Management of common forest pests within the Prince George Timber Supply Area

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1 Abstract

This paper describes three insects that affect BC forestry, specifically the Prince George Timber Supply Area: White pine weevil (*Pissodes strobe)*, Forest tent caterpillar (*Malacosoma disstria*), and Spruce beetle (*Dendroctonus rufipennis)*. These insects pose a challenge to forest managers by: defoliation of regenerating seedlings, tree mortality, and defoliation of deciduous tree species.

The main purpose of this paper is to provide recommendations from studies conducted across North America and Northern Europe, and not to describe the insect in great detail. The aim is to find effective, and cost efficient methods of preventing insect outbreaks in BC that are detrimental to environmental, economic, and social factors. The mountain pine beetle has not been included in this review; the populations are declining, and a future outbreak will not occur in decades. This paper's scope focuses on native insect populations in BC, and does not describe alien insects affecting BC's forests. This paper also does not discuss the numerous fungi that affect trees.

Contents

2 Introduction

Biotic disturbances account for the largest spatial disturbances across North America (Weed et al, 2013). In BC, insects have impacted forests ecosystems beyond their recorded natural variation (Patriquin et al, 2007). Economically, licensees have benefited from beetle disturbance, as the annual allowable cut (AAC) has increased in the short term, however it is predicted that the future AAC will reduce significantly within fifteen years due to the lack of green standing timber (Patriquin et al, 2007).

Climate change is creating uncertain and novel ecosystems in BC's forests. Biotic disturbances may become increasingly common as a result (Weed et al, 2013). Biotic agents are often accompanied by abiotic disturbance regimes in the future, such as high intensity fires that occur due to large spatial tracts of dead trees (Weed et al., 2013). Reduced precipitation due to climate change and increased fuel availability due to biotic disturbance agents are increasing the intensity and severity of fire regimes (Dale et al., 2001).

Increased temperatures influence biotic disturbance agents. Warmer winters allow insects historically restricted to southern regions of the province to expand their habitats north (Dale et al., 2001). Warmer winters have also changed insect life histories and some species, such as spruce beetle, may complete their life cycle in one year rather than the historic two year cycle (Gray, 2013). Furthermore, increases in temperature may negatively affect predator species that have historically kept insect populations at endemic levels (Dale et al., 2001).

Climate change may increase the risk of drought in certain areas (though some regions may see increased precipitation) (Dale et al., 2001). As trees are exposed to longer drought periods, the natural defences of the tree are compromised. Trees become stressed and become more vulnerable to attack from insects (Weed et al., 2013).

Changes in climate affect biotic and abiotic disturbances, which have socioeconomic repercussion to communities that rely on forests to maintain local economies (Patriquin et al, 2007). Short term economic gains by increases in the AAC will be negated by long-term reductions in timber supplies (Patriquin et al., 2007). Adaptive management of forest insects must be addressed in forest management planning to promote long term forest resilience, which in turn benefits economic, social and environmental factors (Patriquin et al, 2007).

Three species affecting the Prince George timber supply area (TSA) will be addressed in this paper: white pine weevil, forest tent caterpillar, and spruce beetle. White pine weevil has been selected because it affects regenerating spruce plantations by destroying up to 3 or 4 years of leader growth thereby delaying the time it takes for trees to reach merchantable size. Forest tent caterpillar has been selected as it defoliates deciduous species important to birds and reduces cover for regenerating, late-successional coniferous species (Taylor & Cozens, 1994). Spruce beetle has been selected, as it is the leading disturbance agent of mature spruce species, and because climate change is allowing the beetle to expand its habitat as well as shortened its life history (Dale et al., 2001).

3 White Pine Weevil

3.1 Introduction

White pine weevil (*Pissodes strobe)* has major implications for silvicultural management in the sub-boreal spruce biogeoclimatic zone (Alfaro et al., 1994). In BC, it is considered the most serious pest species in regenerating spruce stands (Alfaro et al., 1995). In interior BC, *P. strobi* causes economic damage to hybrid spruce (White x Engelmann spruce) (*Picea glauca x engelmannii* spp.). On the coast, the weevil attacks Sitka spruce (Tumquist & Alfaro, 1996). Regenerating trees are affected: weevil attacks will reduce leader growth and cause trees to grow multiple leaders which can lead to forking (Belyea & Sullivan, 1956). Forest managers must choose a set of strategies before choosing one or a combination of management techniques. The strategy may be to remove weevil populations, increase the resistance of host species, or accept a certain level of weevil damage to crop trees if the costs of mitigation outweigh the benefits of management.

