

Weather associated with the start of mountain pine beetle outbreaks

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Extreme weather conditions associated with mountain pine beetle outbreaks were evaluated by graphical techniques for six locations throughout British Columbia. Three major associations of extreme weather patterns with lodgepole pine growth and mountain pine beetle outbreaks were identified. (i) Weather effects prior to, or early in, the growing season can reduce growth without releasing the beetle population. (ii) Weather conducive to beetle establishment and early brood development can occur too late in the season to have a noticeable effect on tree growth and therefore will not be recorded in the annual growth rings. (iii) Warm, dry periods during the summer are associated with tree growth reduction and the beginnings of outbreaks. In each of these three cases, extreme low precipitation levels were involved. Average precipitation in some months did not compensate for the effects of unfavourable extremes in other months on tree growth.

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Des conditions climatiques extrêmes associées avec le début des infestations du Dendroctone du Pin évaluées, utilisant des techniques graphiques pour six endroits en Colombie-Britannique. Trois associations majeures furent identifiées entre différents types de conditions climatiques extrêmes, le taux de croissance du Pin taxifolié et le début d'infestation du Dendroctone du Pin. (i) Les conditions climatiques avant ou au début de la saison de croissance peuvent avoir pour effet de réduire la croissance sans stimuler la population de Dendroctones. (ii) Des conditions climatiques propices à l'établissement du Dendroctone et à un développement précoce de la couvée peuvent survenir trop tard dans la saison de croissance pour avoir un effet notable sur la croissance de l'arbre et l'effet sera indiscernable dans les cernes annuels. (iii) Les périodes de temps sec et chaud au cours de l'été sont associées à une réduction de la croissance de l'arbre et à des débuts d'infestations. Dans chaque cas, des précipitations extrêmement faibles étaient en cause. Les précipitations moyennes de certains mois n'ont pas compensé les effets sur la croissance des arbres des précipitations extrêmes défavorables d'autres mois.

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Introduction

The mountain pine beetle (MPB), *Dendroctonus ponderosae* Hopkins, is a univoltine species with a relatively well-defined period during which maturation of new adults, attack, and establishment occur. Maturation generally occurs in June and July, with attack and gallery establishment in late July and August, sometimes extending into September. However, the exact timing varies by a few weeks from year to year and from location to location, depending on the weather pattern, since development requires accumulation of a specific number of heat units (Safranyik 1978).

Success of the attack and gallery establishment is greatly influenced by the wound response of the host. The wound response of lodgepole pine, *Pinus contorta* Dougl. var. *latifolia* Engelm., includes secretion of resin (Reid *et al.* 1967) which, in sufficient quantities, is a major mortality factor of MPB. With high resin flow, the beetles are less successful in gallery construction and may even leave (Amman 1975). When heavy resin flow occurs during egg hatch and early larval development, either as a result of protracted production or of delayed onset of resin flow, high mortality of eggs (Reid and Gates 1970) and larvae (Berryman 1976) also results. In addition, the resin-soaked material is nutritionally depleted and may be unsuitable for development of surviving larvae (Shrimpton 1973a). Moisture stress can reduce wound healing (Puritch and Mullick 1975).

Resin production is positively correlated with radial growth rate (Shrimpton 1973b); fertilizer application increases both growth rate and resistance to bark beetles (Merker 1967). As

trees age, the change in current annual increment parallels the ability of trees to produce a strong resinous response to attack (Safranyik *et al.* 1974).

Shrimpton and Thomson (1981, 1983) showed that MPB outbreaks occurred after the attainment of physiological maturity in six widely separated areas; i.e., at a time when radial growth was generally declining.

During endemic periods, the mountain pine beetle attacks weakened lodgepole pine (Craighead *et al.* 1931); drought has long been considered a major stress factor contributing to outbreaks of the beetle (Hopping and Mathers 1945). In the growth patterns illustrated by Shrimpton and Thomson (1983), outbreaks in some areas were associated with periods of unusually low growth rates similar to the pattern of growth generally associated with drought conditions. In other areas, the outbreaks were associated with small fluctuations in growth below the average. Not all periods of reduce growth were associated with an outbreak.

