Disturbance, Forest Age, and Mountain Pine Beetle Outbreak Dynamics in BC: A Historical Perspective

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Abstract

During the past 85 years, there have been four large-scale outbreaks by the mountain pine beetle (*Dendroctonus ponderosae*) in the pine forests of British Columbia. Using contemporary forest inventory data in combination with wildfire and logging statistics, we developed a simple age-class projection model to estimate changes in pine age-class distribution between 1910 and 2110. We compared past and present mountain pine beetle activity to forest age structure, and projected future forest conditions relevant to mountain pine beetle susceptibility. "Backcast" forest conditions suggest that during the early 1900s, approximately 17% of pine stands were in age classes susceptible to mountain pine beetle attack. Since then, the amount of area burned by wildfire in British Columbia has significantly decreased. This reduction in wildfire has resulted in an increase in the average age of pine stands to the present day such that approximately 55% of pine forests are in age classes considered susceptible to mountain pine beetle. At the present rate of disturbance, average stand age is forecast to continue to increase, but the amount of susceptible pine will decline following 2010 and stabilize at about 18% by 2110. The extent of mountain pine beetle outbreaks was correlated with the increase in amount of susceptible pine during 1920-2000. However, outbreak extent increased at a greater rate than the increase in susceptible forest indicating that other factors such as climate may be affecting mountain pine beetle epidemics. Theoretical fire-return cycles of 40 - 200 years would generate a long-term average susceptibility range of 17% - 25% over large areas. This suggests that the extent of age-related, mountain pine beetle-susceptible pine forests in British Columbia is beyond the natural range of variability at a provincial scale.

Introduction

In forests originating from age-independent stand-replacing disturbance processes such as wild fire, the rate of disturbance is the key determinant of forest age dynamics. Where fires occur randomly in space at a more or less constant rate, and stands have an equal probability of burning irrespective of age and location, forest age structure will reach a steady state approximated by the negative exponential distribution (Van Wagner 1978; Li and Barclay 2001). By contrast, in forests where tree age- or size-

dependent disturbance processes predominate, such as clearcut harvesting or forest insect mortality, the forest age structure determines the maximum potential disturbance rate. No matter the type or pattern of disturbance, forest age distributions can be seen as exhibiting a kind of ecological memory (Peterson 2002). Therefore, when switching between age-independent and age-dependent disturbance regimes it may be many decades before the forest age structure reaches a new quasi-steady state.

Although logging began in British Columbia (BC) over 100 years ago, our forests are still in transition from an unmanaged state influenced by various natural disturbance processes to a managed condition in which we attempt to suppress natural disturbances and impose forest harvesting as the dominant disturbance regime. In the lodgepole pine forests of BC, the effects of changing the disturbance regime are playing out on a vast scale.

Pine stands cover some 14 million hectares of forest land in BC (British Columbia Ministry of Forests 1995). Five pine species, lodgepole, ponderosa, western white, whitebark, and limber occur in BC but lodgepole pine is by far the most abundant by area. Lodgepole pine stands in BC are almost entirely of fire origin and principally from stand replacing crown fires, although there is evidence of a surface fire regime in lodgepole pine stands on the dry, cold Chilcotin plateau in central BC (unpubl. data). Lodgepole pine trees are easily killed by fire; however, in the process seeds are released from serotinous cones. Following crown fires where the majority of trees are killed, virtually even-aged pine stands are usually re-established within a few years. Fire frequency varies throughout the range of lodgepole pine from less than 100 years to over 500 years (Brown 1975). Based on an analysis of forest inventory data, Smith (1981) suggested that the average fire-cycle in lodgepole pine forests in BC was about 60 years.

Forest fire suppression began in BC approximately 100 years ago. The effectiveness of fire suppression is widely believed to have increased in the 1960s. By 2002, the BC Ministry of Forests average annual initial attack success rate (fires constrained to < 4 ha in size) was 95% (1992-2002 average)[1]. Logging of lodgepole pine began for railway ties also about 100 years ago but large-scale exploitation for lumber and pulp did not occur until the 1960s. Consequently the disturbance rate across the vast pine forests of BC has been greatly reduced from the pre-management level.