3.2 Life History

P. strobi produces a new generation every year and begins its life cycle in spring (Tumquist & Alfaro, 1996). Adults overwinter in the duff layer near the juvenile tree that was attacked the year before (Alfaro et al, 1994). The attack starts with the adult weevils climbing to the top of a juvenile hybrid spruce's leader. Between April and July, the adults will feed, mate, and lay their eggs in the sapwood of the previous year's growth (Alfaro et al, 1994). Larvae will then move into, and down the leader, feeding on the phloem. Depending on the level of infestation, larvae can destroy up to four years of terminal growth (Tumquist & Alfaro, 1996). Larvae will then overwinter in the affected leader and emerge as adults from the leader in late summer (Tumquist & Alfaro, 1996). Adults then commence feeding on terminal leaders or branches before overwintering in a duff layer (Tumquist & Alfaro, 1996). Many regenerating spruce may lose epinastic control, leading to multiple leaders and increasing the number of habitats for oviposition in subsequent years (Tumquist & Alfaro, 1996).

3.3 Economic consequences.

The *P. strobi* may reduce stand growth by up to 40% (Alfaro et al., 1995). Several branches from the top whorl will attempt to become the leader. The consequence may be multiple leader growth which often leads to forking (Alfaro et al., 1994). Permanent defects due to *P. strobi* may cause a point of weakness and reduce timber quality (Alfaro et al., 1994). A study conducted over nine years at Nitinat Lake, found that only 36% of trees affected by *P. strobi* recovered fully (Alfaro et al., 1994).

A major implication of the *P. strobi* on silviculture efforts is that affected spruce will be more susceptible to secondary infestation/infection by other biotic agents. Additionally, trees often develop a weak point, which can be susceptible to breakage under snowpack (Alfaro et al., 1994).

3.4 Pest Management

3.4.1 Detection and monitoring

Pest management of *P. Strobi* requires initial detection and monitoring. This allows forest managers to isolate areas of current attacks (Tumquist & Alfaro, 1996). Effective detection and monitoring in the early stages of an attack reduces the costs of management (Tumquist & Alfaro, 1996). There are several methods of detection that can be used to isolate and map weevil infestations: ground detection, aerial detection, and suitable habitat detection (Timberline Forest Inventory Consultants Ltd., 2004).

Ground detection can be conducted by silviculture crews who can identify signs and symptoms of current *P. strobi* attacks and effectively map areas of infestation (Timberline Forest Inventory Consultants Ltd., 2004). The simplest method to isolate attack centers is to observe dead leader growth from the previous year (Tumquist & Alfaro, 1996). To identify new attacks, silviculture crews must recognize tree symptoms and signs, such as increased resin production flowing from small puncture points (Tumquist & Alfaro, 1996). Locating new attacks is effective in isolating high risk areas in the early stages of attack, and can prevent further damage in adjacent regenerating stands (Tumquist & Alfaro, 1996).

Aerial detection requires aircrafts to fly at low heights in order to observe leader damage (Timberline Forest Inventory Consultants Ltd., 2004). Photo points are collected with corresponding GPS points (Timberline Forest Inventory Consultants Ltd., 2004). The operator or remote sensing technician can then delineate the location, size, shape, and number of infected trees occurring on a landscape (Johnson & Wittwer, 2008). Aerial detection is efficient, cost effective, and has the ability to provide information about forest health over a large area (Johnson & Wittwer, 2008).

Understanding the life history of *P. strobi* can help map and isolate areas of potential infestation. Mapping and recording areas with favourable temperatures can isolate potential attack centers

(Hodgkinson et al, 2011). Vulnerable stands are 0.5m-12m tall in warm climates where 820 degree days of temperatures of over 7.2°C (Hodgkinson et al, 2011).

3.4.2 Hazard rating and prioritization

To provide the most efficient and cost effective management technique, areas susceptible to *P. Strobi* must be hazard rated. This allows forest managers to prioritize their actions, and focus management on specific areas (Hodgkinson et al., 2011). Furthermore, areas with different hazard ratings will require a different set of management techniques (Hodgkinson et al., 2011). By quantifying the risks of infestation, forest managers can target high hazard stands.

3.4.3 Tactics to minimize damage

3.4.3.1 Genetic Selection

Certain chemical deterrents contained within the bark negatively affect weevil feeding (Timberline Forest Inventory Consultants Ltd., 2004). Seeds can be sourced from the Vernon Seed Orchard #211, which provide genetically resistant spruce seeds (Hodgkinson et al., 2011). Genetic variability may include: changes in resin canal density, increased traumatic resin production, and the physical and chemical composition of resin in the tree (Timberline Forest Inventory Consultants Ltd., 2004).