There were three objectives of the present study: (i) to examine the weather pattern associated with the start of MPB outbreaks, to test the hypothesis that weather in an outbreak year or the year preceding an outbreak exhibits a common, unique feature in all areas and outbreaks studied; (ii) if the weather hypothesis is supported, to investigate the timing, duration, and frequency of such a feature; and (iii) to explain the observed pattern of radial growth and MPB outbreaks in relation to the unique feature of the weather pattern.

Implicit in the above hypothesis is the assumption that, although endemic MPB populations may fluctuate from year to year in relation to weather, an extreme departure from the normal pattern is required to modify the population dynamics

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sufficiently to release the population from its normal regulating agents.

Although the importance of the blue stain fungi (*Ceratocystis montia* Rumb. and *Europhium clavigerum* Robinson and Davidson) is recognized (Safiranyik *et al.* 1975), fungal dynamics were not considered in the present analysis. Weather may enhance the detrimental effect of those fungi on the tree, or increase the beetle population through improved nutrition resulting from increased fungal growth. Moisture stress results in an increase in soluble nitrogenous compounds and soluble sugars (Parker 1968). The presence of these nutrients in soluble form should enhance the rate of fungal growth (Merrill and Cowling 1966).

Royama (1978) indicates that statistical tests of weather relationships may lead to spurious correlations and recommends the use of graphical techniques to evaluate weather effects. This is especially true for the effects of occasional very extreme years as in the present study, where we are not attempting to quantify a relationship but rather to establish the nature of the relationship. The present study is therefore based on graphical procedures, similar to a study of weather effects on western spruce budworm, *Choristoneura occidentalis* (Freeman) (Thomson *et al.* 1984).

Methods

The six study sites and methods of tree sampling and stem analysis were described in Shrimpton and Thomson (1983). Records of monthly precipitation and average temperature were obtained for the period 1930–1979 from the closest weather stations to the study sites. Big Creek weather records were used with the Riske Creek site, Vernon (Coldstream) records with Enderby, Princeton Airport records with Ashnola, and New Hazelton records with the Kispiox site. The Invermere weather station was used for both Golden and Invermere sites.

In each study site the outbreak had originated from a small nucleus of infested trees and had continued to spread. The year in which the small nucleus of trees was attacked was defined as the beginning of the outbreak (Pacific Forest Research Centre, survey records).

Long-term average precipitation and temperature for each station were summarized using climate diagrams or Climographs, which are plots of monthly average temperature versus monthly precipitation. The long term average has a characteristic trace. Climographs of years preceding outbreaks, outbreak years, and years of reduced radial growth were superimposed on the long-term average. Deviation from the long term pattern reflects the extremeness of the weather patterns.

Results

Relationship between weather and MPB outbreaks

Long-term average climographs for the five stations are illustrated in Fig. 1a–1e and indicate considerable differences between regions. Big Creek has dry winters and wet summers, while the reverse occurs at Princeton. Vernon and Invermere have a more even pattern of precipitation, while New Hazelton has dry springs and wet autumns.

Years preceding outbreaks (Figs. 1f–1j) were characterized by warm dry periods ranging in duration from 7 months (February–August) at Princeton and Big Creek, to a single month (August) at New Hazelton. Warm dry months were also associated with the outbreak years with the single exception of New Hazelton. Because monthly average temperatures are used, the standard deviation of temperature values for a particular month is small, and a difference of only 2–3°C from the average can represent a most extreme condition, e.g., August temperatures at New Hazelton in Fig. 2.

