographs to enable easy relocation. Due to logistical constraints, eight (8) prism plots per stand were established instead of 10. The location of these stands is shown in Figure 3. In both Manning Park and Tweedsmuir Park, the same within-stand methodology was used and is described below.

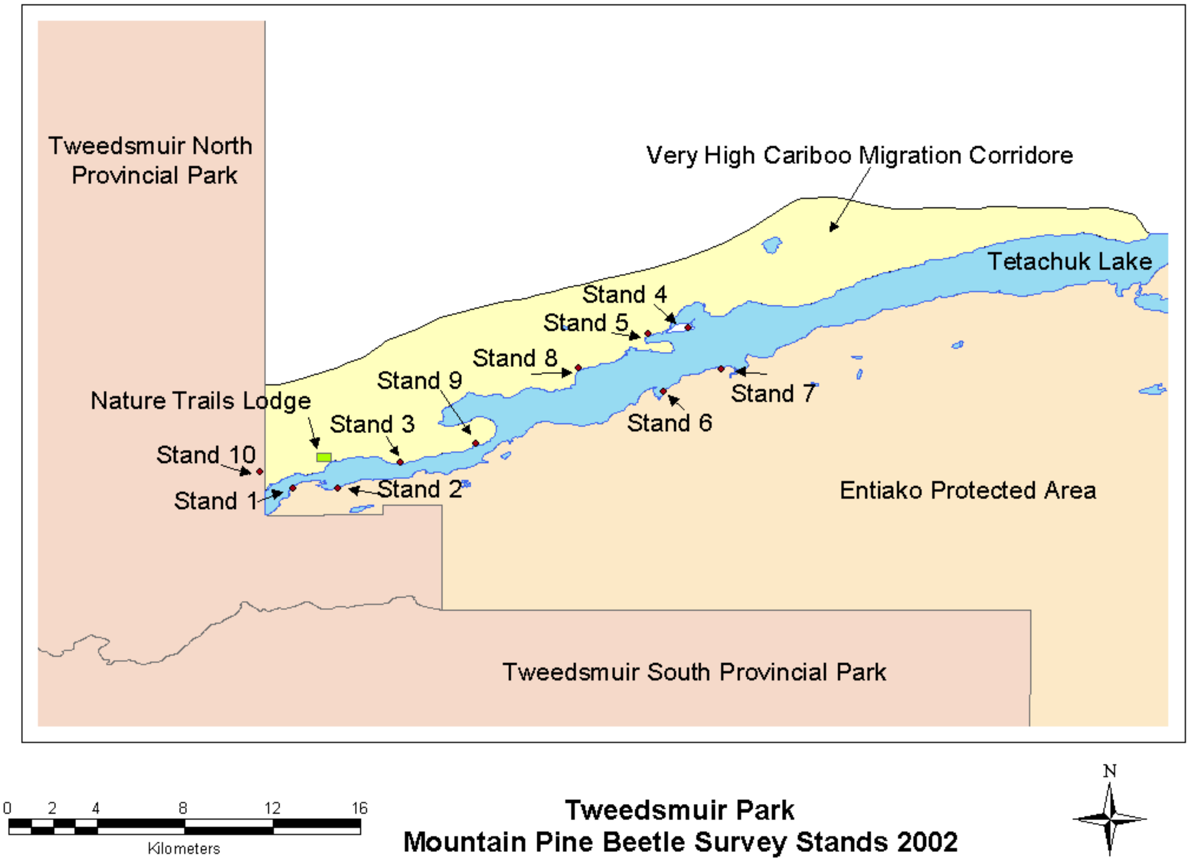


Figure 3: Tweedsmuir Provincial Park Stand Dynamics stands.

Overstory Measurements

Prism plots were established at each plot, with the BAF selected to capture a minimum 7-8 trees per plot. ìInî trees were tagged with aluminum tags 50cm above the ground at Manning Park, and at eye level with fluorescent paint flashes at Tweedsmuir. The diameter, species, presence of firescars, and presence of any pathogens of each ìinî tree were recorded. Standing dead ìinî trees were examined to determine the cause of death. If beetle galleries were present, they were examined to determine whether it was MPB or *Ips* species that had killed the tree. The height of all snags was estimated and each snag was assigned to a decay class using criteria contained in Wildlife Tree Committee of BC (2001).

Two trees of each species present in each plot were measured for height and height to live crown. These same trees measured for height were aged by taking two increment cores on opposite sides of the tree at breast height. Cores were preserved for subsequent growth-ring analysis.

Understory Measurements

Seedlings were tallied by species and height class (0-0.10m, 0.10-0.50m, 0.50-1.0m, 1.0-1.5m) in a 3.1m radius plot nested in each prism plot. Saplings greater than 1.5m in height and less than 7.0cm diameter were counted in a 5.64 m or 7.98m radius circle. The radius of the plot was chosen to capture a minimum of 6 saplings in the plot. Saplings were tallied by species in two DBH classes: 0-3.9cm or 3.9-7.5 cm. In the event that a sapling is measured as an ìinî tree in the overstory count, it will be excluded from the regeneration/understory count.

Woody Debris Measurements

In each plot, coarse woody debris (>7cm diameter) and fine fuels (<7cm diameter) were examined on a 30 m transect along a random compass bearing from plot center. For coarse woody debris, the diameter and species of each piece intersected by the transect tape was recorded. Each piece was assigned to one of five classes of decomposition. Fine fuels were tallied along the first 25m of the transect line using the method by Trowbridge *et al.* (1986). The end of the transect line was marked by a steel pin. Photographs were taken at each plot from the plot-centre stake along the woody debris sampling line.

Data Analysis

Data Storage

Data collected in the 2002 field season was entered into the same database containing the 2001 field season data and original 1987 data obtained by Shore *et al.*

Data Summaries

Data collected in 2001 has been under analysis during the past year, and a journal article is in preparation. Data summaries included in the year end report for Phase 1 (2001 activities) have been updated and numerous errors have been fixed. Summary tables and graphs have been created to show the number of living and dead stems per hectare by species and diameter class (classes in 5cm increments). The same was done to show both living and dead volume (m^3/ha) by species and diameter class, and living and dead basal area per hectare (m^2/ha) by species and diameter class. Figures and tables for the 2001 resampling have only been constructed thus far for the Cariboo Forest Region. To enable direct comparison between the initial study and the 2001 sampling, tables and figures were constructed for the initial study using only the stands and plots relocated in 2001.

ACCOMPLISHMENTS 2002-2003

2002-2003 APPROVED QUARTERLY WORKPLAN

	Research and Extension Activities to be Achieved	*Accomplished?*
Quarter 1 (Apr 1 ñ Jun 30)	1. Project team members meeting.	Yes
	2. Obtain surveys of 2001 MPB outbreak to determine sample stand locations.	Yes
	3. Consult with Regional MOF Forest Health and Mgt., and Provincial Park staff on sample locations in current outbreak areas in southern and northern BC.	Yes
	4. Complete of 2001 field data entry, preliminary analysis, and summary tables and graphs.	Yes
	5. Analyze and interpret chronologies of 2001 tree cores to determine growth release of host and non-host trees in Chilcotin.	Yes
	6. Dendrochronology analysis of pole-sized tree discs.	Yes
Quarter 2 (July 1 - Sept 30)	1. Presentation and paper (submit manuscript Nov. 1, special issue CJFR) entitled ìEffects of a MPB Outbreak on Stand Dynamics in the Central Interior of BCî at 4th International Workshop on ìDisturbance Dynamics in Boreal Forests Disturbance Processes and Their Ecological Effects in Boreal Forestsî, University of Northern British Columbia, Prince George, BC, August 9 - 14, 2002.	Partial[1]
	2. Complete of dendrochronology analysis of 2001 tree cores and pole-sized tree discs, and Bull Mt. D-f release analysis.	Yes
	3. Dendrochronology and growth release analysis of Bull Mountain tree cores. Quantify and describe the growth release of Douglas fir after lodgepole pine mortality.	Yes
	4. Establish permanent plots in 15 stands in current MPB outbreak in northern BC and 5 stands in southern BC.	Yes/altered[2]
Quarter 3 (Oct 1 ñ Dec 31)	1. PFC Information Forestry article, Dispatch (Northern Forest Products Assoc. newsletter) submission on project, and 1st Nations newsletter.	No[3]
	2. Fire and beetle scar dating of 2001 tree discs for Cariboo, Kamloops, and Nelson Regions.	Yes
	3. Data entry of 2002 field data.	Yes
	4. Field tour of 2002 sampled stands.	No[4]

Quarter 4 **(Jan 1 ñ Mar 31)**	1.	Two draft journal papers on MPB outbreak reoccurrence and Bull Mt. long-term growth. release of D-f after lodgepole pine mortality.	Yes
	2.	Preliminary data analysis and summary of 2002 sampled stands.	Yes
	3.	CFS PFC public web site section on project description and preliminary results.	Yes
	4.	Annual report preparation.	Yes

NOTE: Any deviations from approved workplan are discussed in section below titled ìChanges to the research plan and problems experiencedî

2002-2003 Project Accomplishment Details

Conference presentation - ìEffects of a MPB Outbreak on Stand Dynamics in the Central Interior of BCî at 4th International Workshop on ìDisturbance Dynamics in Boreal Forests Disturbance Processes and Their Ecological Effects in Boreal Forestsî, University of Northern B.C., Prince George, BC, August 9 ñ14, 2002. Delivered by Dr. Brad Hawkes.

Dendrochronology analyses - Completed dendrochronology analysis of 2001 tree cores. Tree cores have been analysed and results graphed. Sapling (regeneration >1.5m height, < 7.0cm dbh) discs have been sanded, aged, and scanned for tree ring release. Release has been quantified. These results are attached as Appendices 2 (release) and 3 (regeneration).

Dendrochronology and growth release analysis of Bull Mountain tree cores. This analysis required new samples to be collected due to original cores being collected while trees were too cold, thus ruining the original samples. CFS internal funding covered the cost of resampling. Growth release of Douglas-fir after lodgepole mortality has been quantified and described. Preliminary report of Douglas-fir and lodgepole pine response to mountain pine beetle is completed. This report is attached as Appendix 4.

New plot establishment - Established permanent plots in 15 stands in current MPB outbreak in northern BC and 5 stands in southern BC. Permanent plots were established in ten stands in Northern BC (the Entiako Protected Area/Tweedsmuir Provincial Park/Very High Cariboo Migration Corridor) and five stands in Southern BC (Manning Provincial Park). Data entry is complete and analysis is underway.

Website preparation ñ

- Preliminary results of this project were combined with the FII funded natural disturbance database project results on a web page on the CFS Pacific Forestry Centre web site.

  http://www.pfc.cfs.nrcan.gc.ca/entomology/mpb/historical/index_e.html.
- Additional website material covering this project specifically has been completed, and has been handed to the CFS website development team to translate into French and to be adjusted to the common design requirements for CFS websites. It will be posted in April, 2003.

Presentation - ìMountain Pine Beetle And Fire Interactionsî, Feb. 7, 2003, University of Northern BC, Natural Resources and Environmental Studies, Colloquium Series, by Dr. Brad Hawkes, Victoria, BC, 70 people attended including industry foresters, UNBC NRES and other faculties and students, McGregor Model Forest Association, Consultants, B.C. Ministries of Protection and Timber Supply, Ministry of Sustainable

Resource Management, Ministry of Lands and Parks.

Workshop attendance - Steve Taylor attended the ìAccounting for the Influence of Large Scale Natural Disturbances in Canadian Forest Ecosystems: Fire and Insectsî workshop held by CFS Carbon Accounting Team (CAT), National Forest Carbon Accounting System for Canada in Victoria, BC on March 17-20, 2003. He was attending to provide expertise on the effects, influence and magnitude of historical MPB epidemics on forest ecosystems based on the findings to date of this project.

Workshop attendance ñ Steve Taylor and Chris Stockdale attended a MPB modeling workshop hosted by Carmen Wong, funded by her FII project and it was held in PFC facilities. Results of this project were presented.

Fire and beetle scar dating - Tree-disc samples collected in Year 1 of this project in the Cariboo, Kamloops, and Nelson Regions have been analyzed and a journal article is in progress. See FII 2003-0111 Final Report for draft paper on fire and beetle scar analysis that includes the discs taken in 2001 as part of this project.

Data entry of 2002 field data. - Data entry of Manning and Entiako /Tetachuck Lake data is completed.

Annual report preparation. - This annual report.

Ongoing data analysis - Analysis has been underway, and is ongoing for data collected in both years 1 and 2 of this project.

Journal article preparation - A journal article is in progress by Brad Hawkes, Chris Stockdale, Steve Taylor and Terry Shore on the short and long-term effects of the 1980ís MPB epidemic on stand dynamics in the Cariboo Forest Region. A draft of this article will be completed early in the first quarter of the 2003-2004 fiscal year.

Changes to the research plan and problems experienced

[1]*-Conference presentation and paper submitted to CJFR for special issue* - ìEffects of a MPB Outbreak on Stand Dynamics in the Central Interior of BCî at 4th International Workshop on ìDisturbance Dynamics in Boreal Forests Disturbance Processes and Their Ecological Effects in Boreal Forestsî, University of Northern B.C., Prince George, BC, August 9 ñ 14, 2002. Delivered by Dr. Brad Hawkes. The presentation was completed as scheduled, however we were not able to meet the November 1, 2002 deadline for submission of an accompanying paper to CJFR for its special issue on this conference. The paper was unable to be completed in this time frame as significant errors and discrepancies were detected in the original data supplied by T. Shore that took more time to resolve than we had to meet the Nov 1 deadline. This paper is currently in progress and all data errors and discrepancies have been resolved.

[2]*-Plots established in new outbreak:* The original workplan proposed establishing 15 new study stands in the north and 5 in the south of the province. We met the objective for 5 stands in the south, but were only able to establish 10 stands in the north. Due to the loss of more than half of the study stands established by T. Shore in the late 1980ís, we had decided that new stands needed to be established in protected areas and parks to ensure their continued presence for long term monitoring. Steve Taylor and Chris Stockdale did a 5-day reconnaissance in the north of the province after obtaining GIS coverages showing the extent of the current epidemic. Unfortunately, there were very few options for putting study stands into protected areas, as most of the heavily MPB-infested stands in protected areas were not in easily accessed areas. Due to the remoteness and expense of getting to

suitable areas for sampling (Tetachuk Lake on the border of Tweedsmuir Provincial Park), we only had resources to establish 10 stands in the north.

