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Modeling lodgepole and jack pine vulnerability to mountain pine beetle expansion into the western Canadian boreal forest

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ABSTRACT

The mountain pine beetle (MPB) (*Dendroctonus ponderosae* Hopkins) outbreak in western North America is the largest recorded in history, impacting over 14 million ha of pine forests in British Columbia alone. Large regions in western North America have become more favorable to the MPB, which has extended its range into higher elevations and more northerly latitudes, previously considered climatically unsuitable. Various investigators, and recent forest health surveys in Alberta have suggested that the beetle's range could shift further east on both lodgepole (*Pinus contorta* Dougl.) and jack pine (*Pinus banksiana* Lamb.) into the boreal forest. A risk assessment of the threat of MPB to Canada's boreal forest identified effective monitoring and detection in areas vulnerable to infestation as the most critical information need.

Changing climate may also be independently impacting pine forests, for instance through moisture stress. Species' vulnerability to climate change is reflected in modeled increases or decreases in the probability of its presence across its range. We hypothesize that areas within the current ranges of lodgepole and jack pine that have historically been sub-optimal for beetle expansion may become increasingly vulnerable as a result of climate change. In our analysis, we first test the ability of physiologically-based models to predict the recorded distributions of lodgepole and jack pine for 12,456 ground plots across British Columbia, Alberta and Saskatchewan, using monthly climatic data derived for a calibration period between 1950 and 1975. Both the presence and absence of the two tree species recorded on survey plots were predicted, on average, with an accuracy of 85% for the calibration period. We then identified locations that appear to have become less suitable for these pine species in each subsequent year between 1976 and 2006 and found that the suitable range area for lodgepole and jack pine for >50% of years in the period decreased by 45% and 40%, respectively. These results were compared with outputs from a climate-suitability model that identified areas of potential range expansion by MPB for two periods: 2001–2030 and 2010–2040. The area of vulnerable lodgepole pine forests that coincided with the area of potential beetle expansion was 40,000 km^2 in 2001–2030 and 45,000 km^2 in 2010–2040. The area of vulnerable jack pine was much less, ranging from 4000 to 8000 km^2 for the two periods. This analysis is unique in that it acknowledges the complexity of the beetle–host interaction by incorporating the potential impact of climate change on each of these elements into predictions of future host susceptibility to infestation. Such information is vital for assessing the ongoing risk of MPB range expansion and for designing future monitoring programs.

1. Introduction

The current outbreak of the mountain pine beetle (MPB) (*Dendroctonus ponderosae* Hopkins (Coleoptera, Curculionidae)) in western North America is ten-times larger than any previously recorded (Wulder et al., 2010). This outbreak started in the mid-1990's and has spread to almost 14 million ha of pine forests in British Columbia alone (Wulder et al., 2010). The potential distribution of MPB covers a significant portion of western North America from Northern Mexico to central British Columbia in Canada, and east from the Pacific Coast to the Black Hills of South Dakota in the United States (Safranyik et al., 2010). The beetle can successfully attack a number of pine species; in western Canada; it principally infests lodgepole pine (*Pinus contorta* Dougl.) and to a lesser extent western white pine (*Pinus monticola* Douglas ex D. Don), ponderosa pine (*Pinus ponderosa* C. Lawson), and whitebark pine (*Pinus albicaulis* Engelm.). The distribution of MPB is determined by the occurrence of suitable host species and climatic conditions with the most recent outbreak attributed to range