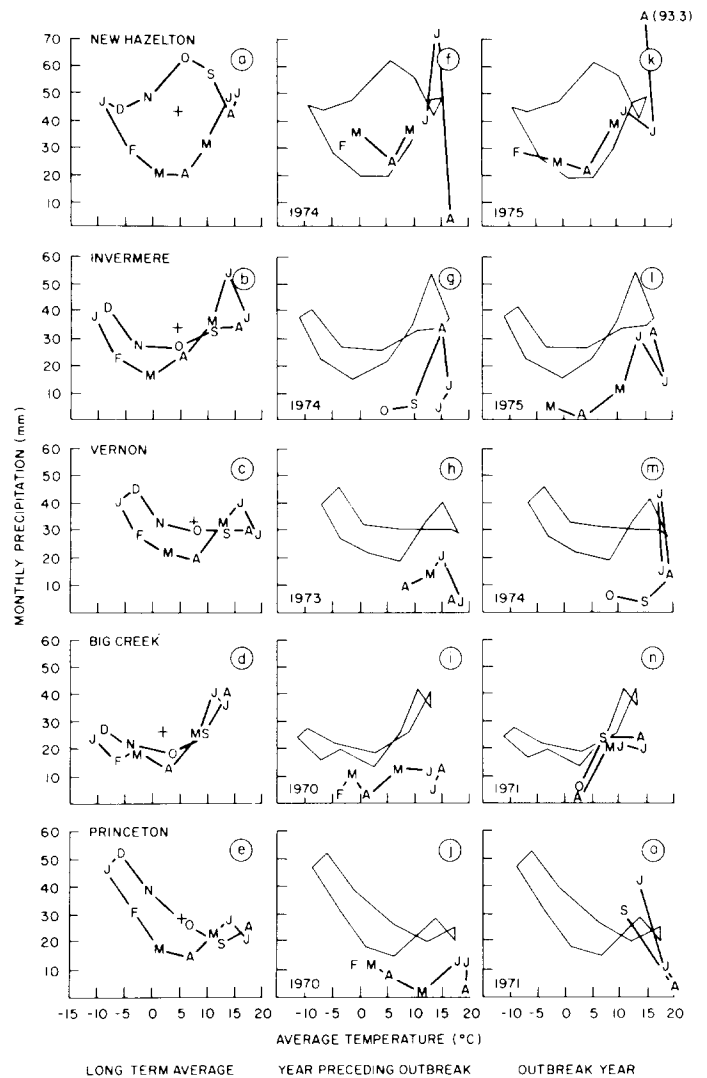


FIG. 1. (a–e) Climographs of long-term average precipitation for the months January (J) through December (D) for five weather stations. (f–j) Climographs of the pre-outbreak year and (k–o) for the outbreak year at each station, in relation to the long-term average. The annual average precipitation and temperature of the station are indicated by +.

The distribution of August precipitation and temperature levels at New Hazelton is illustrated in Fig. 2 for each year from 1930 to 1979 and is a representative example of the observed pattern of weather variability in general. The year 1974, which preceded the outbreak in this area, had one of the warmest, driest Augusts on record. Conditions earlier in the year were close to average, as were those in the early part of 1975, the year of outbreak (Figs. 1f, 1k). In 1963, which had an equally warm dry August, June and July were much wetter than average (66.0 and 99.5 mm, respectively) and no outbreaks occurred.

Weather effects on lodgepole pine growth

Extremely low precipitation levels in some or all the months May–August were associated with the periods of reduced growth in the Riske Creek, Princeton, and Enderby regions, e.g., 1970, the year of minimum growth at Princeton (Fig. 1j). A period of reduced growth in the New Hazelton region from 1954 to 1957 was associated with extreme cold and (or) dry months in the winter and early spring (Fig. 3). No MPB out-

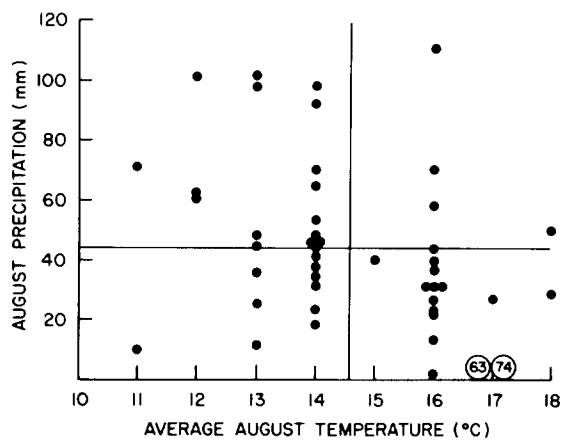


FIG. 2. Relationship of August temperature and precipitation at New Hazelton for the years 1930–1979, illustrating 1974 which preceded the outbreak and 1963 which did not precede an outbreak. The vertical line indicates mean temperature and the horizontal line mean precipitation.

break occurred at this time.

