LIMITED REPORT

Impact of Climate Change on Boreal Forest Insect Outbreaks

by

M. Johnston

Environment Branch

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INTRODUCTION AND OBJECTIVES

Western Canadian boreal forests are dominated by frequent and intense disturbances. The most well-know of these is forest fire, affecting on average *ca.* 835,000 ha annually in the three prairie provinces (National Forestry Database 2000). In contrast, insect outbreaks affect an average of 2.8 million ha annually in the prairies (National Forestry Database 2000). Fleming (2000) reported that commercial timber volumes losses from insect outbreaks were 1.6 times that due to fire and represented 33% of the volume harvested. Recent research suggests that climate change may affect the ways in which insects affect the forest and consequently the human use of forest resources (Kurz et al. 1995). The objective of this chapter is to review the recent literature on the potential interactions between climate change and the western Canadian boreal forest, and to assess the implications of these interactions for continued human use of forests. The focus is on pests important to the western Canadian boreal forest, in particular spruce budworm *(Choristoneura fumiferana* Clem.) (SBW), jack pine budworm (*C. pinus* Freeman) (JPBW) and forest tent caterpillar *(Malacosoma disstria* Hübner) (FTC).

INSECTS AND CLIMATE CHANGE

Impacts of climate change on insect populations are manifested in several different ways: direct effects of environmental conditions (e.g. temperature and moisture); interactions between the insect and its host; and interactions between the insect and other non-host species in its environment (e.g. predators, diseases). In addition, changes to forest structure or species composition, due either to natural or human-caused impacts, will also affect insect populations at broader spatial scales; examples include forest fragmentation and the introduction of exotic tree species.

Temperature

A number of researchers have examined the role of temperature in either promoting or limiting insect populations in northern latitudes. Insects are poikilothermic and are hence directly affected by temperature to a much greater degree than are homeothermic organisms (Fleming 2000). Insects are more active at higher temperatures, and so activities such as feeding and reproduction should be greater under a warmer future climate (Kingsolver 1989). Most climate models indicate that winter temperatures are expected to increase more than summer temperatures, so that the degree to which frozen conditions control insect populations may be less. This has been suggested for defoliators in northern continental US forests (Williams et al. 2000) and for SBW in spruce-dominated forests of Alaska (Niemela et al. 2001). Sieben et al. (1997) mapped the extent of 785 accumulated degree days above 7.2°C for the Mackenzie Basin region to represent the area of suitable conditions for the white pine weevil. They found that this area expanded significantly under the GISS climate change scenario as compared to the 1951-80 normal temperatures. Cerezke and Volney (1995) report a major decrease in SBW populations across western Canada in 1969 associated with large-scale spring frosts which severely damaged the current years' foliage and interfered with the development of SBW larvae that year. If, as seems likely, late spring frosts occur less frequently under a warmer future climate, then this aspect of weather's control on population dynamics will be lessened (Fleming and Volney 1995). However, Fleming and Candau (1998) caution that the data on which this conclusion was based are questionable and that the association of a weather event with a phase of the outbreak cycle does not demonstrate a cause and effect relationship.

Drought

Drought is particularly important in determining the nature of the western Canadian boreal forest. The boundary between the grassland and forest biomes in the prairie provinces has been shown to be determined by moisture availability (Hogg 1994, 1997; Hogg and Hurdle 1995). Increases in drought frequency and severity are expected under future climate change scenarios for the prairie provinces (Herrington et al. 1997, Johnston and Wheaton 2001). Mattson and Haack (1987) outline six mechanisms by which drought can affect insect behaviour and physiology.