3.4.3.2 Silviculture

Spruce should be planted in accordance to appropriate provenances. This will reduce the chance of over-vigorous growth that attract weevil (Hodgkinson et al., 2011). Monoculture stands should be minimized. Incorporating non-host species in a plantation reduces the susceptibility of the stand as it is makes it more difficult for *P. strobi* to find a susceptible host (Hodgkinson et al., 2011).

In low to moderate risk areas, spruce should be planted at maximum densities of greater than 1600 stems per hectare (SPH), and any spacing and thinning should be postponed. This will reduce vigorous growth of leaders and reduce the risk of weevil attack (Tumquist & Alfaro, 1996). In high-risk areas, spruce should be allowed to regenerate under a canopy of deciduous species which will limit weevil infestation; weevils are negatively affected by partial shade (Figure 1) (Tumquist & Alfaro, 1996). Deciduous trees can then be removed once spruce reach 20m, as *P. strobi* attack is unlikely past this height. Changing harvesting regimes can reduce stand susceptibility (Hodgkinson et al., 2011). Utilizing ‘nurse trees’ or shade trees through partial cut harvesting may reduce *P. strobi* success. Vigorous leader growth will be reduced, and lower temperatures on the ground due to shading may reduce *P. strobi* survival (Hodgkinson et al, 2011).

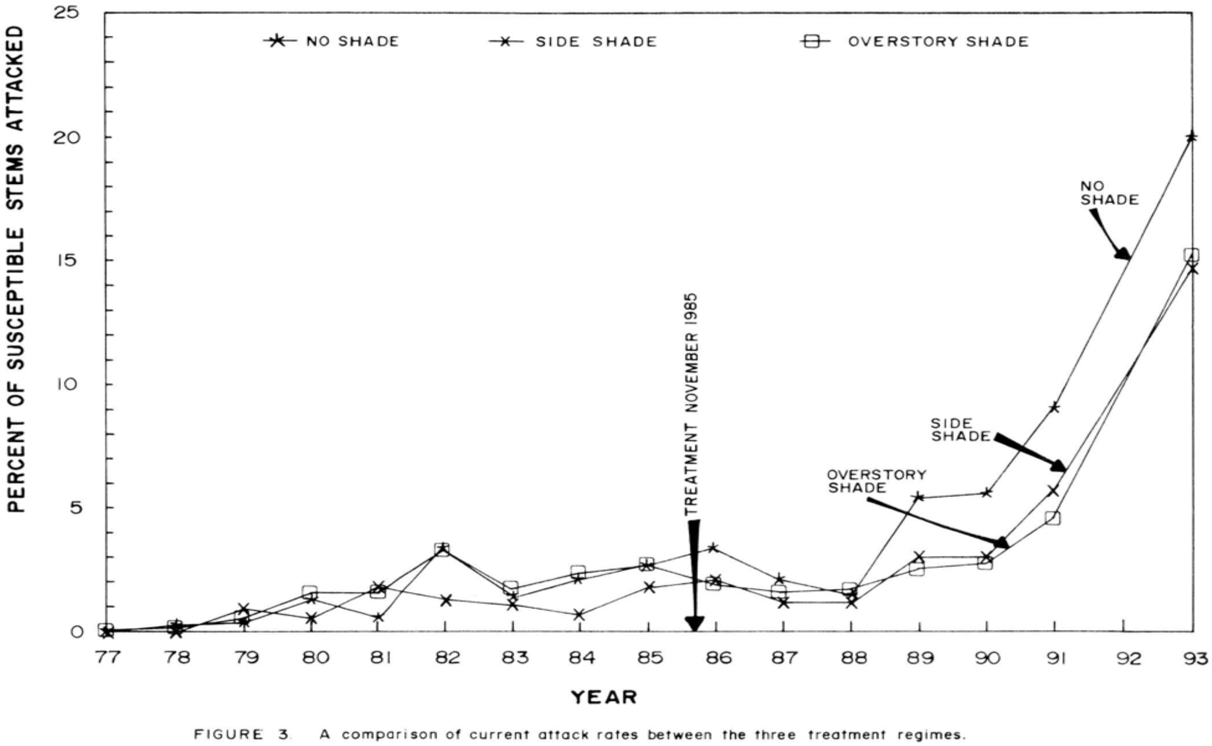

Figure 1. Correlation between amount of shade provided, and percentage of susceptible stems attacked.