Mountain pine beetle is also a major cause of mortality in lodgepole pine. For a mountain pine beetle outbreak to develop, two requirements must be satisfied. First, there must be a sustained period of favourable weather over several years (Safranyik 1978). Factors including summer heat accumulation, winter minimum temperatures, weather conditions during the dispersal period and water deficit influence mountain pine beetle populations directly through impacts on beetle survival, and/or indirectly through influences to host-tree quality/resistance (Safranyik et al. 1975; Carroll et al., 2004). In areas where summer heat accumulation is limited or where winter minimum temperatures are below a critical threshold, mountain pine beetle infestations cannot establish and persist (see Carroll et al.2004).

The second requirement for outbreak development is that there must be an abundance of susceptible host trees (Safranyik 1978). Since mountain pine beetle larvae develop within the phloem tissue of their hosts, large-diameter trees with their thicker phloem are the optimal resource for the beetle (e.g., Amman 1972). Shore and Safranyik (1992) have shown that once lodgepole pine stands reach 80 years old they are generally the most susceptible to mountain pine beetle. However, senescing or unthrifty trees tend to have thinner phloem and are thereby less suitable to mountain pine beetle (e.g., Berryman 1982). Thus, within areas that are climatically benign for mountain pine beetle, forest age-class structure will be the primary factor influencing host susceptibility and outbreak severity.

Mountain pine beetle infestations have been recorded in southwestern Canada for about 85 years. In 2003, approximately 4 million ha of pine forests in BC were infested by the mountain pine beetle (*Dendroctonus ponderosae* Hopk.) (Ebata, 2004).

A better understanding of the historical context of the present epidemic and of the lodgepole pine forest may help to direct longer-term management strategies. In this paper we review the historical distribution of mountain pine beetle infestations in BC, explore links between disturbance and host

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[1] BC Ministry of Forests Protection Branch web site www.for.gov.bc.ca/protect/suppression/

susceptibility to mountain pine beetle, and present a simple age-class projection model to explore the influence of decreased forest fire and other disturbances on the amount of mountain pine beetle-susceptible pine forests.

Historical Mountain Pine Beetle Activity

The mountain pine beetle has been present in BC's forests for millennia. Evidence of mountain pine beetle infestations from many decades ago has been found directly in lesions on lodgepole pine trees, and dendrochronological studies suggest significant outbreaks from previous centuries (see Alfaro et al., 2004). Mountain pine beetle outbreaks were observed directly in the early 1900s by J.M. Swaine (the first Dominion Entomologist) during field surveys in western Canada. Following the establishment of the Dominion Forest Biology Lab in Vernon in 1919, significant outbreaks occurring in southern BC were surveyed and mapped.

In 1959, the Canadian Forest Service, Forest Insect and Disease Survey (FIDS) implemented annual systematic province-wide aerial overview surveys of forest insect outbreaks. Infestations were classified into "low", "moderate" and "high" severity classes corresponding to <10%, 10-30% and >30% attacked (i.e., red) trees, respectively. The extent of infestations and damage were mapped and summarized each year until 1996. Subsequently, the BC Ministry of Forests took over this function and has carried out annual overview forest health surveys since 1999. In 2001, we completed digitizing the historical mountain pine beetle outbreak records. The annual overview maps can be viewed at: www.for.gov.bc.ca/hfp/FORSITE/overview/webmap.htm; and in animated form at www.pfc.cfs.nrcan.gc.ca/entomology/mpb/historical/index_e.html.

The total cumulative area infested by mountain pine beetle between 1959 and 2002 (i.e., up to and including attacks during 2001) was approximately 4.5 million ha. Of this, 35%, 25% and 40% of the infested area fell in low, moderate and high severity classes, respectively.

Infestations are summarized by decade in Figure 1 overlayed upon the distribution of stands in which pine species predominate [derived from the 1994 Forest, Range, and Recreation Resource Analysis (British Columbia Ministry of Forests 1995); see below].

Some highlights of recorded infestations in BC [updated from detailed reviews by Powell (1966) and Wood and Unger (1996)] are given below:

1) Significant outbreaks in the 1920s were recorded around Aspen Grove and in the Kettle Valley in lodgepole and ponderosa pine.
2) In the 1930s and 40s large areas of mountain pine beetle-caused mortality were recorded in Kootenay and Banff National Parks. Smaller infestations were recorded in western white pine in the Shuswap region and in coastal BC.
3) During the 1950s and 60s, one of the longest duration outbreaks ever recorded (18 years) was observed around Babine Lake and Stuart Lake in north-central BC. A smaller infestation was observed in shore pine (*Pinus contorta* var *contorta*) on Vancouver Island.
4) Major infestations developed in the 1970s and 1980s on the Chilcotin plateau and in southeastern BC.
5) During the 1990s, the present outbreak began to develop in north central BC and is the largest recorded outbreak to date.