[3]*-Information Publications* - A PFC Information Forestry article, Dispatch (Northern Forest Products Assoc. newsletter) submission on project, and 1st Nations newsletter were all scheduled for the 2002-2003 fiscal year but have been delayed until 2003-2004 due to the PFC information forestry editor indicating that these articles would be best served by waiting for the 3rd year of project when publications and final results can be included and highlighted.

[4]*-Field tour of 2002 plots ñ* The plan for having a field tour was created before we encountered the difficulties of locating suitable protected areas to establish new study plots in. As field sampling for the 2002-2003 fiscal year was not completed until late September, time became a significant limiting factor for conducting a field tour due to poor weather in the fall. Financial limitations were also a major factor in not being able to conduct a field tour of new study stands. The same reasons we had to reduce the number of study stands in the north hold true here. We went over-budget on field sampling costs, and there were no funds available to hold the field tour. Conducting a field tour of the Tetachuk Lake plots will be expensive due to the need to either charter flights or boats to access the plots. Additional funding is being sought to cover the costs of a field tour in the coming fiscal year.

APPLICABILITY OF RESULTS / END USERS

The objectives for our extension activities are to:

1. Transfer knowledge of the impacts of uncontrolled MPB attack on stand and ecosystem dynamics and the fire management implications of these impacts to forest science researchers, MOF forest health and ecology specialists, industrial and ministry forest, park, and fire managers, 1st Nations people, and the general public.
2. Incorporate the project results into forest and fire management plans, landscape disturbance modeling, timber supply modeling, carbon budget modeling, and revisions/additions to the results-based code.
3. Translate stand and ecosystem dynamics information into possible alternative silvicultural systems for managing lodgepole pine by approximating MPB and fire natural disturbance in these ecosystems.

The project results will be communicated through various media to ensure forest manager and public education on the effects of MPB epidemics on stand dynamics and impacts on forest resource values. These results will aid in the creation of local MPB management solutions, larger scale policy decisions, and practices such as prioritizing salvage logging activities and future MPB-epidemic damage reduction strategies for lodgepole pine forests. Results from this study will also improve capabilities and methods for monitoring the success of alternative MPB management strategies and practices to direct future research and extension activities. Working directly with Lignum and Riverside forest companies on this project will ensure that effective transfer of project results takes place with field and planning foresters.

CFS-PFC is currently in discussion with FORREX (FII extension provider) to coordinate extension and is committed to the community extension concept. The PFC marketing/extension group will work with the Project proponents and members of the natural resource community to develop the most appropriate extension vehicles.

Specific outputs expected:				
Extension Outputs/Activities	2	0	0	3
	1	2	3	4
PFC Info Forestry			■	
journal articles			■	■
PFC Info Report			■	
FORREX LINK article		■		
Publications and presentation material on PFC web site	■	■	■	■
University and course presentations	■	■	■	■

2003-2004 Milestones and Deliverables

1. PFC Info Report:. Bull Mtn. Douglas-fir release	Jan. , 2004
2. Journal article: Frequency and severity of past MPB outbreaks	March, 2004
3. Journal article: Interaction of fire and MPB in the SBPSxc/IDFdk3	March, 2004
4. Journal article: MPB outbreak effects on stand dynamics	March, 2004
5. MPB risk rating of MPB impact project plots in BC interior	Dec, 2003
6. Prognosis^{BC} IDF, SBS and SBPS testing and validation	March, 2004
7. Prediction of changes in fuel characteristics and potential fire behavior	Dec, 2003
8. Data analysis of the current MPB outbreak plot data	Jan., 2004
9. Data analysis of stand dynamics 22 yr old plots in Waterton National Park	Feb., 2004
10. Project post-outbreak stand dynamics through modeling.	October 2003[*]
11. Fire behaviour potential analysis.	October 2003**

[*] PROGNOSIS-BC and the Forest Vegetation Simulator model and Fuel Dynamics and Fire Effects Model extension (Teck et al. 1996; Beukema et al. 1998; Taylor et al 1998) will be used as the framework to project the development of the residual stand density, species composition, canopy closure and woody debris dynamics. Projections will be carried out for the sample plots beginning with the residual stand conditions in order to explore longer term (30-100 year) impacts and to demonstrate the use of the model to project MPB impacts. The model will be calibrated using the periodic increment data. Snag fall down rates and regeneration rates will be adjusted if necessary. Other models such as TASS (Mitchell and Grout 1995) may be evaluated when stand species and conditions are suitable.

[**] Changes in fuel characteristics and potential fire intensity will be forecast using a metric version of the Fuel Dynamics and Fire Effects Model extension of FVS (Beukema et al. 1998) and data on fuels and stand structure. Changes in fire behavior over time will be projected from changes in vegetation (fuel type), and from topographic and climatic data using the climatological approach of Taylor et al. (1998).

Participation of Team Members and Identified Partners in the Project

Most partners in the project will not be making their contributions until year 3 of the project plan. Abdel-azim Zumrawi, BC MoF, will test the recently developed version of BC Prognosis (FVS) for the IDF biogeoclimatic zone to predict stand structure and volume changes in year 3. Steve Taylor will test the USFS fire and MPB module of FVS to predict stand dynamics, fuel succession and fire behavior in year 3 as well. Dr. Terry Shore will be running his

MPB stand and pine hazard rating models on 1987 and 2001 stand data to determine changes in stand susceptibility due to MPB mortality. Dr. Allan Carroll will determine the proportion and timing of MPB versus *Ips spp.* beetle tree induced mortality using galleries identified on dead sampled lodgepole pine trees.

Advancement of Current Status of Research Knowledge

Policy makers considering policies to encourage emulation of natural disturbance have been provided with knowledge of some of the long-term impacts of MPB, one of the most important agents of natural disturbance in BC. Preliminary results from Year 1 (2001-2002) of this study have already been used by MoF research branch in a project compiling information about natural disturbance return intervals throughout BC. Forest management and health practitioners have some preliminary data to project the long-term impacts of MPB outbreaks in the SBPSxc and IDFdk3 biogeoclimatic subzones and limited ecological zones in southern BC. These data are proving useful for development of mitigation measures for disturbances that increase fire hazard and reduce timber yield. Preliminary results from year 1 of the work plan have already increased our understanding of how fire and MPB interact as natural disturbance agent in BC. Significant growth release of associated tree species like Douglas-fir on Bull Mountain has already effected the options for salvage of killed lodgepole pine in mixed species stands.

Other conference/journal papers that result from this project will enhance the science, technology and extension profile of BCís science, technology, and extension providers and provide possible stimuli for similar research in the USA.

Preliminary project results of fire and MPB natural disturbances is already assisting in managing the lodgepole pine forests in a sustainable manner. The benefits include improving forest management planning and salvage operations in the past and current MPB attacked stands since the project has provided the stand conditions after 15-18 years of succession.

Potential end-users/resource practitioners and how they will use the project results:

Riverside Forest Products Ltd. and Lignum Ltd. have indicated that they will use forthcoming results to determine the impact of MPB on their timber resources, incorporate the results into their natural disturbance projects commenced within their Innovative Forest Practices Agreement, and enable improved localized planning. Other forest industries currently being affected by the MPB would also benefit in these ways.

Ministry of Forests regional ecologists will use the project results to develop guidelines, under the Cariboo-Chilcotin Land Use Plan, for attribute-based seral stage classification of MPB attacked stands. New understanding of MPB long-term effects on structure and dynamics could challenge pre-conceived ideas in ecology and lead to better management strategies and guidelines. MoF forest health practitioners see this project assisting in evaluating the impact of MPB on timber supply, habitat values, and fire hazard. Cariboo fire managers see the fire potential information as a high priority since they need to adjust their protection pre-suppression and prevention plans to deal with any increased level of fire hazard on the landscape.

BC Park managers have identified themselves as ìend usersî of the information gathered from this study. The project results will be invaluable in developing MPB management strategies in BC Parks. The MoF Prognosis^{BC} development team will implement the study results in the Prognosis^{BC} growth and yield model which will then be available to forest industry managers to use in determining timber supply impacts of MPB damage and assist in making salvage decisions.

SUMMARY AND CONCLUSIONS

Impact of the Project on BCís Forest Sector

Eric Johansen and Gregor Lee, BC Ministry of Forests, Inventory Branch, Williams Lake Forest Region indicated that the stand volume loss and live versus dead tree density results were critical in determining the annual allowable cut currently being re-assessed for the timber supply area in the Williams Lake area. These data were also critical to confirm their estimates of pre-beetle live stand volumes using permanent plot sample results (establishment in 1996). The project results were also useful for prioritizing and scheduling the remaining salvage of stands affected by the 1980ís MPB outbreak in the Cariboo Forest Region, as well as, the current salvage of the new outbreak in northern BC. In the current outbreak logging companies should target low productivity stands first since high productivity stands will still have economic levels of salvage later in the salvage operations.

The preliminary stand dynamic and volume results were presented to the BC MoF Chief Forester, Larry Pederson, by Eric Johansen and Gregor Lee to illustrate that they now have the capability to provide a more detailed layout of stand degradation and change after MPB attack. Lignum Ltd. and Riverside Forest Company staff have indicated that the study results will assist them in understanding the natural role of fire and MPB disturbances and their interaction in creating the stand structures in the past and in the present landscape. The project results will also help determine appropriate forest harvest and silvicultural systems that will approximate natural stand level processes and structure, while minimizing MPB and fire losses.

Recommendations to Policy Makers and Stakeholders

Only preliminary results have yet been released from analysis conducted in year 1 of the three-year MPB stand dynamics project. Final analysis is underway and results will be available by the second quarter of the 2003-2204 fiscal year. It would be inappropriate to make final recommendations at this point, although preliminary results of stand volume and density impacts of MPB have already been proven useful. They have been used to guide timber supply analysis, estimates of pre-1980s stand conditions, salvage priorities in the 1980ís and current outbreaks, and understanding the natural role of fire and MPB disturbances to assist in guiding forest harvest and silvicultural systems. One of the limitations of using these data from plots sampled after the previous outbreak is that the results are mainly applicable to the SBPSxc and IDFdk3 biogeoclimatic subzones, in mixed surface and crown fire regimes, and in lodgepole stands with multi-age and size classes. The current MPB outbreak in BC is occurring in more northern and wetter biogeoclimatic zones that experience crown fires at long intervals and have more even-aged stands with trees of similar size. The plots established in the current outbreak area in year 2 (2002-2003) of this project will expand the range of our analysis, but will not provide us with long-term change data in the northern regions. These plots may prove invaluable as they will provide baseline data for sites that can be followed up in years to come as we have done with plots established by T. Shore in the outbreak in the 1980ís in the Cariboo, Kamloops and Nelson Forest Regions.

REFERENCES CITED

Agee JK. 1993. *Fire ecology of Pacific northwest forests.* Island Press, Washington DC. 493 pp.

BC Ministry of Forests. 2001. Province attacks mountain pine beetle- action plan released. BC Ministry of Forests News Release, Ref# 2001:099. Prince George.

Beukema SJ, Greenough JA, Robinson DCE, Kurz WA, Reinhardt ED, Crookston NL, Brown JK, Hardy CC, and AR Stage. 1998. An introduction to the fire and fuels extension to FVS. pp. 191-195 *in* Proceedings: Forest Vegetation Simulator Conference. Feb. 307, 1997, Fort Collins, CO. R Teck, M Moeur, and J Adams, *compilers*. USDA For. Serv. Gen. Tech. Rep. INT-GTR-373, Ogden, UT.

Canadian Forest Service. 2001. Meeting landscape-level objectives with mature and aging lodgepole pine. *Avaliable online at* www.pfc.cfs.nrcan.gc.ca/entomology/mpb/proofing/index_e.html

Cole WE, and GE Amman. 1980. Mountain Pine Beetle Dynamics in Lodgepole Pine Forests. Part I: Course of an Infestation. General Technical Report INT-89. USDA Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT.

Delong CS, and WB Kessler. 2000. Ecological characteristics of mature forest remnants left by wildfire. *Forest Ecology and Management*. 131(1-3):93-106.

Heath R, and R Alfaro. 1990. Growth response in a Douglas-fir/lodgepole pine stand after thinning of lodgepole pine by the mountain pine beetle. *Journal of the Entomological Society of British Columbia* 87: 16-21.

Hughes J, and R Drever. 2001. Salvaging solutions: science-based management of B.C.ís pine beetle outbreak. David Suzuki Foundation, Vancouver BC. 39 pp.

Johnson EA, and DF Greene. 1991. A method for studying dead bole dynamics in Pinus contorta var. latifolia ñ Picea engelmannii forests. *Journal of Vegetation Science* 2: 523-530.

Lotan JE, Brown JK and LF Neuenschwander. 1985. Role of fire in lodgepole pine forests. *In:* Lodgepole pine: the species and its management, Symposium Proceedings. May 8-10, 1984, Spokane WA. Baumgartner DM, Krebill RG, Arnott JT and GF Weetman, *eds.*Washington State University, Pullman, WA.

Lundquist JE, and JF Negron. 2000. Endemic forest disturbances and stand structure of ponderosa pine (Pinus ponderosa) in the upper pine creek research natural area, South Dakota, U.S.A. *Natural Areas Journal* 20(2):126-132.

Maclauchlan LE, and JE Brooks. 1994. Strategies and tactics for managing the mountain pine beetle, *Dendroctonus ponderosae.* BC Ministry of Forests, Kamloops Forest Region, Forest Health, Kamloops, B.C.

McMullen LH, Safranyik L, and DA Linton. 1986. Suppression of mountain pine beetle infestations in lodgepole pine forests. Canadian Forest Service Information Report BC-X-276. 20 pp.

Mitchell, K.J.; Grout, S.E. 1995. Userís guide for producing Managed Stand Yield Tables with WinTipsy Version 1.3 under Microsoft Windows. B.C. Ministry of Forests, Research Br., Forest Productivity and Decision Support Section (FPDS), Victoria, B.C.

Mitchell RG, and HK Preisler. 1998. Fall rate of lodgepole pine killed by the mountain pine beetle in central Oregon. *Western Journal of Applied Forestry* 13:23-26.

Peterman RM. 1978. The ecological role of mountain pine beetle in lodgepole pine forests. *In*: Theory and Practice of Mountain Pine Beetle Mangement I Lodgepole Pine Forests. Proceedings of a Symposium, April 25-27, 1978, Pullman, WA. U.S. Forest, Wildlife and Range Experiment Station, University of Idaho, Moscow, ID.