No relation between weather and the 1973 decline in growth at Golden was obvious, except that 1972, which preceded the decline, was one of the wettest years on record. The Golden plot was on a long gentle slope and the Invermere plot was about 25 m from a steep embankment. Differences in drainage may have ameliorated effects of this extreme precipitation at Invermere. Reduced growth in 1974 and 1975 was associated with low precipitation (Figs. 1g, 1f).

In all areas studied, precipitation close to average in some months did not appear to compensate for unfavourable effects of extremely low precipitation in other months and thus maintain high growth rates or reduce MPB outbreak probability.

Extreme dry conditions generally resulted in reduced growth. Extremely wet conditions were also associated with reduced growth. Peaks in growth often occurred in years where conditions throughout the growing season were close to the long-term average.

Discussion

Three types of climatic effect on lodgepole pine growth and its relationship to MPB outbreaks can be proposed. (i) Early growth can be reduced by climatic effects prior to or early in the growing season. However, if the climatic effects do not continue into the period when beetles attack trees, tree resistance is not affected, and no outbreak will result (e.g., Kispiox 1954–1959). (ii) Warm dry conditions toward the end of the growth period and extending into the autumn have a negligible effect on total radial growth. However, tree resistance will be lessened. This time period coincides with beetle establishment and the early stages of brood development. Warm dry conditions are beneficial to the beetles at these stages in the life cycle. Kispiox in 1974 illustrates this type of effect. (iii) Warm dry conditions during the summer are associated with reduced radial growth and will also lessen tree resistance. If the effects of the drought are still manifested late enough to coincide with the beetle attack and establishment in trees, the beginnings of an outbreak are associated with marked reductions in tree growth.

In all these cases, low precipitation levels are involved. The three types of responses indicate that radial growth may often correlate with the trees' resistance to MPB and therefore with

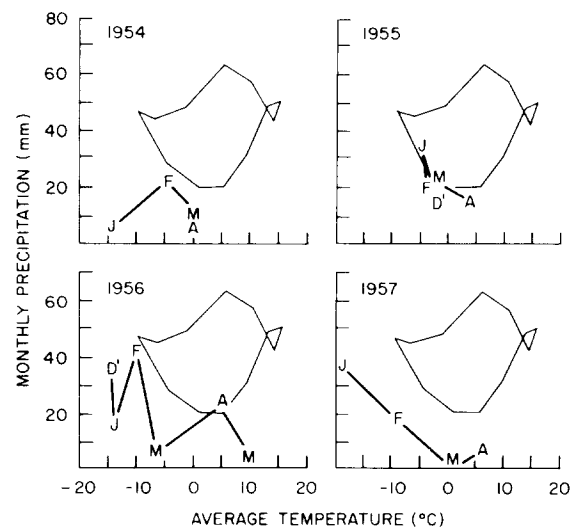


FIG. 3. Climographs for the years of reduced growth at New Hazelton emphasizing the cold and (or) dry conditions in winter and early spring.

the beginnings of an outbreak. The tree ring sequence, however, does not fully record historical periods of susceptibility. A hazard rating for MPB should therefore include both lodgepole pine growth rates and a measure of deviation of weather patterns from the long term average. Extremely dry conditions at the time of attack and gallery establishment are associated with outbreaks. The relative infrequency of such conditions may be estimated from long-term weather records. Incorporation of weather conditions at the time of establishment in the currently used hazard rating system (Safranyik *et al.* 1974, 1975), along with the time from physiological maturity of stands, should provide an improved and more stand-specific hazard rating system for damage from mountain pine beetle.

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