In total, the forest insect survey records indicate that there have been four to five significant outbreak periods in BC during the last century. They also suggest that mountain pine beetle outbreaks have been increasing in the total area affected over time. However, infestations have not occurred throughout the full range of the beetle's primary host, lodgepole pine (see Fig. 1).
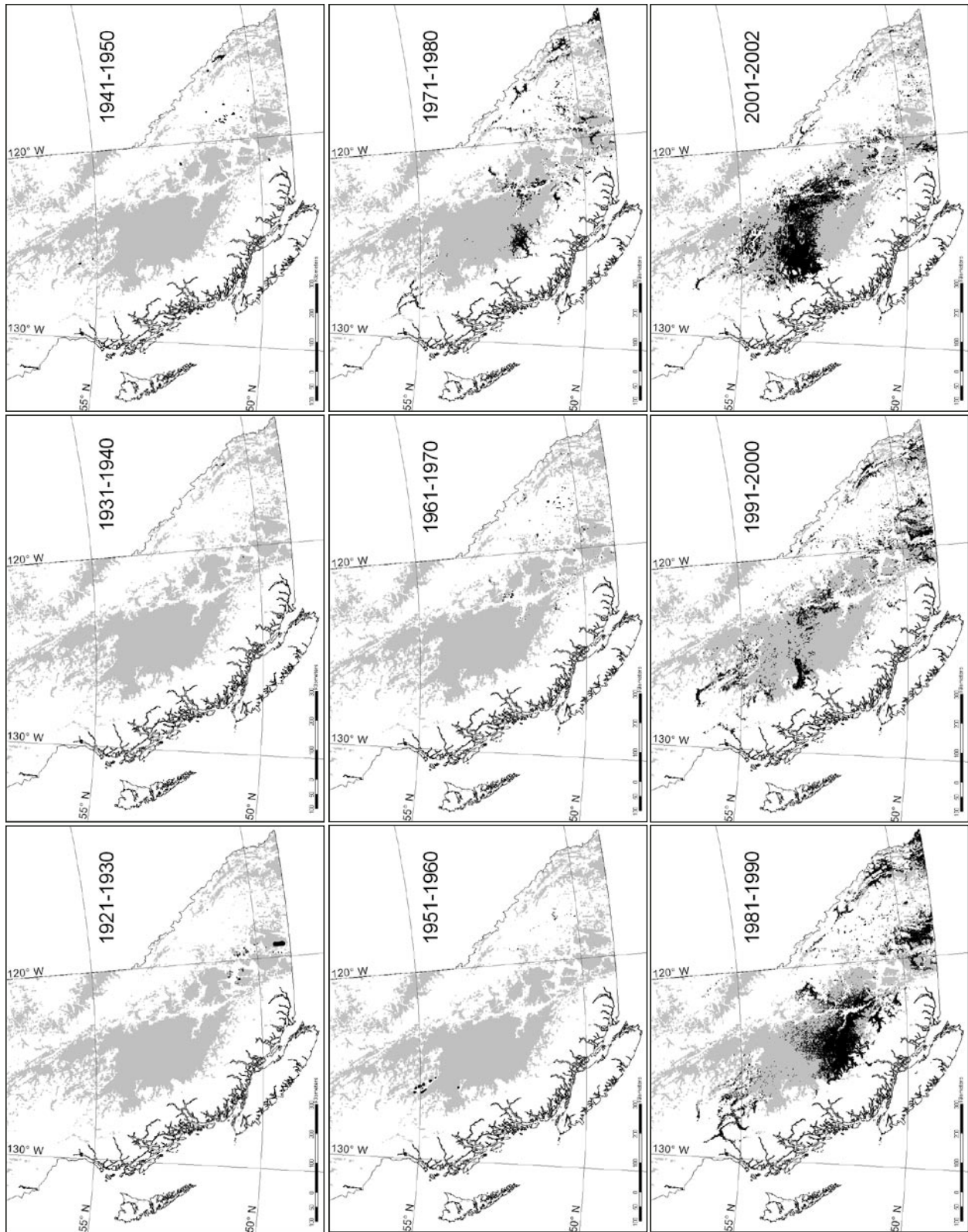
Figure 1. Historical distribution of mountain pine beetle infestations (black) overlaid on pine distribution (gray) in British Columbia during 1920-2002 from forest insect survey records.