Roe AL, and GD Amman. 1970. The mountain pine beetle in lodgepole pine forests. Research Paper INT-71. USDA Forest Service, Intermountain Research Station, Ogden, UT.

Safranyik L, Shrimpton DM, and HS Whitney. 1974. Management of lodgepole pine to reduce losses from the mountain pine beetle. Natural Resources Canada, Canadian Forest Service. Forestry Technical Report 1. 24ppg.

Safranyik L, Barclay H, Thomson A and WG Riel. 1999. A population dynamcis model for the mountain pine beetle, *Dendroctonus ponderosae* Hopk. (Coleoptera : Scolytidae). Natural Resources Canada, Canadian Forest Service. Information Report BC-X-386. 35 pp.

Shore TL, and L Safranyik. 1992. Susceptibility and risk rating systems for the mountain pine beetle in lodgepole pine stands. Forestry Canada Information Report BC-X-336. 12 pp.

Stuart JD, Agee JK, and RI Gara. 1989. Lodgepole pine regeneration in an old, self-perpetuating forest in south central Oregon. *Canadian Journal of Forest Research* 19(9):1096-1104.

Taylor SW, Baxter GJ, and BC Hawkes. 1998. Modeling forest succession on fire behavior potential in southwestern B.C. pp. 2059-2071 *in* Proceedings: III International Conference on Forest Fire Research, 14th Conference on Fire and Forest Meteorology. 16-20 Nov. 1998, Luso, Portugal.

Teck R, Moeur M, and B Eav. 1996. Forecasting Ecosystems with the Forest Vegetation Simulator. *Journal of Forestry* 94:7-10.

Trowbridge R, Hawkes B, Macadam A, and J Parminter. 1986. Field handbook for prescribed fire assessments in British Columbia: logging slash fuels. Land management handbook no. 11. BC Ministry of Forests, Victoria BC.

Turner MG, Romme WH, and RH Gardner. 1999. Prefire hetergeneity, fire severity, and early postfire plant reestablishment in subalpine forests of Yellowstone National Park, Wyoming. *International Journal of Wildland Fire* 9(1):21-36.

Whitehead RJ, Martin P, and A Powelson. 2001 Reducing stand and landscape susceptibility to mountain pine beetle. Stand density management diagram, British Columbia Ministry of Forests, Victoria, 12pp.

Wildlife Tree Committee of British Columbia. 2001. Wildlife/Danger tree assessorís course workbook. *Onlne at:* http://www.for.gov.bc.ca/hfp/wlt/ WTWB-web.pdf

APPENDIX 1: STUDY STAND LOCATIONS

Table 1: 2001 MPB sample stand locations, condition and biogeoclimatic zones.

Forest Region	Stand	Latitude	Longitude	BGCZ	Location	Status
Cariboo	101	51.34.800	122.49.350	MSxv	Gaspard Road	Unknown
Cariboo	102	51.36.900	122.36.050	IDFdk 4	Churn Creek	Unknown
Cariboo	103	51.32.565	122.38.560	IDFdk 4	Churn Creek	Good
Cariboo	104	51.43.710	123.02.377	IDFdk 4	2400 Rd garbage dump	Good
Cariboo	105	51.42.256	122.52.622	IDFdk 4	2400 Road	1 plot logged
Cariboo	106	51.41.850	123.01.650	IDFdk 4	Mons Lake	Blowdown?
Cariboo	107	52.09.881	120.09.391	SBPSxc	Anah Lake	4 plots logged
Cariboo	108	52.12.750	123.10.600	SBPSxc	4600 Rd	Clearcut
Cariboo	109	52.17.300	123.28.500	SBPSxc	Alexis Creek	Clearcut
Cariboo	110	52.17.225	123.24.200	SBPSxc	Off 4600 Rd	Unknown
Cariboo	111	52.17.100	123.52.550	SBPSxc	Chezacut	7 plots logged
Cariboo	112	52.20.850	123.56.400	SBPSxc	Chezacut	9 plots logged
Cariboo	113	52.16.995	123.10.760	SBPSxc	117 Rd	2 plots logged
Cariboo	114	52.15.900	123.21.600	SBPSxc	4600 Rd	Clearcut
Cariboo	115	52.14.700	123.51.050	SBPSxc	Chezacut	Clearcut
Cariboo	116	51.59.884	123.45.363	IDFdk 4	Chilko River N	Good
Cariboo	117	52.05.519	124.07.469	IDFdk 4	Chilanko Forks	Burned
Cariboo	118	52.00.354	124.19.788	SBPSxc	Chilanko Forks	3 plots logged
Cariboo	119	51.57.798	124.55.392	SBPSxc	Kleena Kleene	3 plots logged
Cariboo	120	51.46.500	124.05.650	SBPSxc	Chilco River	Burned
Cariboo	121	51.50.380	124.31.947	IDFdk 4	Chilco Lake Rd	3 plots logged
Cariboo	122	51.47.300	123.28.300	SBPSxc	Taseko Lk	Clearcut
Cariboo	123	52.15.900	123.54.800	SBPSxc	Puntzi Lake	Clearcut
Cariboo	124	52.06.200	125.04.100	SBPSxc	Clearwater Lk	1 plot logged
Cariboo	125	51.54.942	124.36.265	SBPSxc	Tatla Airstrip	Good
Cariboo	126	52.07.830	124.03.192	IDFdk 4	Chilanko	1 plot logged
Cariboo	127	52.13.700	125.03.900	SBPSxc	Hwy 20 McKlenchie	Clearcut
Cariboo	128	51.52.667	124.35.231	SBPSxc	Tatla Lk South	1 plot logged
Cariboo	129	51.55.320	124.33.738	SBPSxc	Tatla Airstrip	1 plot logged
Cariboo	130	51.56.510	124.27.674	SBPSxc	Hwy 20 Tatla rest stop	Good
Nelson	205	50.07.530	115.37.107	MSdk	White Swan Rd	Good
Kamloops	301	49.15.679	120.34.331	IDFdk 2	Sunday Crk Rd	4 plots logged
Kamloops	302	49.40.197	120.13.923	IDFdk 2	Gellico	Good
Kamloops	304	49.40.068	119.13.110	IDFdm 1	Stirling Rd	Good
Kamloops	305	49.40.631	119.13.860	MSdm 1	201 Okanagan Mtn Rd	Good

*Stands 201-204, 303 all logged between 1987 and 2001, not reestablished

**GPS positions of stands not sampled in 2001 are estimates.

***GPS of stands resampled in 2001 are actual measurements.

Table 2: 2002 MPB sample stand locations and biogeoclimatic zones.

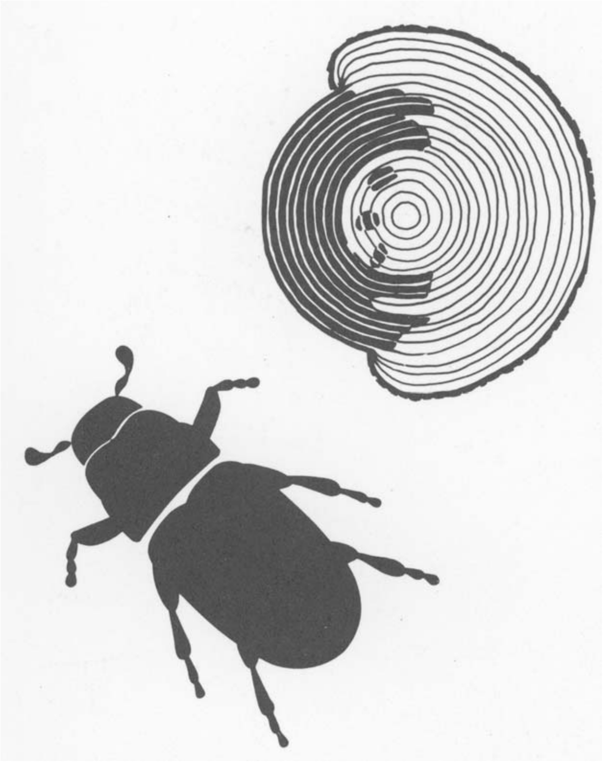
Forest Region	Stand	Latitude	Longitude (west)	BGCZ	Location
Tweedsmuir	1	53.25675	126.07264	SBSdk	Entiako PA
Tweedsmuir	2	53.25714	126.05416	SBSdk	Entiako PA
Tweedsmuir	3	53.26744	126.02865	SBSdk	VH Caribour migration corridor
Tweedsmuir	4	53.32251	125.91110	SBSdk	VH Caribour migration corridor
Tweedsmuir	5	53.32022	125.92744	SBSdk	VH Caribour migration corridor
Tweedsmuir	6	53.29664	125.92124	SBSdk	Entiako PA
Tweedsmuir	7	53.30591	125.89737	SBSdk	Entiako PA
Tweedsmuir	8	53.30611	125.95567	SBSdk	VH Caribour migration corridor
Tweedsmuir	9	53.27510	125.99779	SBSdk	VH Caribour migration corridor
Tweedsmuir	10	53.26360	126.08599	SBSdk	Tweedsmuir Park North
Manning	1	49.06694	120.79758	ESSFmw	Manning Park
Manning	2	49.07662	120.80182	ESSFmw	Manning Park
Manning	3	49.07544	120.80208	IDFdk2	Manning Park
Manning	4	49.07189	120.79127	IDFdk2	Manning Park
Manning	5	49.07317	120.7932	ESSFmw	Manning Park

Appendix 2

FII REPORT : RECURRENCE OF MOUNTAIN PINE BEETLE INFESTATIONS IN SOUTH-CENTRAL BRITISH COLUMBIA, CANADA

RenÈ Alfaro, Rochelle Campbell and Brad Hawkes

Pacific Forestry Centre, March 2003



Introduction

The mountain pine beetle (*Dendroctonus ponderosae* Hopk.) (MPB) (Coleoptera: Scolytidae) is an aggressive bark beetle whose populations periodically increase to outbreak levels in infestations that kill thousands of trees, and is catalogued as one of the major natural disturbance agents in North America (Furniss and Carolin 1977). In British Columbia (BC), the main host species is lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.), but western white pine (*Pinus monticola* Dougl.), ponderosa pine (*Pinus ponderosa* Laws), whitebark pine (*Pinus albicaulis* Engelm.), and limber pine (*Pinus flexilis* James) are also attacked (Furniss and Carolin 1977, Unger 1993). Occasionally, non-host trees such as Engelmann spruce (*Picea engelmannii* Parry) are attacked, but beetle populations do not persist in these occasional hosts (Unger 1993). MPB generally attacks stands that are more than 80 years old with trees over 25 cm in diameter (Safranyik *et al.* 1974). Although MPB can attack younger trees, outbreaks have not been reported in stands younger than 60 years and they rarely occur between 60 and 80 years (Safranyik *et al.* 1974).

Peterman (1978) described the post-outbreak dynamics in climax lodgepole pine stands under different conditions. Beetle-kill thins the stand and promotes increased growth among the remaining pines and other vegetation in the stand, allowing the establishment of regeneration in the understorey. During an outbreak, MPB preferentially kills trees of the largest diameter (McGregor and Cole 1985). Cole and Amman (1980) investigated the characteristics of residual stands (> 100 years old) in Wyoming and Idaho to determine the effect of past beetle outbreaks on stand structure. Increment cores from understorey fir and spruce indicated a growth release following the death of overstorey pine trees killed by MPB.

Tree rings maintain a record of the disturbance history for a locality, and are therefore useful as indicators of ecosystem function (Alfaro 2001) and have been used to examine historical outbreaks of bark beetles (Heath and Alfaro 1990; Veblen *et al.* 1991a, 1991b; Perkins and Swetnam 1996 ; Zhang *et al.* 1999; Eisenhart and Veblen 2000) and defoliating insects (Swetnam and Lynch 1993; Burleigh *et al.* 2002; Zhang and Alfaro 2002, 2003). The identification of growth release periods in surviving host and non-host trees, that are synchronous with the mortality of host trees, is the most common method of historical beetle outbreak detection in tree ring series. Release is not precisely simultaneous because not all hosts are attacked nor die in the same year (Eisenhart and Veblen 2000). Using tree rings, Stuart *et al.* (1989) demonstrated that older trees displayed seemingly synchronous periods of poor growth followed by release due to MPB attack.

In spite of its prevalence as a disturbance agent of BC forests, studies to understand the impacts of MPB on stand dynamics are few. In 1987, the Pacific Forestry Centre established 30 research plots to measure ecological changes induced by MPB in lodgepole pine forests in the South Central BC (Shore and Safranyik 1996). In 2001, a comprehensive study of MPB impacts was launched in response to increased outbreaks in BC. As part of that study, in the summer of 2001, we re-visited 18 of the plots established in these studies (Fig.1). Budgetary constraints as well as loss of some of the plots to logging and fire prevented us from measuring all plots. Fifteen of the plots are located in the Chilcotin area of the Cariboo Region (henceforth referred to as the Cariboo plots), two are in the Okanagan area of southern BC (Okanagan plots) and one is located in the Rocky mountains (Nelson plot) (Fig. 1).

History of MPB in Central British Columbia

The following information on the history of MPB outbreaks in Central British Columbia was summarised from Wood and Unger (1996) and is based on ground observations by the Forest Insect and Disease Survey (FIDS) of the Canadian Forest Service, conducted annually from 1913 until 1996. Since then, with the dismissal of FIDS, records have become inconsistent. Since the 1960ís, beetle-killed stands were delineated from aircraft and supplemented the ground observations.

The first report of MPB in the Okanagan area of central British Columbia dates to 1910, near Princeton and Peachland, and continued until 1919. The area around Trout Creek experienced repeated infestations in 1974, 1980 and 1990. Many small outbreaks were recorded in the Valley between 1917 and 1928. From 1980 through 1988 approximately 8 million trees were killed in the Valley.

An outbreak of MPB was reported in the Cariboo Region of BC from 1930 to 1936 in the Takla Lake area, when 60 to 90 percent of infested lodgepole pine over 650 000 ha were killed. In the 1940s beetle-killed trees were reported in the Alexis Creek area (DR. Les Safranyik, Can. For. Serv., Pers. Comm. 2003). A series of MPB outbreaks occurred throughout the 1970s in the Cariboo Region. In 1974 the Klinaklini River drainage had reported infestations, which by 1975 had spread over most of the West Chilcotin. In 1981 over 9 million trees were killed by MPB on 72 800 ha of the Chilcotin Plateau.