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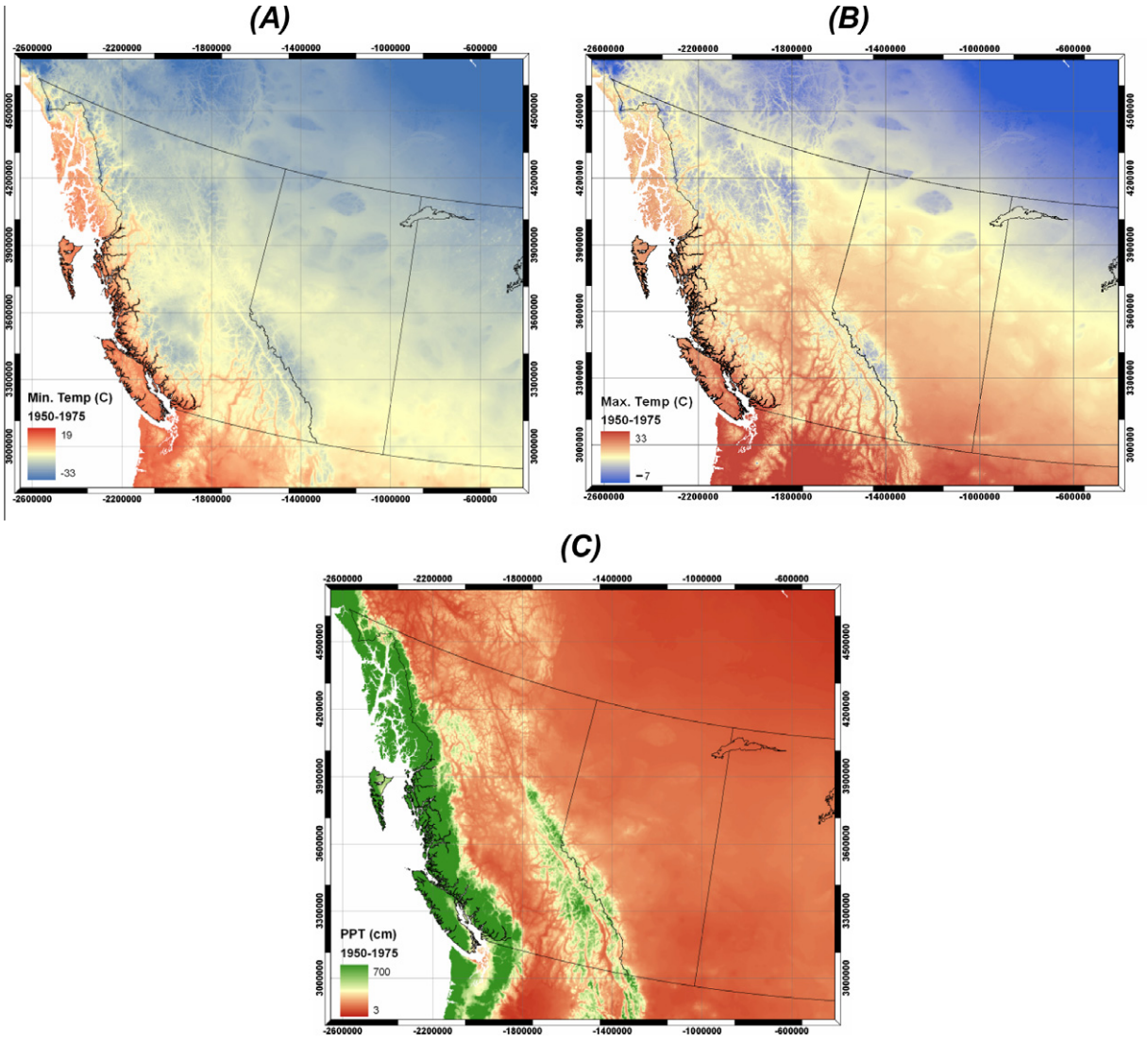

Fig. 1. (A)–(C) Predicted climate surfaces of annual minimum and maximum temperature, and precipitation across the study areas as derived from Climate-WNA for the calibration period (1950–1975).

expansion which is understood to be due principally to intensive fire suppression activities, which have caused the amount of mature lodgepole pine forest to triple in the past century (Fettig et al., 2007), and several years of favorable climatic conditions, which have increased the climatically suitable areas for brood development (Carroll et al., 2004).

The range of lodgepole pine continues north to Alaska and east into Alberta, suggesting that climatic conditions associated with these limits are, or were, beyond that suitable for the bark beetle (Safranyik, 1978). The beetle's range is clearly temperature limited (Bentz et al., 2010). In summer, the temperature must remain sufficiently warm to ensure a univoltine lifecycle and synchronous emergence (Carroll and Safranyik, 2004; Carroll et al., 2004). In the winter, temperatures below −40 °C affect brood survival (Safranyik, 1978), with the most impact at the season's extremes when the concentrations of glycerol in the insects is below maximum (Safranyik and Carroll, 2006). Host-tree vigor also affects the rate that insect populations expand across a region (Waring and Pitman, 1985; Logan et al., 1998; Whitehead et al., 2006).

It has been posited that mature lodgepole pine are under increased susceptibility to infestation by MPB when physiologically stressed (Waring and Pitman, 1985). Changes in climate have also been linked to vegetation stress (Case and Peterson, 2007; Chhin et al., 2008). Susceptibility to infestation by MPB is typically based upon, at the stand level, the amount and age of pine, stand density, and a location factor (Shore and Safranyik, 1992). Stands can be found susceptible, but not at risk of infestation if there are few beetles present. As such, susceptibility alone cannot be understood as a likelihood of infestation. Beetle pressure, that is the presence of beetles, can be combined with susceptibility to form a notion of risk to infestation. An additional consideration to likelihood of mortality due to infestation is tree vigor. Larsson et al. (1983) present that trees with lower vigor as related by growth increment had a higher likelihood of infestation. Among a variety of mechanisms suggested (e.g., Safranyik, 1978), it can be understood that the capacity of a given tree to use natural defenses to expel attacking insects will be lessened in low vigor situations. As such, we propose that climatically driven pine stress can be used as an informative aspect of infestation likelihood by MPB.

Under a changing climate, large areas in western North America have become more favorable for the MPB, leading to range expansion toward higher elevations and more northerly latitudes (Carroll et al., 2004). This expansion has lead to speculation that the beetle's range could extend into the boreal forest region creating an