Forest Fire Cycle Length and Forest Susceptibility to Mountain Pine Beetle

We suggest that before management, lodgepole pine forest susceptibility to mountain pine beetle would have been controlled by the forest fire regime, principally the fire cycle length. By constraining the window of age-related susceptibility to mountain pine beetle for lodgepole pine between 80 and 160 years (the latter due to thinning phloem associated with senescence) and applying it to various negative exponential age distributions resulting from different fire cycle lengths, we can see that the proportion of stands susceptible to mountain pine beetle increases with fire cycle length to a maximum of 25% with a 120-year fire-return cycle, and then declines (Fig. 2).
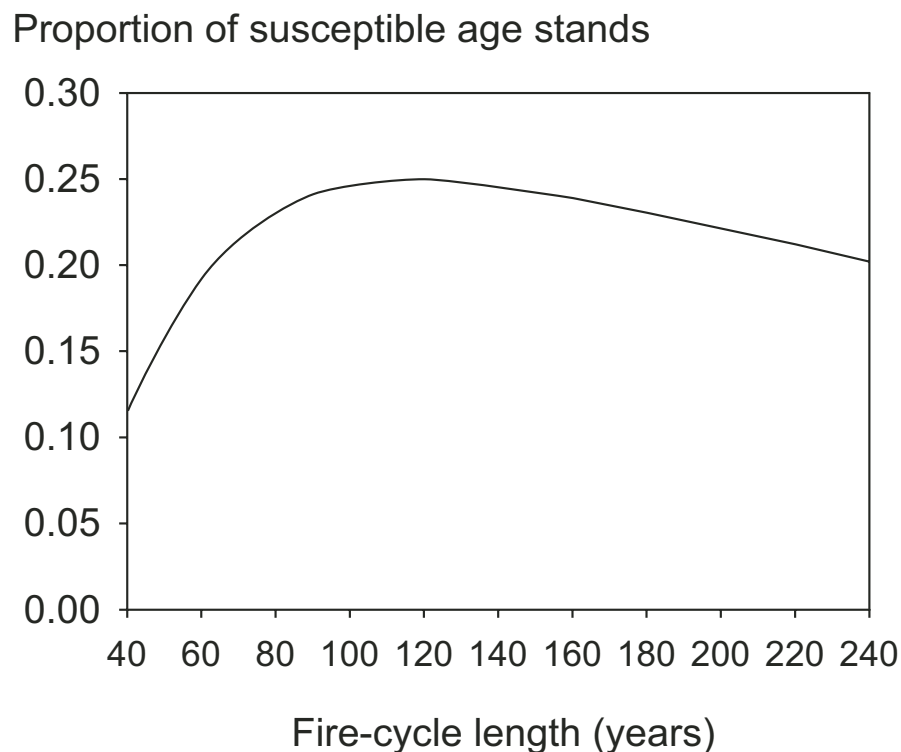
Proportion of susceptible age stands

Figure 2. Relationship between fire-cycle length and the proportion of stands susceptible to mountain pine beetle in forests with a negative exponential age-class distribution.

Examples of age distributions for 60- and 100-year fire-return cycles and a "normal" fully regulated forest[2] with a 100-year rotation length are shown in Figure 3. On average, approximately 17%-25% of stands in a lodgepole pine forest would be in age classes susceptible to mountain pine beetle in a wildfire-dominated disturbance regime with fire-return intervals between 40 and 200 years. This proportion might be exceeded on a regional basis where there is deviation from the negative exponential age-class distribution because of spatial and temporal auto-correlation in wildfire occurrence (e.g., Andison 1996).