Further to the east, in the Nelson Region, infestations were recorded between 1949 and 1956, near Invermere and the White River drainage. An infestation occurred in Coyote Creek, near the town of Skookumchuck in 1966. The White River drainage was infested again from 1971 to 1976 and 1979 to 1981.

The present study intended to determine the history of MPB outbreaks in Central BC for the last 100 years in the research plots originally established in the 1980ís. These plots cover a substantial portion of the range of MPB in BC. For this we used dendrochronological methods to identify release periods attributable to beetle outbreaks in increment cores collected in 2001

Methods

Dendroecological Methods

In the summer of 2001, increment cores were collected and analysed from 15 of the 30 locations in the Cariboo Region and 5 of the 11 locations in the Okanagan and Nelson Regions (Fig. 1). Stands in the Region were located in the Sub-boreal Pine Spruce (SBPS) and Interior Douglas-fir (IDF) biogeoclimatic zones (Meidinger and Pojar 1991) (Table1).

Increment core sample collection and preparation

Increment cores were collected from lodgepole pine, Douglas-fir, interior spruce, sub-alpine fir (*Abies lasiocarpa* (Hook) Nutt.), trembling aspen (*Populus tremuloides* Mitchx.) and western larch (*Larix occidentalis* Nutt.). The lowest and highest numbered tree in each MPB plot, depending on availability, was selected for coring. A variable number of non-host (trees not normally attacked by MPB) trees were also selected for coring, if they occurred in the plot. The cores (one per tree) were extracted at breast height with an increment borer parallel to the slope contour. In the field, each core was labelled with stand and plot number, tree number and species. Collected cores were transported to the Pacific Forestry Centre, Canadian Forest Service, Victoria, BC for storage and analysis.

In the laboratory, 310 increment cores (268 from MPB host lodgepole pine and 42 from non-host Douglas-fir and spruce) were glued and mounted in slotted mounting boards, which were labelled with tree identifiers. The surface of these cores was sanded with progressively finer sand paper (grits 220 to 600) to enhance the boundaries between annual rings.

Sample measurement and chronology development

The ring-width measurement was conducted using a Windendro^{TM} tree-ring measuring system and a Measu-Chron incremental measuring system in the Tree-Ring Laboratory of the Pacific Forestry Centre. The precision of the measurement was 0.01 mm. The measured ring-width sequences were plotted and the patterns of wide and narrow rings were cross-dated among trees. The cross-dating was aided by the presence of distinctive narrow rings, and the quality of cross-dating was examined by the program COFECHA (Holmes 1983). COFECHA (Holmes 1983) detects measurement and cross-dating errors by computing correlation coefficients between overlapping 50-year segments from individual series (Eisenhart and Veblen 2000).

All cross-dated series were standardised by dividing each ring width by the mean series ring width (Eisenhart and Veblen 2000). Standardising series by their mean preserved the long-term growth trend necessary to identify canopy disturbances (Veblen *et al.* 1991a). Each chronology was visually inspected for abrupt and sustained increases in growth rate that might indicate a mountain pine beetle outbreak. Chronology standard deviations were calculated and used to identify periods of release where growth was greater than one standard deviation from the mean. We defined a growth release as a year that exhibited a 50% increase with respect to the mean ring width of the previous five years. Thus, the magnitude of the release was compared only with the tree-ring indices that directly preceded the release and not to the whole chronology (Eisenhart and Veblen 2000). Veblen *et al.* (1991) and Velben and Eisenhart (2000) used the same method for detecting release in Engelmann spruce (*Picea engelmannii* (Parry) Engelm.) trees following spruce bark beetle outbreaks in Colorado.

Lodgepole pine (host) chronologies were developed for 15 stands in the Cariboo Region, two stands in the Okanagan and one in then Nelson regions. In the initial decades of long tree-ring chronologies, when sample size is inevitably small, interpretation of releases is difficult (Eisenhart and Veblen 2000). Therefore interpretation of chronologies was limited to where the sample size was $\geq$ 5 trees.

Four non-host chronologies were constructed. One spruce chronology for stand 113 and one Douglas-fir chronology for stand 116 in the Cariboo region, one Douglas-fir chronology for stand 205 in the Nelson Region, and one spruce chronology for stand 304 in the Okanagan Region. Non-host chronologies were examined for periods of release and compared to host chronologies to determine if periods of release in lodgepole pine were synchronous with periods of release in non-host species.

Results

Outbreak history based on tree rings

Over 90% of lodgepole pine cores were successfully cross-dated and included in the tree-ring analysis. The number of cores included in the stand chronologies ranged from 6 to 21 (Table 2). Four non-host chronologies were constructed (Table 3). Although one chronology (stand 113) contained one tree born in 1758 (243 years old, Table 3), the average year when the sample size was at least 5 trees was 1897. Therefore our results can be applied with confidence only to the period after 1890.

Synchronous periods of release in the Cariboo region (stands No. 103 to 130) that were inferred from the tree-ring chronologies occurred in three periods since 1890 (Table 4, Fig. 3). The average year of start and end for each period was (no. chronologies that showed the release is given in brackets): 1893-1906 (5); 1935-1949 (16); and 1980-1994 (16). The initiation and ending of each release period varied somewhat. The last release period extended in some stands until 2000. The two stands in the Okanagan region (stands 302 and 304) released at same time beginning in 1900 and then again in 1990.

Spatial synchrony of the 1980ís outbreak.

Visual inspection of the comparative pattern of releases in Fig. 3 does not show any particular pattern of sequential timing of outbreaks in the geographic range studied (ie. no evidence of spread). Rather, it disclosed that all three outbreaks (1890ís, 1940ís and 1980ís) occurred in approximate synchrony in the areas studied. A weak but significant negative correlation ($r = -0.27$, $P<0.01$) between the magnitude of the correlation between two tree ring chronologies and the distance (km) between them indicated a general trend for two chronologies to have increasingly differing patterns with increasing distance between them. However, the weak correlation is probably due to between-location differences in the climatic signal contained in the rings (the further apart, the more different the climate), rather that to differences in the beetle signal.

Literature Cited

Alfaro, R. 2001. Dendrochronology and insect impacts on productivity. In: Volney, W.J.A., Spence, J.R., and E.M. Lefebvre (eds). Boreal Odyssey: Proceedings of the North American Forest Insect Work Conference, May 14-18, 2001, Edmonton, Alberta, Canada.

Burleigh, J.S., R.I. Alfaro, J.H. Borden, and S. Taylor. 2002. Historical and spatial characteristics of spruce budworm *Choristoneura fumiferana* (Clem.) (Lepidoptera: Tortricidae) outbreaks in northeastern British Columbia. Forest Ecology and Management 168: 301-309.

Cole, W.E. and G.E. Amman. 1980. Mountain Pine Beetle Dynamics in Lodgepole Pine Forests. Part I: Course of an Infestation. Gen. Tech. Rep. INT-89. U.S.D.A. Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT.

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

Furniss, R.L. and Carolin, V.M. 1977. Western Forest Insects. USDA Forest Service Miscellaneous Publication No. 1339. 654pp.

Heath, R. and R.I. Alfaro. 1990. Growth response in a Douglas-fir/lodgepole pine stand after thinning of lodgepole pine by the mountain pine beetle: A case study. J. of Entomol. Soc. of British Columbia 87: 16-21.

Holmes, R. 1983. Computer-assisted quality control in tree-ring dating and measurement. Tree-Ring Bull. 43: 69-75.

Meidinger, D, and J. Pojar. 1991. Ecosystems of British Columbia. B.C. Ministry of Forests Special Report Series 6.

McGregor, M.D. and D.M. Cole (eds). 1985. Integrating Management Strategies for the Mountain Pine Beetle with Multiple-resource Management of Lodgepole Pine Forests. Gen. Tech. Rep. INT-174. U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT.

Perkins, D.L. and T.W. Swetnam. 1996. A dendroecological assessment of whitebark pine in the Sawtooth-Salmon River region, Idaho. Can. J. of For. Res. 26: 2123-2133.

Peterman, R.M. 1978. The ecological role of mountain pine beetle in lodgepole pine forests. In: Theory and Practice of Mountain Pine Beetle Mangement In Lodgepole Pine Forests. Proceedings of a Symposium, April 25-27, 1978, Pullman, WA. U.S. Forest, Wildlife and Range Experiment Station, University of Idaho, Moscow, ID.

Safranyik, L., Shrimpton, D.M. and Whitney, H.S. 1974. Management of lodgepole pine to reduce losses from the mountain pine beetle. Forestry Technical Report 1. Environment Canada, Canadian Forest Service, Victoria, B.C.

Shore, T. and L. Safranyik. 1996. The impact of the mountain pine beetle, *Dendroctonus ponderosae* on lodgepole pine stands in British Columbia, Canada. In: Korpilahti, E, Salonen, T., and S. Ojal (eds.) Caring for the forests: research in a changing world: abstracts of invited papers, IUFRO XX World Congress, 6-12 August 1995. Tampere, Finland.

Stuart, J.D., Agee, J.K., and Gara, R.I. 1989. Lodgepole pine regeneration in an old, self-perpetuating forest in south central Oregon. Canadian Journal of Forestry Research 19: 1096-1104.

Swetnam, T.W. and Lynch, A.M. 1993. Multicentury, regional-scale patterns of western spruce budworm outbreaks. Ecol. Monog. 63: 399-424.

Unger, L. 1993. Forest Pest Leaflet, Mountain Pine Beetle, 1996. Canadian-British Columbia Partnership Agreement on Forest Resource Development: FRDA II.

Veblen, T.T., Hadley, K.S., Reid, M.S. and Rebertus, A.J. 1991a Methods of detecting past spruce beetle outbreaks in Rocky Mountain subalpine forests. Can. J. of For. Res. 21: 242-254.

Veblen, T.T., Hadley, K.S., Reid, M.S. and Rebertus, A.J. 1991b. The response of subalpine forests to spruce beetle outbreak in Colorado. Ecology 72: 213-231.

Zhang, Q. B., R.I. Alfaro, and R.J. Hebda. 1999. Dendroecological studies of tree growth, climate and spruce beetle outbreaks in Central British Columbia, Canada. Forest Ecology and Management 121:215-225.

Zhang, Q. and Alfaro, R.I. 2002. Periodicity of two-year cycle spruce budworm outbreaks in central British

Columbia: a dendro-ecological analysis. Forest Science 48: 722-731.

Zhang, Q. and Alfaro, R.I. 2003. Spatial synchrony of the two-year cycle budworm outbreaks in central British Columbia. Oikos (in press)

Table 1. Mountain pine beetle stands sampled in Cariboo, Kamloops and Nelson, B.C.

Forest Region	Stand	Latitude	Longitude	BGCZ	Location
Cariboo	103	51.32	122.38	IDFdk4	Churn Creek
Cariboo	104	51.43	123.02	IDFdk4	2400 Rd garbage dump
Cariboo	105	51.42	122.52	IDFdk4	2400 Rd.
Cariboo	107	52.09	120.09	SBPSxc	Anah Lake
Cariboo	113	52.16	123.10	SBPSxc	117 Rd.
Cariboo	116	51.59	123.45	IDFdk4	Chilko River N
Cariboo	118	52.00	124.19	SBPSxc	Chilanko Forks
Cariboo	119	51.57	124.55	SBPSxc	Kleena Kleene
Cariboo	121	51.50	124.31	IDFdk4	Chilco Lake Rd.
Cariboo	124	52.06	125.04	SBPSxc	Clearwater Lk.
Cariboo	125	51.54	124.36	SBPSxc	Tatla Airstrip
Cariboo	126	52.07	124.03	IDFdk4	Chilanko
Cariboo	128	51.52	124.35	SBPSxc	Tatla Lk. South
Cariboo	129	51.55	124.33	SBPSxc	Tatla Airstrip
Cariboo	130	51.56	124.27	SBPSxc	Hwy 20 Tatla reststop
Nelson	205	50.07	115.37	MSdk	White Swan Rd.
Kamloops	302	49.40	120.13	IDFdk2	Gellico
Kamloops	304	49.40	119.13	IDFdk2	Stirling Rd.
Cariboo	163	51.39	121.97	IDFdk3	---
Cariboo	359	51.44	121.77	IDFdk3	---

Table 2. Summary data for Lodgepole Pine (host) site chronologies used to study recurrence of mountain pine beetle disturbances in BC.

Stand	No. of cores crossdated	Chronology period	Year with more than 5 cores	Mean Serial Correlation*
103	21	1890-2001	1897	0.618
104	21	1849-2000	1890	0.590
105	16	1865-2000	1869	0.569
107	9	1886-2000	1915	0.493
113	14	1758-2000	1809	0.448
116	19	1849-2001	1889	0.558
118	14	1853-2000	1867	0.456
119	14	1912-2000	1951	0.544
121	13	1901-2000	1931	0.403
124	16	1887-2000	1915	0.43
125	17	1886-2000	1905	0.454
126	14	1864-2000	1915	0.496
128	16	1865-2000	1941	0.457
129	18	1860-2000	1891	0.495
130	18	1895-2000	1906	0.493
205	10	1882-2001	1894	0.444
302	12	1865-2001	1881	0.365
304	6	1877-2001	1888	0.337
163	7	1864-2000	1873	0.628
359	15	1886-2000	1910	0.689

*describes the amount of common signal within the chronology (Zhang and Alfaro 2002)

Table 3. Summary data for non-host site chronologies used to study recurrence of mountain pine beetle disturbances in BC.

Stand No.	Species	No. of cores cross-dated	Chronology period	Mean Serial Correlation
113	Spruce	10	1894-2000	0.379
116	Douglas-fir	9	1901-2001	0.764
205	Douglas-fir	12	1880-2001	0.595
304	Spruce	11	1890-2001	0.457

Table 4. Dates of inferred release, duration of ring width reductions, interval between reductions, in lodgepole pine trees during outbreaks of mountain pine beetle in Cariboo, Kamloops and Nelson, BC. Dashed line indicates that there was no interval (one release only).