1. **Favourable thermal environment**. Higher temperatures are generally associated with drought, which allow insects to grow and reproduce more rapidly.
2. **Drought-stressed plants are behaviourally more attractive to insect pests**. Plant characteristics associated with drought, such as leaf yellowing, higher leaf temperatures and greater infra-red reflectance may make them more attractive or acceptable to insects. Acoustical cues associated with cavitation due to drought may also attract insects. Drought stress also changes the biochemical make-up of plants, and these changes may produce compounds that attract insects.
3. **Drought-stressed plants are physiologically more suitable for insects**. Under drought stress, plant nutrients are more concentrated, increasing the nutritional quality of plant tissues for insects. Examples include increased concentration of nitrogen compounds, carbohydrates and minerals. Drought also causes a decline in plant defensive compounds, e.g. decreased oleoresin production in conifers.
4. **Drought enhances insect detoxification systems and immunocompetence**. The increased temperatures associated with drought may increase the insects' ability to detoxify plant defensive compounds, and increased nutritional quality may allow the insects to resist the effects of these compounds and increase the efficacy of their immune systems.
5. **Drought favours mutualistic microorganisms but not natural enemies**. The higher temperatures and higher levels of plant nutrients generally enhance the growth of microorganisms that are beneficial to insect growth. In contrast, higher temperatures and lower humidity may reduce the activity levels of diseases, predators or parasites.
6. **Drought may induce genetic changes in insects**. Drought may trigger genetic changes that allow increased detoxification and nutrient utilization.

While these remain hypotheses for many insect species in the prairie provinces, there is reason to believe that in aggregate, drought will probably increase the frequency and severity of insect outbreaks.

Drought has been shown to predispose jack pine to attack by JPBW. Survival of early instars of JPBW is enhanced by the production of staminate flowers on jack pine, and production of these flowers increases when the trees are under drought stress (Volney and Fleming 2000). Hogg and Schwarz (1999) have shown that aspen decline in western Saskatchewan is associated with periodic drought which induces water stress in trees and increases susceptibility to attack by FTC; this decline syndrome is particularly acute along the grassland-forest boundary where the frequency of drought is highest. Volney and Fleming (2000) also suggest that drought along the southern margins of the range of white spruce is associated with an increase in the frequency of SBW outbreaks. In general, drought at the southern margins of host species appears to be associated with greater frequency of insect outbreaks.

Host - Insect Interactions

Insects depend on the host plant for food and shelter, so that insect population dynamics are usually strongly synchronized with the development patterns of the host species. For example, early spring development of SBW larvae depends on the availability of newly-developing foliage and buds with high levels of nutrients (especially N) and low levels of defensive compounds (Fleming and Volney 1995). Changes in climate could alter the rate of development of foliage and buds, which would in turn change the availability of these food sources during SBW development. However, poikilotherms respond rapidly to changes in their thermal environment and would probably adjust to the new climate regime quickly enough to track any changes in host tree phenology (Fleming 1996). In contrast, changes in phenolgical development in aspen due to extreme weather events (e.g. early spring frosts) have been shown to negatively affect FTC larval development; apparently this species is less successful at tracking the penology of its host species (Volney and Fleming 2000). If climate change affects the phenology of aspen, populations of FTC may decline due to lack of food resources. On the other hand, climate change effects are more likely to occur in the form of drought, especially in the southern margins of aspen's range (Hogg 1994), and this may enhance FTC outbreaks, as described above.

Insects and Non-host Interactions: Stand and Landscape-level Effects

Insect populations are affected by other organisms in their environment, especially predators, parasites and diseases. Climate change could affect these interrelationships with potentially large impacts on insect pest populations. Crawford and Jennings (1989) examined the effect of bird predation on spruce budworm in eastern North America. They found that bird species in the warbler and kinglet families were effective at limiting budworm populations when SBW larval density was at relatively low levels (*ca.* 10^4 larvae ha^{-1}) but had very limited impact on SBW populations when larval density was high (*ca.* 10^6 larvae ha^{-1}). As outlined above, densities of SBW could increase under a warmer, drier future climate and increase the potential food supply for these bird species. However, Crawford and Jennings (1989)also found that quality of bird habitat was important, with higher populations of birds, and hence higher rates of SBW consumption, in more suitable habitat. Climate will likely change the distribution of tree species in the boreal forest (Shafer at al. 2001), altering habitat suitability for SBW predators. For example, forest fire activity is forecast to increase (Flannigan et al. 2001), and would drive forest composition toward early successional species (e.g., aspen or jack pine). This would decrease abundance of the SBW host white spruce, reducing numbers of insects and those bird species who depend on SBW as a food source. However, in areas not recently affected by fire, white spruce would be under increased moisture stress on some sites, and might be more susceptible to SBW attack (see above). In these areas, bird populations might increase due to the increased food source. Therefore, it is the interactions among host species, disturbance, insects and predators that will determine whether insect pest populations will increase or decrease.