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[2] The "normal" forest is an even-aged forest with an equal amount of area by age class to a fixed rotation age, that is, a rectangular distribution. While rarely achieved, it is the most simple and fully regulated condition and a useful model for comparison.
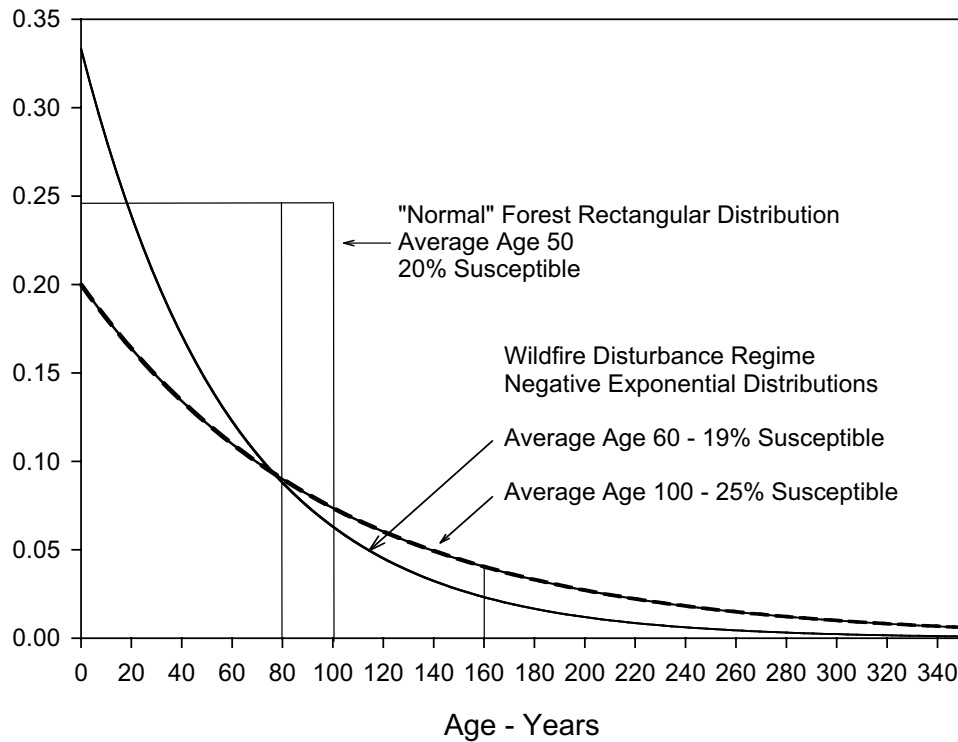
Figure 3. Theoretical distribution of age classes susceptible to mountain pine beetle in a normal forest with a 100-year rotation, and in forests with 60- and 100-year fire cycles.

Modelling Historic Forest Age Distribution and Susceptibility to Mountain Pine Beetle

To assess past and present mountain pine beetle activity in relation to forest age structure, and examine projected future forest conditions relevant to mountain pine beetle, we developed a simple age-class projection model to estimate changes in pine age-class distribution in BC from 1910 to 2110. Two disturbance types, wildfire and logging, were included in the simulation. Pine age class data were extracted from the 1994 Forest, Range, and Recreation Resource Analysis (FRRRA) (British Columbia Ministry of Forests 1994) for the 1990 base year. The age data were in 20 year classes from 0-140 years, 140-250 years and >250 years. The 140-250 year age-class polygons were randomly reassigned to new 20-year age classes between 140-240 years. It was assumed that 45.0%, 29.5%, 19.5%, 2.5% and 1% of stands in the 140-250 age class were in the 140-160, 160-180, 180-200, 200-220, and 220-240 age classes, respectively. Andison (1996) derived these proportions by field sampling the stand age of approximately 100 stands between 140 and 250 years old in west-central BC.

The total amount of disturbed area in pine forests was estimated in 20-year periods for the 80 years 1910-1990 from age-class data (assuming that pine forests regenerated immediately following disturbance) modified by disturbance estimates using a backcasting method as follows. Beginning in 1990, the amount of area in each age class was estimated for the prior 20-year period by taking the amount of area disturbed in that time step (the current 0-20 year class) and redistributing it across the other age classes. Wildfires were assumed to occur across all age classes in proportion to the area in each class. Logging was assumed to occur in ≥100-year age classes only and in proportion to the area in each 20-year age class.

The area disturbed by fire in pine forests in BC between 1919-2000 was determined by intersecting coverage of wildfire boundaries in the BC digital fire atlas with the FRRRA pine coverage using a GIS. There is a strong trend in decreasing area burned in pine-dominated forests (Fig. 4).

The area logged between 1910-1990 was then determined as the difference between the total disturbed area and the burned area, except where historical records indicated that there was no appreciable logging of pine. In forecasting beyond 1990, the age of areas in each age cohort were incremented by 20 years in each time step. It was assumed that the disturbance rate and ratios beyond 1990 were constant and unchanged from the 1970-90 period.