Stand No.	Release Dates	Duration of release (Years)	Interval (Years)
103	1939-1950	11	---
	1989-2000	11	39
104	1895-1903	8	---
	1938-1950	12	35
	1975-1985	10	25
105	1939-1950	11	---
107	1932-1944	12	---
113	1898-1904	6	---
	1926-1947	21	22
116	1887-1902	15	---
	1933-1944	11	31
	1986-1998	12	42
118	1895-1910	15	---
	1980-2000	20	70
119	1941-1946	5	---
	1975-1993	18	29
121	1932-1955	23	---
	1980-1987	7	25
124	1959-1968	9	---
	1988-1993	5	20
125	1935-1944	9	---
	1980-1997	17	36
126	1934-1951	17	---
	1975-1996	21	24
128	1939-1956	17	---
	1982-1998	16	26
129	1890-1912	22	---
	1936-1951	15	24
	1981-1998	17	30
130	1935-1953	18	---
	1982-2000	18	29
205	1926-1949	21	---
	1980-1990	10	31
302	1937-1946	9	---
	1980-1997	17	34
304	1936-1946	10	---
	1974-1983	9	28
	1990-1999	9	7
163	1876-1887	11	---
	1938-1951	13	51

	1975-1984	9	24
	1987-1993	6	3
359	1899-1906	7	---
	1913-1921	8	7
	1943-1951	8	22
	1963-1968	5	12
	1976-1985	9	8
	1989-1995	6	4

Fig. 1. Map of the location of the plots used to study the recurrence of mountain pine beetle infestations in Central British Columbia.

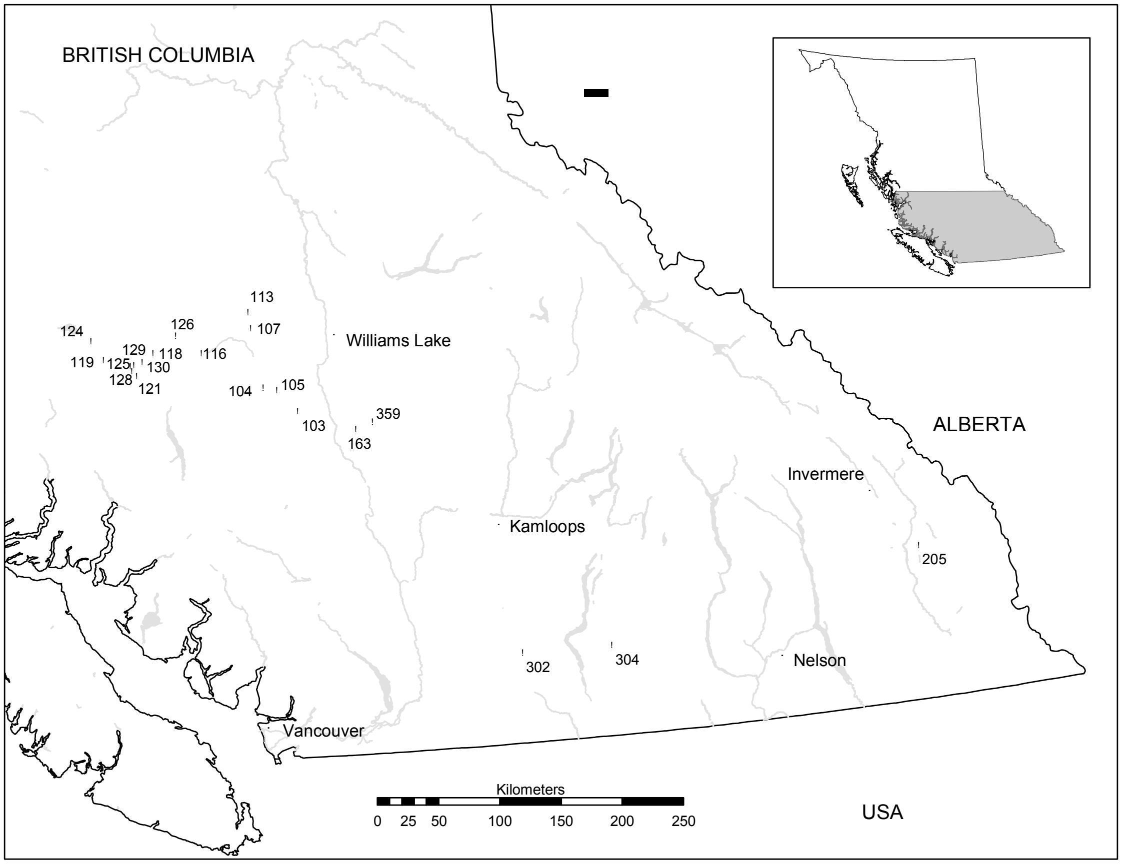


Fig. 2. Example of tree ring chronology (top), sample size for the chronology (middle) and percentage of trees in a given year showing a release greater than 50%, relative to growth in the five preceding years. Ring width indices for this stand (#128, Cariboo Region) clearly show two outbreak periods (1940ís and 1980ís).

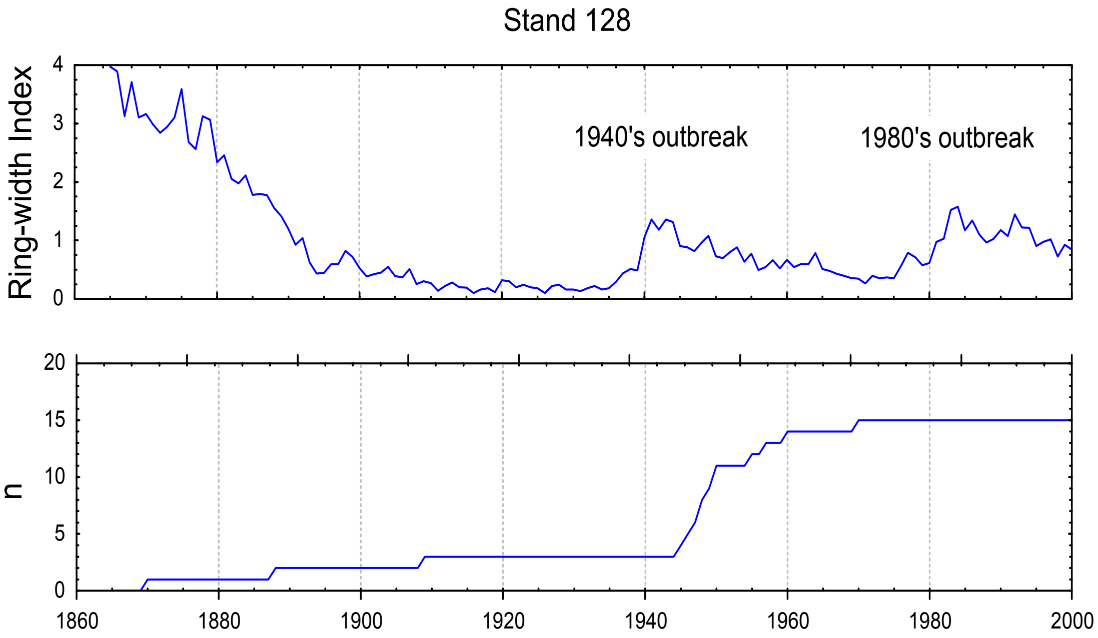
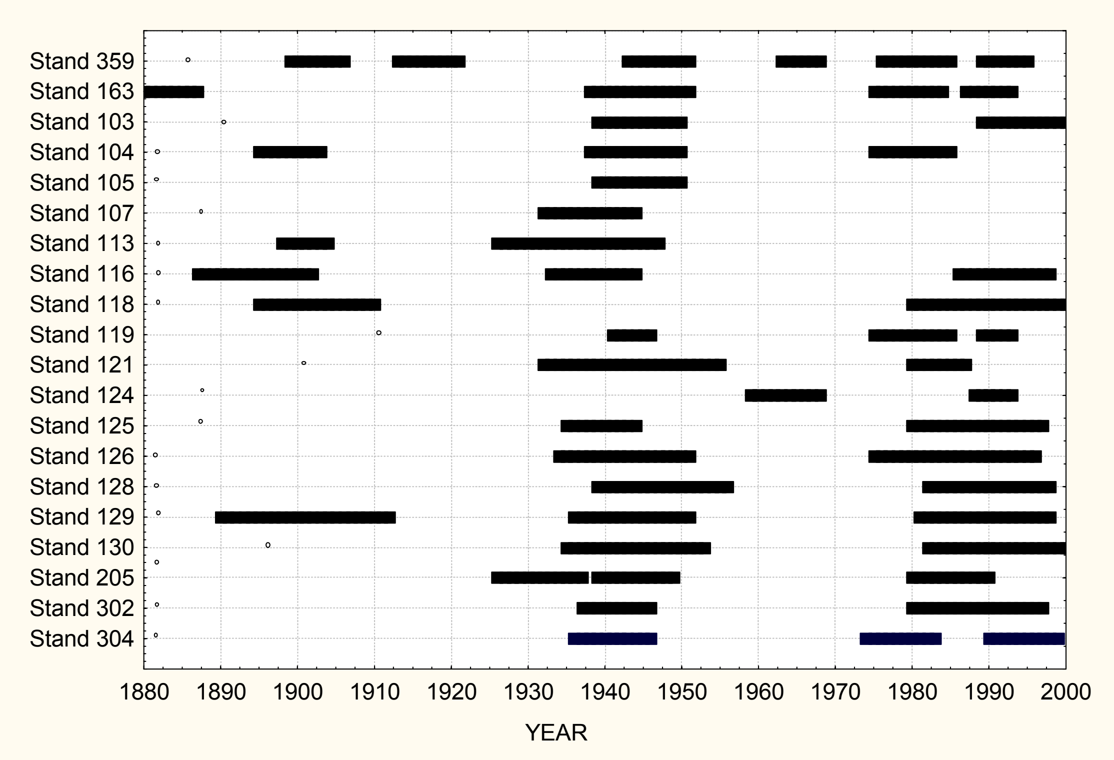


Fig. 3. Mountain pine beetle outbreaks in Central British Columbia inferred from tree ring chronologies. Asterisk indicates end of the chronology.



Appendix 3

IMPACTS OF MOUNTAIN PINE BEETLE ON LODGEPOLE PINE REGENERATION IN THE SOUTHERN INTERIOR OF B.C.

Introduction

The management of stand dynamics in forested ecosystems are affected by a complex array of environmental factors that include climate, insects, fire, and competition between trees, amongst others. For example, massive tree mortality as a result of outbreaks, releases resources that potentially are available to survivors or individuals that subsequently become established. In addition to the direct affects of mortality in the stand, outbreaks may also affect tree growth rates and regeneration patterns, which in turn may alter stand productivity, structure and composition (Amman *et al.*1977, Veblen *et al.* 1991a,b). Trees respond to these influences with corresponding changes in their annual growth rings and a record of past influences such as a MPB outbreak on growth is retained in the tree rings, which can be used to investigate the effects on stand composition and regeneration (Fritts and Swetnam 1989, Veblen *et al.* 1991a,b).

Objectives

This study intended to examine the growth of pole-size lodgepole pine trees after a mountain pine beetle outbreaks in the Chilcotin area of BC.

Methodology

In 1987-88 Terry Shore and Les Safranyik (Pacific Forestry Centre) selected forty-one study plots in the Cariboo, Kamloops and Nelson forest regions. In 2001, fifteen of the thirty locations in the Cariboo forest region and five of the eleven locations in the Kamloops and Nelson forest regions were re-measured. The remaining twenty-six stands were not measured as a result of disturbance by logging, or wildfire. Stands suitable for resampling were revisited in August and Sept 2001.

Stands in the Cariboo forest region were located in the Sub-boreal Pine Spruce (SBPS) and Interior Douglas-fir (IDF) biogeoclimatic zones. This SBPS zone occurs primarily in the Cariboo Forest Region and is characterized by cold, dry winters and cool, dry summers. Mean annual precipitation ranges from 335 to 580 mm (Steen and Coupe 1997). Lodgepole pine is an important succesional species and is the most common species of tree regeneration in the understory (Steen and Coupe 1997). The plots visited in 2001 were located in the SBPSxc (very dry cold) subzone. The IDF zone is characterized by warm, dry summers and cool, dry winters (Meidinger and Pojar 1991). Vegetation on zonal sites in the IDF zone are a Douglas-fir forest, often with a few lodgepole pine in the forest canopy (Steen and Coupe 1997).

Stands in the Kamloops and Nelson Forest Regions were located in two biogeoclimatic zones: the IDF and the Montane Spruce (MS). The Montane Spruce (MS) zone represents a transition between the SBPS or IDF zones, over most of their ranges (Meidinger and Pojar 1991). Lodgepole pine forests with interior spruce (*Picea* spp.) understory dominate the MS landscape (Steen and Coupe 1997).

Within each stand, the centre of each plot was relocated and an orange-painted aluminium stake was hammered into the ground as a permanent marker to replace the original wooden stakes. The location of each stand was recorded using GPS. In addition to this, a detailed map was drawn with driving directions, stand location, and the direction and distance between plots.

Sample collection and preparation

Pole size trees were collected from lodgepole pine (*Pinus contorta* var. *latifolia* (Dougl.)), Douglas-fir (*Psueodutsuga menziesii* (Mirb.)), sub-alpine fir (*Abies lasiocarpa* (Hook) Nutt.) and Engelmann spruce (*Picea engelmannii* (Parry ex Engelm.). All nonhost saplings were collected from the Kamloops forest region (9 discs- Douglas-fir; 15 discs Engelman spruce; 10 discs sub-alpine fir). A minimum of ten saplings was sampled for each plot. Saplings were tallied by species into two DBH classes: 0 - 3.9cm or 3.9 - 7.5cm. All saplings were cut at ground level and at a minimum height of 1.5m from the ground. In the field, each disc was labelled with stand and plot number, tree number and species. Collected discs were transported to the Pacific Forestry Centre, Canadian Forest Service, Victoria, B.C. for storage and analysis.

In the laboratory, 217 cross sections (host and non-host) were cut from the pole size trees and labelled with tree identifiers. The surfaces of these discs were sanded with progressively finer sand paper (grits 80 to 120) to enhance the boundaries between annual rings. The pole size trees were examined for evidence of growth release. Ring-widths were visually inspected for each sample and note was made of release periods seen in the trees that corresponds with documented release periods during the 1970ís 1980ís and 1990ís. A release was defined as a period where tree rings showed an abrupt and sustained change in width, as judged by an experienced observer. Using these criteria the response of trees that composed the understory could be examined.