Recent research has also highlighted the importance of landscape-scale forest structure to insect-parasite and insect-disease interactions. Roland and Taylor (1997) reported that populations of FTC increase with increased forest fragmentation in northern Alberta. The mechanism for the increase was determined to be an decline in parasitic fly populations in fragmented forest. The parasitoids caused a decline in FTC populations of up to 50% in intact forest as compared to populations levels in fragmented forest. Rothman and Roland (1998) reported that infection of FTC larvae by a viral pathogen was greater in contiguous forest, and that the probability of FTC larvae surviving infection dropped from *ca.* 90% in a fragmented forest to *ca.* 50% in intact forest. These studies agree in showing that levels of FTC are up to 50% greater in fragmented forest. Several authors have suggested that climate change, especially increases in drought, will result in greater levels of forest fragmentation (e.g., Nielson 1993, Shafer et al. 2001). This would result in an increase in FTC populations in the western Canadian boreal forest, especially along the southern margin where susceptibility to increasing drought is particularly high and the link between FTC and drought has already been observed (Hogg and Schwarz 1999). White spruce will also be under moisture stress in this area, so two of the most important species in the prairie provinces will be at risk of severe insect attack along the grassland-forest boundary.

MANAGEMENT RESPONSES

Responses to insect outbreaks by forest managers can take several forms. A commonly used option is the application of a non-chemical insecticide made up of the bacteria *Bacillus thuringensis* (Bt). Bt is lethal to the family Lepidoptera of which SBW, JPBW and FTC are members. Spraying is not used to eliminate the insect but rather to reduce foliage mortality so that the trees can live long enough to be harvest with 5 years; this strategy is known as foliage retention. Increased levels of SBW or JPBW may suggest increased levels of spraying, but this would probably be environmentally unacceptable. An alternative could be to put increased effort into scheduling harvesting operations in such a way as to concentrate on the stands most vulnerable to the insects. If this approach were adopted, a detailed stand-level susceptibility rating system would be a requirement, probably based on detailed ecological data such as that gathered in the Forest Ecosystem Classifications currently under development by provincial governments in the prairie provinces (e.g. Beckingham and Achibald 1996).

RECOMMENDATIONS

While the physiology of insect pest species is relatively well understood, much more research is needed on the ways in which insect outbreaks will interact with other the biotic and abiotic effects of climate change. For example, Stocks (1987) investigated the effects of budworm attack on the flammability of balsam fir-dominated stands in Ontario. While those results have been useful in Ontario, the study was carried out in a forest type not representative of those in the prairies in which SBW occurs, i.e. white spruce dominated stands in which balsam fir is a minor to non-existent species.

Research concerning the effects of drought on susceptibility of forest stands to insect attack is also needed. Current literature suggests that there is a positive relationship, but this needs more work, especially quantitative analysis that would allow modelling of this relationship. In addition, we know very little about which insects may migrate into the western Canadian boreal forest under a changed climate.

The effect of forest fragmentation on susceptibility to insect attack is also very important. The examples cited above for FTC indicate some important relationships, but we do not know whether these also hold for other pests. Fragmentation is likely to be an important aspect of the future forest, due either to climate change or to human land use impacts, and either way it will be an important contributor to forest health.

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