The results of our age class modelling suggest that the amount of pine within the age classes most susceptible to mountain pine beetle has increased from about 18% to 53% between 1910-1990 (Fig. 5).
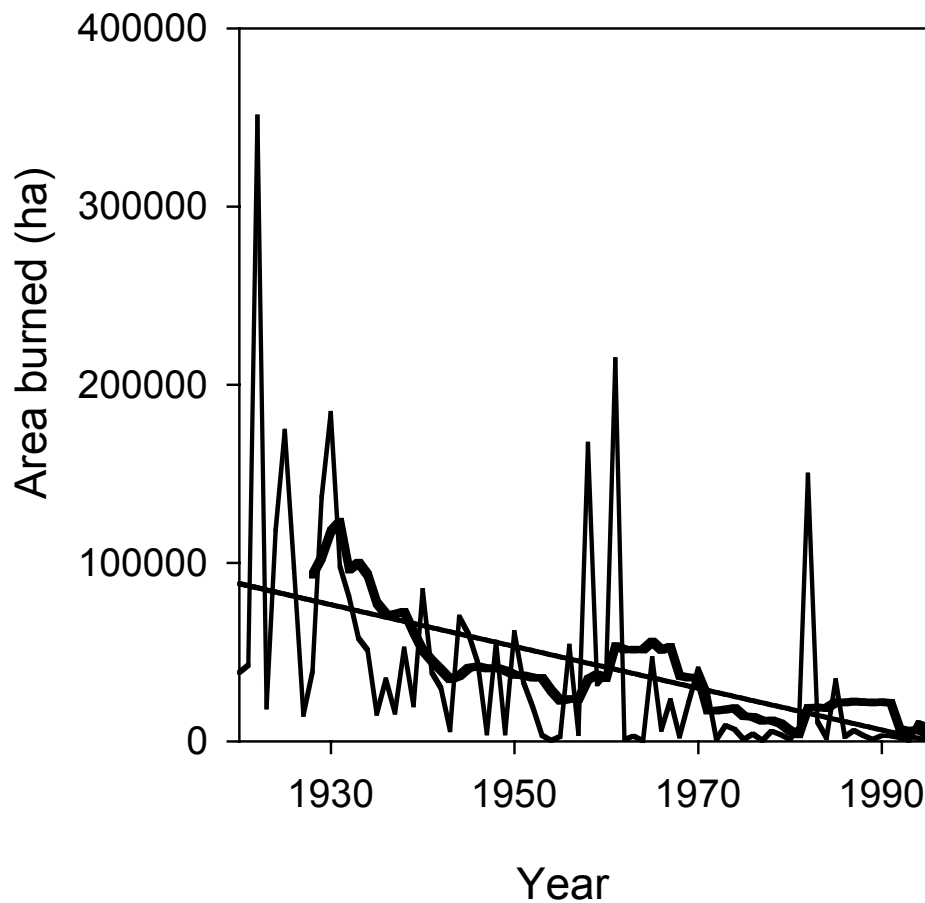