Results

Height growth

It took a mean average of 27 years for pole size trees in the Cariboo, Kamloops and Nelson forest districts to reach 1.34m in height (DBH) with the oldest and youngest trees 112 years and 2 years respectively (Table 1). The Nelson forest district took 42.5 years, Cariboo 29.5 years and the Kamloops forest district 18.7 years to reach DBH (Table 1).

Age of regeneration

The mean age at the base for all pole size samples was 46 years with the oldest and youngest trees 162 years and 13 years respectively. The sample representing the DBH age of all pole size trees was negatively skewed indicating, that the samples were better represented by younger trees (Fig. 1). In contrast there is a normal distribution of ages seen in the base age measurements for all stands (Fig. 2).

Table 1. Mean age (years) of pole-size lodgepole pine trees in the Cariboo, Kamloops and Nelson forest regions.

	N	Mean (age)	Median	Minimum	Maximum	Std. Dev.	Mean earliest year
Nelson (ground)	10	69.6	70.5	43	82	11.3	1931
Nelson (DBH)	10	42.5	46	25	61	11.6	1958
Cariboo (ground)	139	48.3	45	13	162	23.3	1953
Cariboo (DBH)	139	29.5	24	5	112	20.2	1971
Kamloops (ground)	68	37.1	29.5	13	114	22.5	1964
Kamloops (DBH)	68	18.7	12	2	83	18.4	1982
Age at ground for all areas	217	45.8	42	13	162	23.7	1955
Age at DBH for all areas	217	26.7	20	2	112	20.2	1974

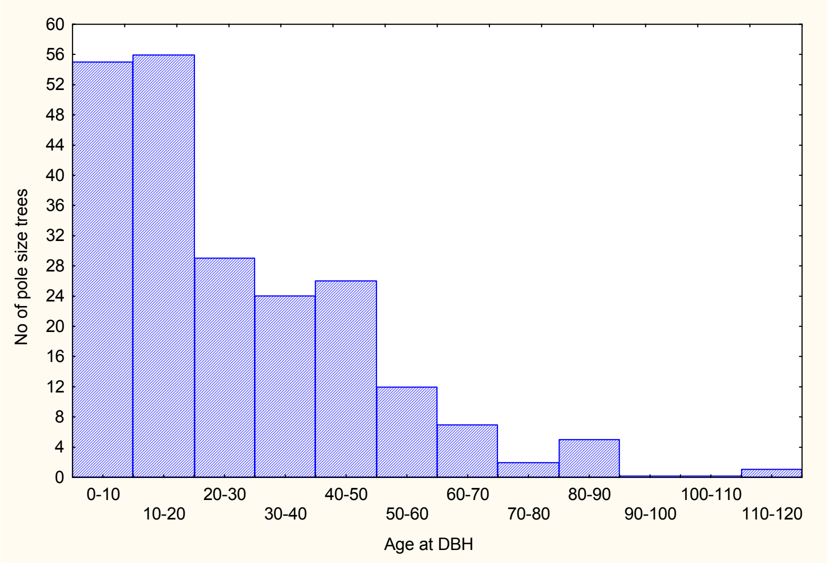


Figure 1. Age distribution at DBH of regenerated lodgepole pine trees collected in the Cariboo, Kamloops and Nelson forest region in areas affected by MPB.

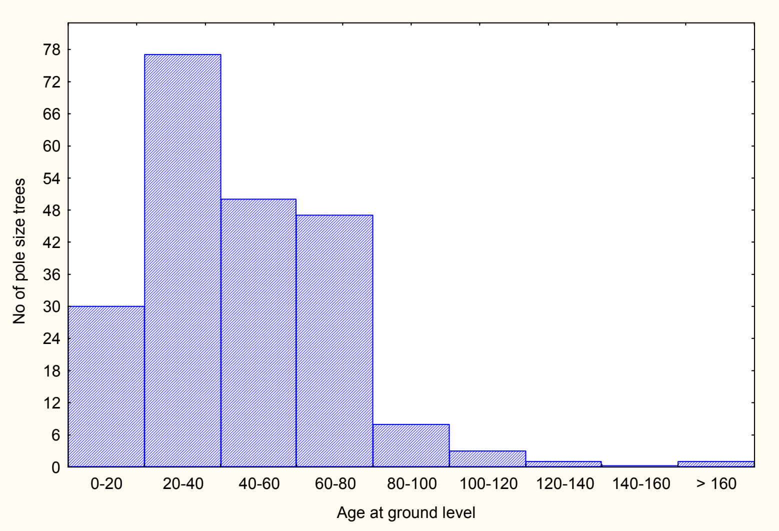


Figure 2. Age distribution at ground level of regenerated lodgepole pine trees collected in the Cariboo, Kamloops and Nelson forest region in areas affected by MPB.

The mean age (ground level) of pole size trees in size class 0 - 3.9cm was 36.3 years (Fig. 3). The age distribution (DBH) for size class (0 ñ 3.9 cm) is highly skewed with a mean age of 16.6 years (Fig. 4).

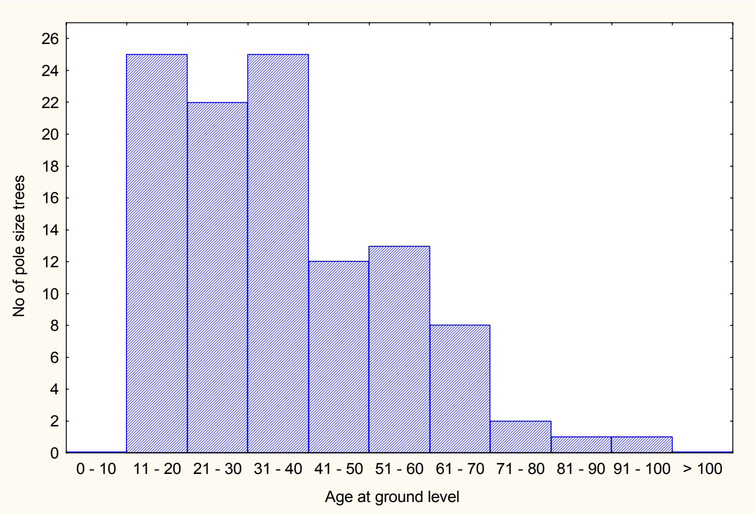


Figure 3. Age distribution at ground level of regenerated lodgepole pine trees collected in the Cariboo, Kamloops and Nelson forest region in areas affected by MPB (size class 0 -3.9cm).

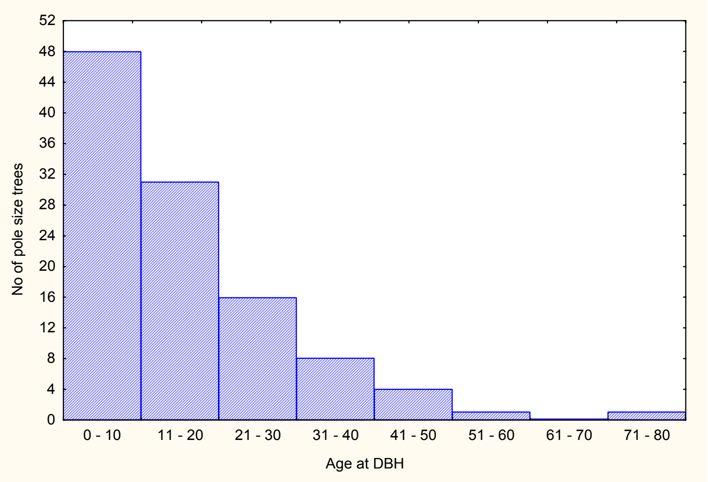


Figure 4. Age distribution at DBH of regenerated lodgepole pine trees collected in the Cariboo, Kamloops and Nelson forest region in areas affected by MPB (size class 0 - 3.9 cm).

When the age distribution at ground level was determined by class size (3.9-7.5cm) the mean age of pole size trees was 55.3 years, the histogram for the age at base shows a relatively normal distribution typical of even-aged stands (Fig. 5). In contrast the age at DBH is negatively skewed with a mean age of 36.9 years (Fig. 6).

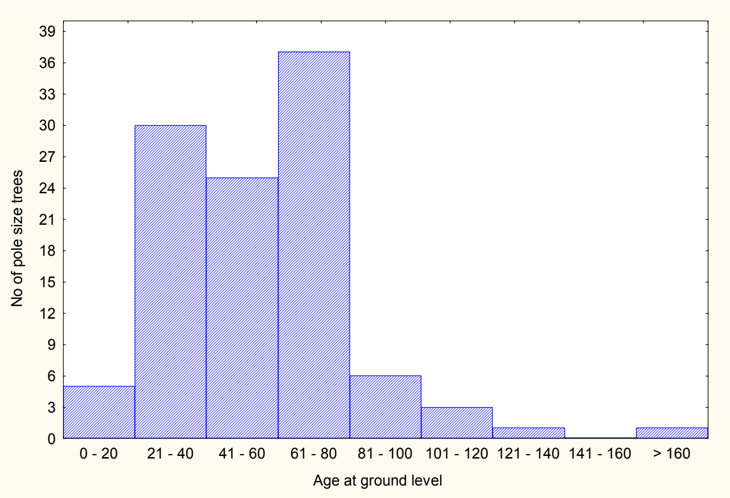


Figure 5. Age distribution at ground level of regenerated lodgepole pine trees collected in the Cariboo, Kamloops and Nelson forest region in areas affected by MPB (size class 3.9 ñ 7.5 cm).

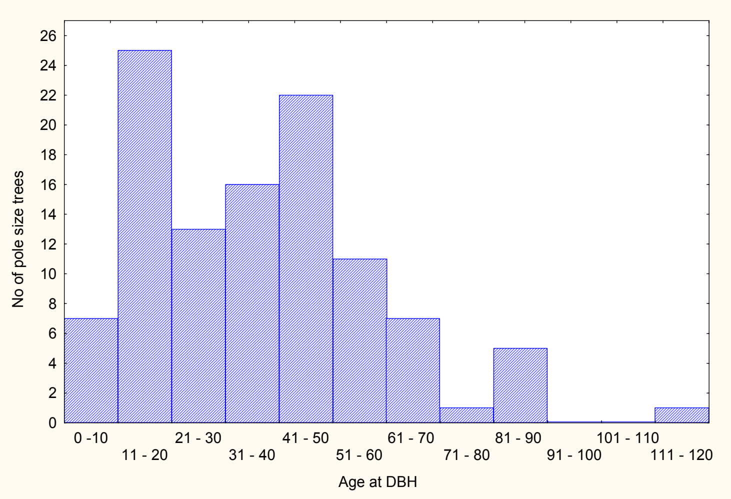


Figure 6. Age distribution at DBH of regenerated lodgepole pine trees collected in the Cariboo, Kamloops and Nelson forest region in areas affected by MPB (size class 3.9 ñ 7.5 cm).

<u>Growth response in relation to outbreaks</u>

In the 0-3.9 cm size class, 21.2% of discs show a response during the 1990ís. The highest proportion seen in discs collected from stand 103 and 126 both located in the Cariboo forest district. The size class 3.9 ñ 7.5cm shows a lower release rate of 9.2%. With the highest proportion seen in stands 103 and 130 both located in the Cariboo forest district. Table 3 is a summary of the base disc samples for the 3.9-7.5cm size class only and suggests that marginally higher proportion of outbreaks occurred in the 1980ís 39.8%, than in the 1970ís 34.7% and 1990ís 22%. Between 1970ís and the end of the 1990ís, 96.6% of the trees had demonstrated a release.

Table 2. Proportion of base disc samples showing release in the 1990s between two DBH classes (0-3.9 cm or 3.9-7.5 cm).

Stand	Total	Proportion (%)	0 - 3.9 cm	Proportion (%)	3.9 - 7.5 cm	Proportion (%)
103	5/10	50	3	30	2	20
104	1/10	10	0	0	1	10
105	1/10	10	1	10	0	0
107	1/10	10	0	0	1	10
113	3/10	30	0	0	3	30
118	1/9	11	1	0	0	0
119	2/10	20	1	10	1	10
121	3/10	30	1	10	2	20
124	2/10	20	1	10	1	10
125	0	0	0	0	0	0
126	6/10	60	2	20	4	40
128	1/10	10	0	0	1	10
129	0	0	0	0	0	0
130	4/10	40	3	30	1	10
205	5/10	50	2	20	3	30
301 (LP)	4/9	44	2	20	2	20
301 (DF)	1/9	11	1	10	0	0
302	2/10	20	2	20	0	0
304 (ES)	1/10	10	0	0	1	10
304 (LP)	1/10	10	0	0	1	10
305 (ES/AlF)	2/10	20	0	0	2	20
305 (LP)	0	0	0	0	0	0
Total	46/217	21.2	20	9.2	26	12.0

Table 3. Proportion of base disc samples (3.9 only) showing a release in the 1970ís, 1980ís and 1990ís.