Figure 4. Area burned by forest fires during 1920-1995 in pine-dominated forests in BC. Annual area burned (solid line), ten-year running average (bold line) and linear regression model (straight line).
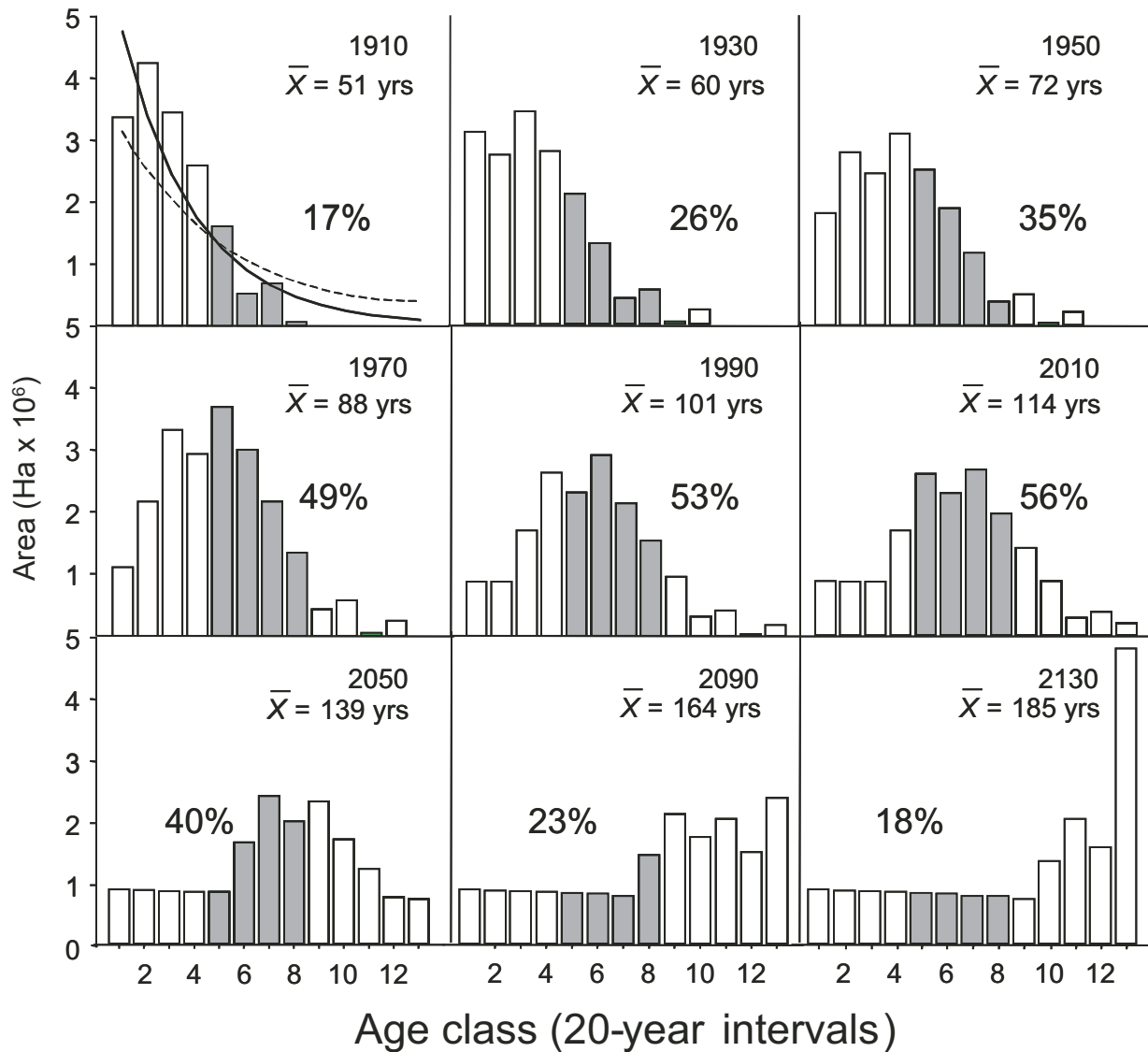
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Figure 5. Age class distribution of pine forests in BC projected from 1990 inventory data. Age classes susceptible to mountain pine beetle are shaded (percentage of total provided). The theoretical age distribution resulting from a 60- (solid line) and 100-year (dashed line) fire cycle is shown in the 1910 plot.

The projected future conditions suggest that average stand age will continue to increase under the present disturbance regime until approximately 2010, after which the proportion of susceptible pine is projected to decline to near 1910-levels by 2130 and stabilize at about 18% (Fig. 5).

Plotting the annual mountain pine beetle outbreak area against the amount of susceptible pine suggests that mountain pine beetle activity was positively correlated with the increase in the amount of susceptible pine (Fig. 6).