Stand	1970s	Proportion (%)	1980s	Proportion (%)	1990s	Proportion (%)	Total	Proportion (%)
103	0	0	2	1.69	2	1.69	4	3.39
104	3	2.54	1	.85	1	.85	5	4.24
105	3	2.54	3	2.54	0	0	6	5.08
107	3	2.54	0	0	1	.85	4	3.39
113	1	.85	0	0	3	2.54	4	3.39
118	1	.85	3	2.54	0	0	4	3.39
119	1	.85	1	.85	1	.85	3	2.54
121	1	.85	1	.85	3	2.54	5	4.24
124	1	.85	3	2.54	1	.85	5	4.24
125	3	2.54	2	1.69	1	.85	6	5.08
126	3	2.54	3	2.54	4	3.39	10	8.47
128	2	1.69	2	1.69	1	.85	5	4.24
129	3	2.54	3	2.54	0	0	6	5.08
130	1	.85	3	2.54	1	.85	5	4.24
205	2	1.69	1	.85	3	2.54	6	5.08
301 (LP)	0	0	2	1.69	2	1.69	4	3.39
301 (DF)	2	1.69	3	2.54	0	0	5	4.24
302	1	.85	4	3.39	0	0	5	4.24
304 (ES)	2	1.69	2	1.69	1	.85	5	4.24
304 (LP)	0	0	4	3.39	1	.85	5	4.24
305 (AlF)	5	4.24	1	.85	0	0	6	5.08
305 (LP)	3	2.54	3	2.54	0	0	6	5.08
Total	41	34.74	47	39.8	26	22.04	114/118	96.6

Discussion

We identified three historical periods of response in the pole-size trees sampled in the Cariboo Forest District. These responses are related to known MPB outbreaks in the Chilcotin area in the 1970ís, 1980ís and 1990ís (Table 3). The first commenced in the early 1970ís that lasted long enough to see response in the tree rings in the mid 1980ís. A second MPB outbreak in the 1980ís resulted in a response in the early 1990ís. The most striking response to the outbreak was the release of previously suppressed individuals of all species. Bark beetle (Scolytidae) influence on forest ecosystems is similar to that of defoliating insects, which are known to improve the environment of surviving trees following an epidemic attack (Mattson and Addy 1975, Wickman 1978). In younger stands it is the veteran trees that are targets for beetle attack. When the older trees die, smaller, younger trees in the stand may respond to the increase in resources available for growth. The subsequent mortality of affected pine after a MPB outbreak permit the accelerated growth of small fir and spruce that result in a shift towards the shade-tolerant species. This pattern of disturbance-mediated acceleration of succession also occurs following blowdown of lodgepole pine-dominated stands (Peet 1981, Veblen et al. 1991). The importance of accelerated growth as opposed to new seedling establishment following a MPB outbreak is a major contrast to what is usually observed following fires (Veblen 1986, Aplet *et al* 1988, Veblen *et al.* 1991a,b). In particular fires in which few if any trees survive. Stand devastating fires favour regeneration of lodgepole pine and other shade intolerant species that regenerate quickly. However, ecosystem responses following a bark beetle attack may be less rapid, because surviving trees may be old and unable to respond and because beetle-killed trees do not immediately drop their foliage (Waring and Pitman 1985). This would explain the release by trees in the sampled stands occurring throughout the last thirty years (Table 3).

Future study

Although the population dynamics of the beetle and its effect on stand structure have been studied, little is known about the effects of a beetle outbreak on ecosystem processes such as productivity, cycling and succession. In order to generalize the release to the Kamloops and Nelson forest district, more plots in each region need to be examined.

References

Amman, G.D., McGregor, M.D., Cahill, P.B., and Klein, W.H. 1977. Guidelines for reducing losses to the mountain pine beetle in unmanaged stands in the Rocky Mountains. USDA For. Ser. Gen. Tech. Rep. INT-36. 19p.

Aplet, G.H., Laven, R.D. and Smith, F.W. 1988. Patterns of community dynamics in Colorado, USA Engelmann spruce-subalpine for forests. Ecology: 69 (2): 312-319.

Fritts, H.C. and Swetnam, T.W. 1989. Dendroecology: a tool for evaluating variations in past and present forest environments. Adv. Ecol. Res. 19, 111-188.

Mattson, W.J. and N.D. Addy. 1975. Phytophagous insects as regulators of forest primary production. Science. 190: 515-522.

Meidinger, D and J. Pojar. 1991. Ecosystems of British Columbia. B.C. Ministry of Forests Special Report Series 6.

Peet, R.K. 1981. Forest vegetation of the Colorado Front Range. Vegetatio, 45: 3-75.

Steen, O.A. and R.A. Coupe. 1997. A field guide to forest site identification and interpretation for the Cariboo Forest Region. B.C. Ministry of Forests. Victoria, B.C. Land Management Handbook. No. 39.

Veblen, T.T. 1986. Treefalls and the coexistence of conifers in subalpine forests of the central Rockies. Ecology, 67, 644-649.

Veblen, T.T., Hadley, K.S., Reid, M.S. and Rebertus, A.J. 1991a. Methods of detecting past spruce beetle outbreaks in Rocky Mountain subalpine forests. Can. J. of For. Res. 21: 242-254.

Veblen, T.T., Hadley, K.S., Reid, M.S. and Rebertus, A.J. 1991b. The response of subalpine forests to spruce beetle outbreak in Colorado. Ecology 72: 213-231.

Waring, R.H. and G.B. Pitman. 1985. Modifying lodgepole pine stands to change susceptibility to Mountain Pine Beetle attack. Ecology 66(3): 889-897.

Wickman, B.E. 1978. A case study of a Douglas-fir tussock moth outbreak and stand conditions 10 years later. United States Forest Research Paper. PNW-244.

Appendix 4

RESPONSE OF DOUGLAS-FIR (*PSEUDOTSUGA MENZIESII* VAR. *GLAUCA*) AND LODGEPOLE PINE (*PINUS CONTORTA* VAR. *LATIFOLIA* DOUGL.) AFFECTED BY MOUNTAIN PINE BEETLE (*DENDROCTONUS PONDEROSAE)* AT BULL MOUNTAIN NEAR WILLIAMS LAKE, B.C.

By Rochelle Campbell, RenÈ Alfaro, and Brad Hawkes

Introduction

Current concepts of forest management require that both the biological diversity of the forests and a viable forest industry be maintained. These values are difficult to reconcile in light of the increasing area affected by insect outbreaks throughout the province of British Columbia (BC). An example, is the mountain pine beetle, (*Dendroctonus ponderosae* Hopk.) (MPB) a native bark beetle whose episodic outbreaks on lodgepole pine (*Pinus contorta* var. *latifolia* Dougl.) forests affect both the aesthetic and economic values of these ecosystems.

Lodgepole pine is the main host species for the MPB in British Columbia. Other species affected include western white pine (*Pinus monticola* Dougl.), ponderosa pine (*Pinus ponderosa* Laws), whitebark pine (*Pinus albicaulis* Engelm.), and limber pine (*Pinus flexilis* James) (Unger 1993). Occasionally, Engelmann spruce (*Picea engelmannii* Parry) is attacked, but beetle populations do not persist in these non-host trees (Unger 1993). MPB generally attacks stands that are more than 80 years old with trees over 25 cm in diameter (Safranyik *et al.* 1974). Although MPB can attack younger trees, outbreaks have not been reported in stands younger than 60 years; and they rarely occur between 60 and 80 years (Safranyik *et al.* 1974). During the endemic stage the MPB affects an average of 50,000 ha of forest in BC annually, but in the course of an outbreak 450,000 ha can be affected annually (Wood and Unger 1996). For example, in B.C. the 2001 outbreak affected more than 600,000 ha (BC Ministry of Forests 2001). At the stand level this may result in 50% or more of the canopy density and basal area being devastated over a few years.

Peterman (1978) described the post-outbreak dynamics in lodgepole pine stand types under different conditions. Beetle-kill thins the stand and promotes increased growth among the remaining pines in the stand, allowing the establishment of seedlings from cones that are not serotinous in the understory. Heath and Alfaro (1990) investigating diameter growth response were able to quantify a release in Douglas-fir (11.7% increase) and surviving lodgepole pine (5.4% increase) in the Bull Mountain site. Cole and Amman (1980) investigated the characteristics of residual stands (> 100 years old) in Wyoming and Idaho to determine the effect of past beetle outbreaks on stand structure.

History

The Bull Mountain Research Reserve was proposed in 1976 as an ecological reserve by the Cariboo Research section. The reserve is approximately 65 ha and was selected when an extensive MPB outbreak was discovered in the area in 1971. Two surveys of the area were conducted by B.C. Ministry of Forests and Lands, Cariboo Region. The first in 1975 consisted of 98 pairs of concentric plots on a 50x50 grid. The second in 1985 consisted of 49 concentric circular plots on a 100x100 grid. Both were conducted to establish the amount and condition (alive or dead) of the overstory and understory. At the end of the outbreak in 1975 many but not all of the lodgepole pine trees were killed. By 1985, the average age of the Douglas-fir component was 63 years; surviving lodgepole averaged 107 years. The understory, defined as trees smaller in height than the lowest live branches of the overstorey (approx. 7m), was primarily stocked with Douglas fir. Douglas fir increase their diameter an average of 1.4 cm or 11.7% in diameter over the estimated size the trees would have reached in the absence of thinning. The surviving lodgepole pine trees gained an average 1 cm or 5.4% over the size of trees would have reached in the absence of the thinning effect.

Objectives

The objective of the 2001 study was to build on previous research done by Health and Alfaro (1990) and to determine if the predicted growth response of trees not killed by MPB did increase enough to compensate for the volume lost in beetle killed trees from the previous outbreaks.

Methodology

The Bull Mountain study site (122^{o} 09í 27îW 52^{o} 11í 48îN) is located approximately 4 km north of Williams Lake, BC in the Cariboo Forest Region (Heath and Alfaro 1990). The study area occupies 65 ha and, is located at an elevation of ≈ 970m, on a relatively flat terrain. The site is in the IDFdk3 biogeoclimatic subzone (Heath and Alfaro 1990). In the fall of 2001 DWB Forest Services Ltd. was contracted to re-sample the Lodgepole pine/Douglas-fir forest type to the east of the main road in the research site at Bull Mountain. The western portion of the original study site was recently logged and can no longer be used to detect growth response due to beetle thinning.

In 2001 twenty prism plots were randomly located within the lodgepole pine/Douglas-fir forest for sampling the overstory. A basal area factor (BAF) of 9 was used in the prism plots. Live trees were recorded for species, DBH, tree class (1-dominant/2-co-dominant/3-intermediate/4-suppressed), height and height to live crown of two dominant/co-dominant trees. Assessment of the MPB of attack (Green, Red, Grey) was also recorded. Fallen and standing dead trees were measured for DBH and classified according to snag class (1-9).

For the dendroecological section of the project, 20 increment cores from both Douglas-fir and lodgepole pine (total of 40 cores) were collected from the site by the contractor (Range 19.6cm to 63.1cm DBH). Twenty cores were also collected from lodgepole pine at the Lyne Creek site (122^{o} 07í 20îW 52^{o} 14í 27îN; 122^{o} 10í 55îW 52^{o} 14í 27îN) an area not previously been attacked by MPB. These control cores were collected to confirm that any growth release detected was due to a thinning effect and not to a coincident period of abnormally favourable weather (Heath and Alfaro 1990). In the fall of 2002 nineteen lodgepole pine and twelve Douglas fir discs were collected by PFC technicians and added to the tree-ring chronology.

Increment core sample collection and preparation

Increment cores (one per tree) were extracted at breast height with an increment borer parallel to the slope contour. In the field, each core was labelled with stand and plot number, tree number and species. Collected cores were transported to the Pacific Forestry Centre, Canadian Forest Service, Victoria, BC for storage and analysis.

In the laboratory, 40 increment cores and 31 discs (29 from MPB host lodgepole pine and 22 from non-host Douglas-fir) were glued and mounted in slotted mounting boards, which were labelled with tree identifiers. The surface of these cores was sanded with progressively finer sand paper (grits 220 to 600) to enhance the boundaries between annual rings.

Sample measurement and chronology development

The ring-width measurement was conducted using a Windendro^{TM} tree-ring measuring system and a Measu-Chron incremental measuring system in the Tree-Ring Laboratory of the Pacific Forestry Centre. The precision of the measurement was 0.01 mm. The measured ring-width sequences were plotted and the patterns of wide and narrow rings were cross-dated among trees. The cross-dating was aided by the presence of distinctive narrow rings, and the quality of cross-dating was examined by the program COFECHA (Holmes 1983). COFECHA (Holmes

1983) detects measurement and cross-dating errors by computing correlation coefficients between overlapping 50-year segments from individual series (Eisenhart and Veblen 2000).

All cross-dated series were standardised by dividing each ring width by the mean series ring width (Eisenhart and Veblen 2000). Standardising series by their mean preserved the long-term growth trend necessary to identify canopy disturbances (Veblen *et al.* 1991). Each chronology was visually inspected for abrupt and sustained increases in growth rate that might indicate a mountain pine beetle outbreak. Chronology standard deviations were calculated and used to identify periods of release where growth was greater than one standard deviation from the mean. The magnitude of the release was compared only with the tree-ring indices that directly preceded the release and not to the whole chronology (Eisenhart and Veblen 2000). Veblen *et al.* (1991) and Velben and Eisenhart (2000) used the same method for detecting release in Engelmann spruce (*Picea engelmannii* (Parry) Engelm.) trees following spruce bark beetle outbreaks in Colorado.

Lodgepole pine (host) and Douglas fir (nonhost) chronologies were developed for Bull Mountain. In the initial decades of long tree-ring chronologies, when sample size is inevitably small, interpretation of releases is difficult (Eisenhart and Veblen 2000). Therefore interpretation of chronologies was limited to where the sample size was $\geq$ 5 trees.

Results

The recurrence of mountain pine beetle at the site was determined using a record comprised of Douglas-fir (Fig.1) and lodgepole pine tree rings (Fig.2). The tree rings from Douglas fir trees show a period of release after the last beetle outbreak in the 1970ís and was fully documented by Heath and Alfaro (1990). The Douglas fir tree rings showed periods of growth release after periods of suppression, these were inferred to be outbreaks by the mountain pine beetle. Periods of growth release occurred in 1762, 1786, 1860, 1900 and 1921 (Fig.1). Tree rings from surviving lodgepole pine trees show a similar period of release after each inferred outbreak of MPB (Fig. 2). The documented MPB outbreak of the 1970ís showed a sustained release until time of sample collection. An inferred outbreak in the 1860ís and 1939 both resulted in an increase in the mean radial growth of lodgepole pine trees at the study site. The Douglas-fir trees at the Bull Mountain site displayed a mean radial growth increase of 68% (.55mm) after the outbreak of Mountain pine beetle in the 1970ís (Fig. 3). Lodgepole pine trees show an increase of 58% (.51mm) in mean radial growth from the same time period (Fig.4). In the Bull Mountain site 52% of Douglas-fir trees show a growth response in the five years after the mountain pine beetle outbreak in the 1970ís (Fig. 5a) as compared to 70% of the remaining lodgepole pine (Fig.5b).