However, the average infestation area has increased sharply since 1980 and at a greater rate than the increase in the amount of susceptible pine. This suggests that other factors such as climate that may have been limiting in the past have also become more favorable for mountain pine beetle epidemics (Carroll et al. 2004).
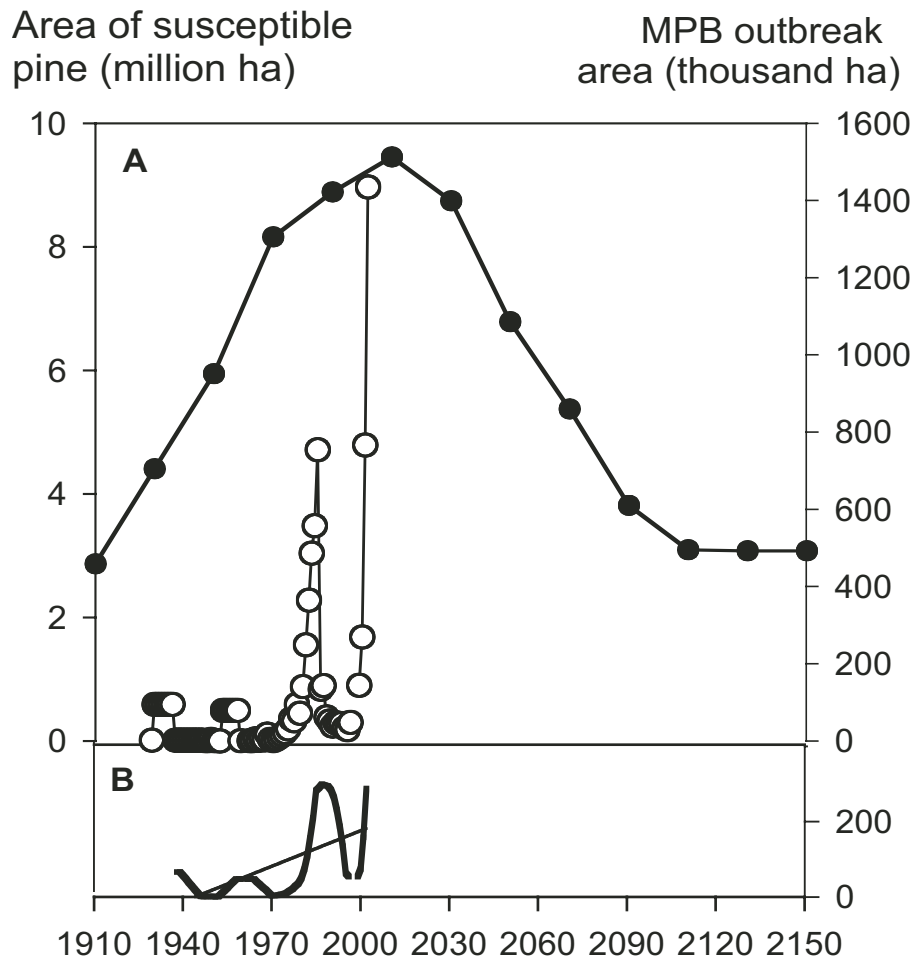
Figure 6. A). Estimated area of mountain pine beetle-susceptible pine (solid circles - million ha)
and of mountain pine beetle (MPB) outbreaks (empty circles - thousand ha) in BC.
B) Ten-year running average mountain pine beetle outbreak area and linear regression
model (thousand ha). Gap is a result of no survey conducted in 1997 and 1998.

Conclusions

There have been at least four major mountain pine beetle outbreaks during the last 85 years. Mountain pine beetle infestations have been observed in all species of pine, but they are principally found in lodgepole pine and infestation size appears to be increasing. The size of mountain pine beetle infestations varies with short-term changes in weather and long-term changes in host availability. In unmanaged forests with a natural fire regime, the average proportion of mountain pine beetle-susceptible stands would reach a maximum of 25% given a 100- to 120-year fire-return cycle, declining with more- or less-frequent fires (Fig. 2).

Clutter et al. (1983) state that if the harvest in a fully regulated forest is changed to a new level there are three possible outcomes:
1) The forest structure will reach a new steady state;
2) The forest will be totally depleted;
3) The forest will become unmanaged (the amount of timber lost to natural mortality exceeds harvesting).

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The disturbance regime of the pine forests of central BC is in transition from a fire-dominated regime where disturbance is not strongly age-dependent, to a condition regulated mainly by harvesting of older stands at a lower rate. Backcasting suggests that a large pine age cohort originated around 1880-1920 in BC, in an amount consistent with a 60-year fire-cycle. With the introduction of fire management, these age cohorts have matured and are now susceptible to mountain pine beetle. At present, the forest age structure is in transition from an approximately negative exponential to an approximately rectangular distribution. Consequently, our analyses suggest that there was approximately three times more area of pine in BC in age classes susceptible to mountain pine beetle in 1990 when compared with backcast estimates for 1910. Currently, depletions by mountain pine beetle are exceeding depletions by harvesting. In time, given that disturbance rates remain relatively constant, a new quasi-steady state with lower susceptibility may be reached. More detailed modelling at a regional scale is needed to define possible future forest structures.

The area of mountain pine beetle infestations was correlated with the estimated amount of susceptible age pine between 1920 and 2000. At the present rate of disturbance, the mean pine forest age will continue to increase, although by 2010 forest age-susceptibility is projected to decline. This decline may be accelerated if the current mountain pine beetle outbreak depletes much of the available host. There may not be a corresponding decline in outbreak severity if climate factors become less limiting in the next decades and the available habitat expands.

Safranyik (2004) suggests that in the long term our focus should be on management of lodgepole pine, not on management of the mountain pine beetle. Understanding the factors influencing lodgepole pine forest dynamics is critical to understanding host susceptibility to developing a long-term management strategy.

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