Discussion

We identified five historic periods of release in the Douglas fir chronologies prior to the known outbreak in the 1970ís (1762, 1786, 1860, 1900 and 1921 (Fig. 1)) and two in the lodgepole pine chronologies (1860ís and 1939 (Fig. 2)). The most striking response to the outbreaks was the release of previously suppressed individuals of Douglas fir and surviving lodgepole pine. Following the outbreaks, growth rates for both species have remained high for > 20 years. The importance of accelerated growth as opposed to new seedling establishment following a MPB outbreak is a major contrast to what is usually observed following fires (Veblen 1986, Aplet *et al* 1988, Veblen *et al.* 1991). In particular fires in which few if any trees survive. Stand devastating fires favour regeneration of lodgepole pine and other shade intolerant species that regenerate quickly. However, MPB influence on forest ecosystems is similar to that of defoliating insects, which are known to improve the environment of surviving trees following an epidemic attack (Mattson and Addy 1975, Peterson 1978, Wickman 1978). In younger stands it is the veteran trees that are targets for beetle attack. When the older trees die, smaller, younger trees in the stand may respond to the increase in resources available for growth. The subsequent mortality of affected pine after a MPB outbreak permit the accelerated growth of small fir and spruce that result in a shift towards the shade-tolerant species. This pattern of disturbance-mediated acceleration of succession also occurs following blowdown of lodgepole pine-dominated stands (Peet 1981, Veblen et al. 1991). However, ecosystem responses following a bark beetle attack may be less rapid, because surviving trees may be old and unable to respond and because beetle-killed trees do not immediately drop their foliage (Waring and Pitman 1985).

Conclusion

By incorporating historical infestations into a model of anticipatory management a more strategic assessment can be obtained of the future biological, social and economic impacts of MPB outbreaks in the Cariboo forest region. Forests that are managed by a criteria that includes conservation of biodiversity, maintenance of forest productivity, maintenance of forest ecosystem health and conservation of soil and water resources exhibit greater abilities for quick recovery from MPB disturbances than stressed stands.

It is evident that the dynamic make up of the interior lodgepole pine forests has been modified by bark beetle-caused tree mortality. These forests have changed from lodgepole pine dominant forest ecosystems to co-dominant lodgepole pine /Douglas-fir ecosystems. In the Cariboo forest region, as in many other areas, this is a result of stand conditions out of balance due to fire suppression, harvesting and salvaging activities. As a result of this imbalance a responsible forest management strategy is required to manage bark beetle populations more actively than we have in the past. Also, current concepts of forest management require that both the biological diversity of the forests and a viable forest industry be maintained. These values are difficult to reconcile in light of the increasing area affected by insect outbreaks throughout the province of British Columbia (BC). A paradigm shift in our thinking from the common perception of bark beetles as unnatural pests to development of management solutions that incorporate an understanding of the bark beetle-caused tree mortality as part of ecological processes will permit successful prevention and suppression tactics.

Literature Cited

Aplet, G.H., Laven, R.D. and Smith, F.W. 1988. Patterns of community dynamics in Colorado, USA Engelmann spruce-subalpine for forests. Ecology: 69 (2): 312-319.

BC Ministry of Forests.2001 Province attacks mountain pine beetle-action plan released. BC Ministry of Forests News Release, Ref# 2001:099. Prince George.

Cole, W.E. and G.E. Amman. 1980. Mountain Pine Beetle Dynamics in Lodgepole Pine Forests. Part I: Course of an Infestation. Gen. Tech. Rep. INT-89. U.S.D.A. Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT.

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

Health, R. and R.I. Alfaro. 1990. Growth response in a Douglas-fir/lodgepole pine stand after thinning of lodgepole pine by the mountain pine beetle: A case study. J. of the Entomo. Soc. of British Columbia 87: 16-21.

Holmes, R. 1983. Computer-assisted quality control in tree-ring dating and measurement. Tree-Ring Bull. 43: 69-75.

Mattson, W.J. and N.D. Addy. 1975. Phytophagous insects as regulators of forest primary production. Science. 190: 515-522.

Peet, R.K. 1981. Forest vegetation of the Colorado Front Range. Vegetatio, 45: 3-75.

Peterman, R.M. 1978. The ecological role of mountain pine beetle in lodgepole pine forests. In: Theory and Practice of Mountain Pine Beetle Mangement I Lodgepole Pine Forests. Proceedings of a Symposium, April 25-27, 1978, Pullman, WA. U.S. Forest, Wildlife and Range Experiment Station, University of Idaho, Moscow, ID.

Safranyik, L., Shrimpton, D.M. and Whitney, H.S. 1974. Management of lodgepole pine to reduce losses from the mountain pine beetle. Forestry Technical Report 1. Environment Canada, Canadian Forest Service, Victoria, B.C.

Unger, L. 1993. Forest Pest Leaflet, Mountain Pine Beetle, 1996. Canadian-British Columbia Partnership Agreement on Forest Resource Development: FRDA II.

Veblen, T.T. 1986. Treefalls and the coexistence of conifers in subalpine forests of the central Rockies. Ecology, 67, 644-649.

Veblen, T.T., Hadley, K.S., Reid, M.S. and Rebertus, A.J. 1991b. The response of subalpine forests to spruce beetle outbreak in Colorado. Ecology 72: 213-231.

Waring, R.H. and Pitman G.B. 1985. Modifying lodgepole pine stands to change susceptibility to mountain pine beetle. *Ecology*, 66(3): 889-897.

Wickman, B.E. 1978. A case study of a Douglas-fir tussock moth outbreak and stand conditions 10 years later. United States Forest Research Paper. PNW-244.

Wood, C.S. and Unger, L. 1996. Mountain Pine Beetle. A history of outbreaks in pine forests in British Columbia, 1910 to 1995. Forest Health Network, Natural Resources Canada, Canadian Forest Service, Victoria, B.C.

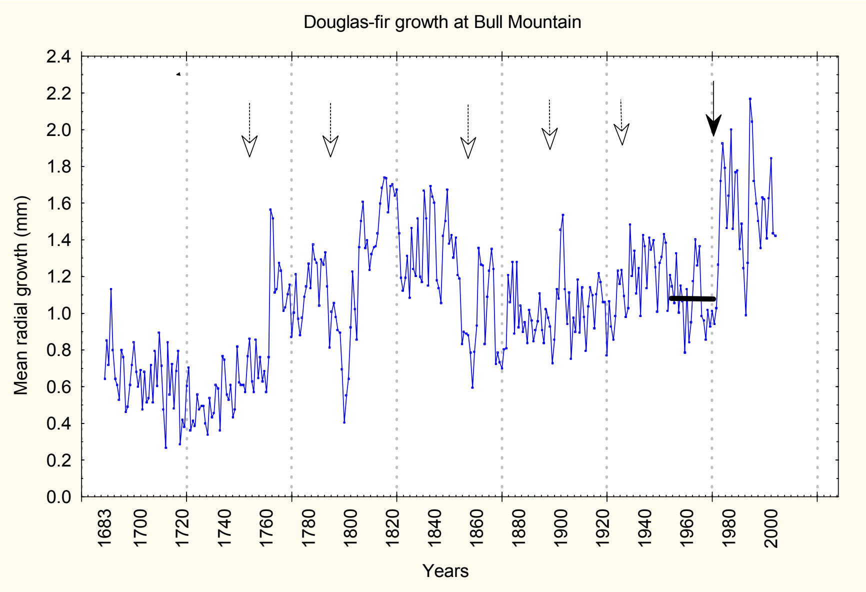


Fig.1. Recurrence of Mountain Pine Beetle at Bull Mtn. near Williams Lake, BC. Tree rings from surviving Douglas-fir trees show a period of release after each episode of bark beetle (indicated by arrows), which killed the lodgepole pine. The last beetle outbreak (1970ís, solid arrow) was fully documented by Heath and Alfaro (1990) and shows a sustained release with respect to the twenty year growth average which preceded the outbreak (horizontal bar). Inferred outbreaks occurred in 1762, 1786 1860, 1900 and 1921 (open arrows).

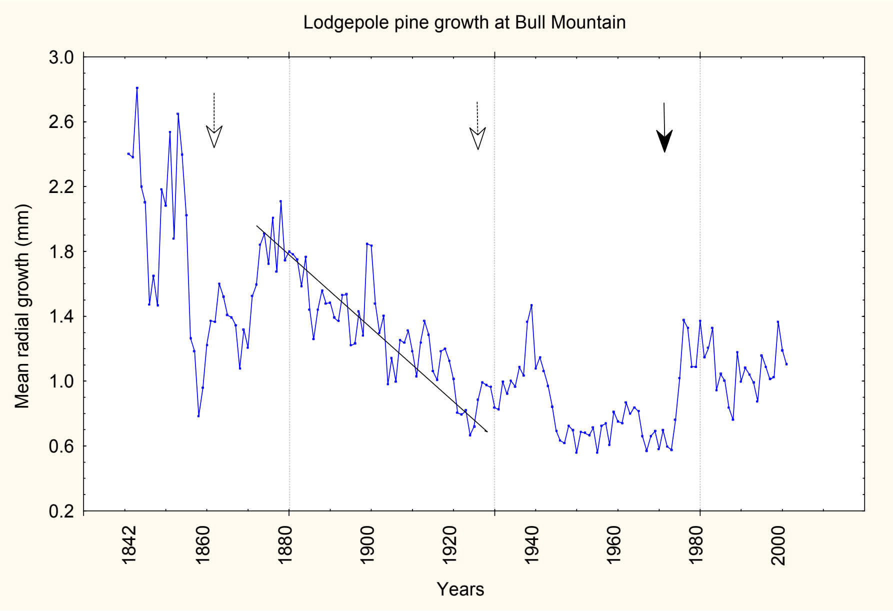


Fig. 2. Recurrence of Mountain Pine Beetle at Bull Mtn. near Williams Lake, BC. Tree rings from surviving lodgepole pine trees show a period of release after each episode of bark beetle, which killed the lodgepole pine. The last beetle outbreak (1970ís, solid arrow) was fully documented by Heath and Alfaro (1990) and shows a sustained release with respect to the twenty year growth average which preceded the outbreak (horizontal bar). Inferred outbreaks occurred in 1860ís and late 1930ís (open arrow).

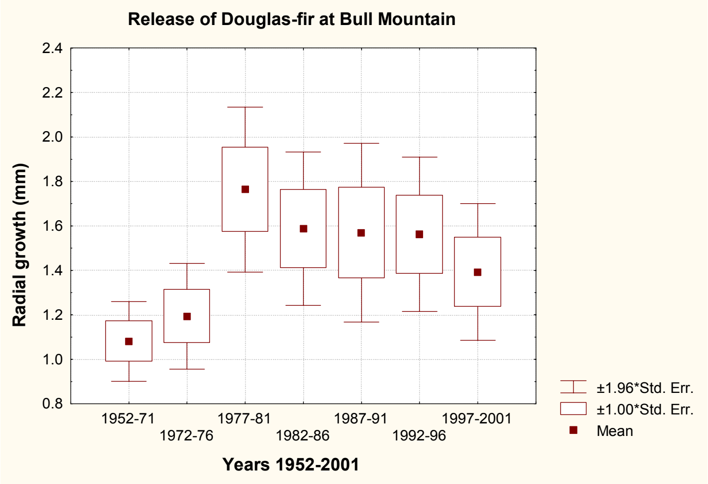


Fig. 3. Mean radial growth of Douglas-fir trees at Bull Mountain. near Williams Lake, BC between 1952-2001.

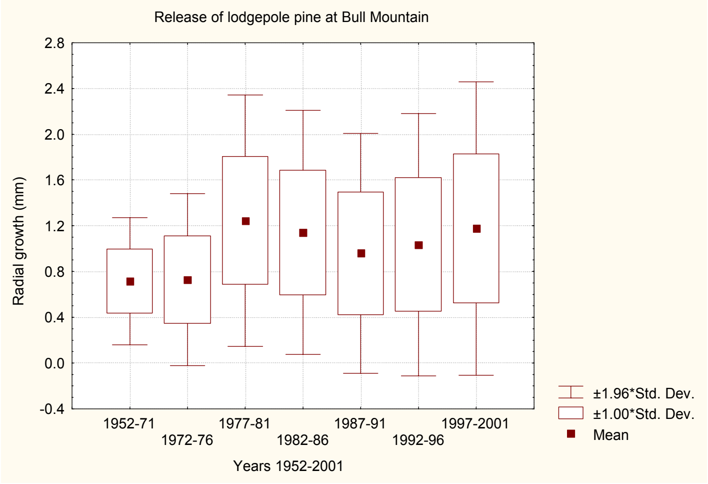
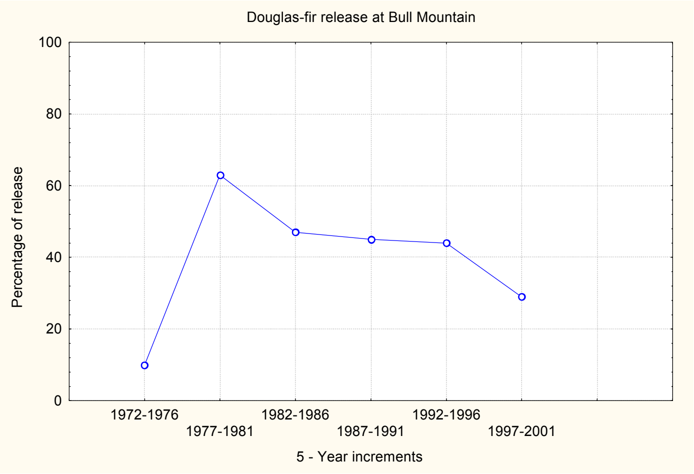
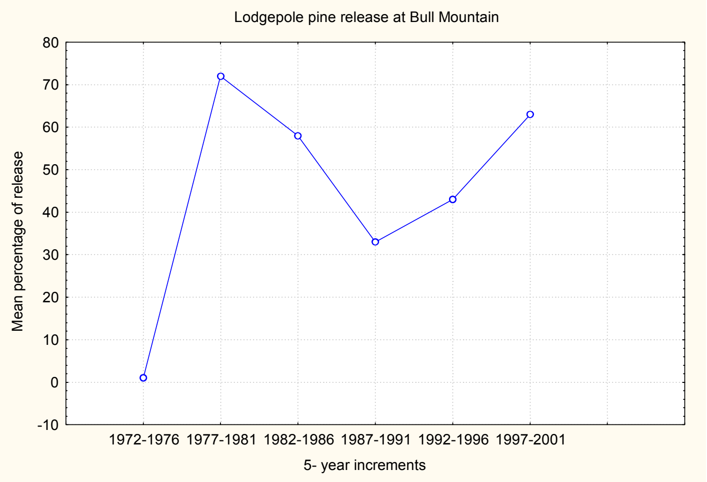


Fig. 4. Mean radial growth of lodgepole pine trees at Bull Mountain near Williams Lake, BC between 1952-2001.



a.



b.

Fig. 5. Percentage of trees Douglas-fir (a) and lodgepole pine (b) that show a growth response during the 1976 mountain pine beetle outbreak.