Figure from Taylor and Cozens, 1994

Pruning vigorous leaders in a stand will reduce the probability of *P. strobi*s establishing (Tumquist & Alfaro, 1996). Removing affected leaders during winter will remove *P. strobi*s overwintering in the leaders. Pruning is cost intensive and may not be an efficient management technique over large spatial scales. If early identification of *P. strobi* attack is conducted and affected areas are small, then pruning can be successful (Hodgkinson et al., 2011). Forest managers should however aim to change stand susceptibility by modifying species composition and harvesting regimes.

4 Forest Tent Caterpillar

4.1 Introduction

M. disstria is a common pest in northern BC affecting trembling aspen (*Populus tremuloides),* paper birch (*Betula papyrifera),* and red alder (*Alnus rubra*) (Wood, 1992). Trembling aspen is an important economic tree species in Alberta and Ontario (Forintek Canada Corp., 2006). In BC, the economic benefits of birch are also being realized, as volumes of commercially viable lodgepole pine are becoming scarce following MPB outbreak (The Centre for Non-Timber Resources, 2006). Deciduous species also play an important role in forest health. Studies conducted in Sweden have found that increasing birch cover has led to an increase in biodiversity including lichen cover and bird species (Felton et al., 2010). Increased deciduous tree cover increases bird densities which prey on other forest pests (Fayt et al., 2005). The repeated defoliation of deciduous species increases the risk of further pest infestations. Furthermore, *M. disstria*s crushed on highways and rails may become dangerous as roads and rails become slippery. Pest management requires forest managers to set objectives, which may vary throughout regions due to economic or ecological values.

4.2 Life History

M. disstria has one generation every year (Wood, 1992). Larval cocoons appear on leaves in June and July. These larval cocoons act as protection when the caterpillars are going through their five life successive molts (Batzer & Morris, 1978). Moths emerge from the final cocoon 10 days later and live only long enough to reproduce and lay eggs (Wood, 1992). The moths may be carried long distances by strong winds, which enable them to find new hosts (Batzer & Morris, 1978). Eggs are laid in the upper crown of the trees, they overwinter, and hatch in the spring (Batzer & Morris, 1978). Studies conducted in Ontario have found outbreak cycles are strongly related to local climates (Cooke & Lorenzetti, 2013). Furthermore, areas with flat topography were more susceptible to outbreaks. This explains past outbreaks in Alberta and Quebec (Cooke & Lorenzetti, 2013)

Outbreaks occur every 10-12 years and last for approximately 3 years (Roland, 1993). Warmer temperatures are conducive to caterpillar populations. Fragmented forests have warmer temperatures near edges, which can result in a rapid increase in populations (Roland, 1993). Reduction of natural predator populations due to degraded forest ecosystems has led to prolonged infestations (Roland, 1993).

4.3 Economic consequences

Forest tent caterpillar is the largest contributor to defoliation of trembling aspen and associated loss in stem growth (Hogg et al., 2002). The caterpillar, along with drought, have been the main cause of aspen dieback in Alberta since the 1990's (Hogg et al., 2002). Radial growth is severely suppressed following multiple years of defoliation. Furthermore, deciduous tree species are more susceptible to a secondary biotic disturbance agent following multiple years of defoliation by *M. disstria* (Natural Resources Canada, 2016).

Tent caterpillar have mainly been a concern of city municipalities and home owners (Wood, 1992). As the economic importance of deciduous species become prevalent following the MPB epidemic, forest managers are increasingly interested in finding solutions to controlling the caterpillar (The Centre for Non-Timber Resources, 2006). Trembling aspen is an important species in Alberta, used in the production of oriented strandboard (OSB), plywood, pulp, and wood pallets (Forintek Canada Corp., 2006). Birch-leading stands make up roughly, 210,000 ha in BC (The Centre for Non-Timber Resources, 2006). The MPB epidemic has changed the composition of the landscape and both trembling aspen and birch-leading stands are predicted to become more prevalent in the future (The Centre for Non-Timber Resources, 2006). As the AAC in BC is decreasing, many First Nations communities, municipal governments, and business owners are interested in the economic value of birch. Birch can provide important extracted chemicals such as xylitol, as well as used for specialty wood products (The Centre for Non-Timber Resources, 2006). *M. disstria* has direct economic consequences on both trembling aspen and birch by reducing the growth and vigor, and increasing the rotation period (Natural Resources Canada, 2016).

M. disstria causes indirect economic consequences by supressing deciduous trees that are important to the structure of regenerating plantations where partial shading by deciduous trees reduce *P. strobi* attack (Tumquist & Alfaro, 1996). This is particularly important for licensees, as *P. strobi* infestations may increase the length of time that a stand requires to reach maturity (Alfaro et al, 1994). Retaining deciduous trees also increases the spacing between susceptible trees, and increases overall resilience of the stand (Felton et al, 2010). Furthermore, reducing deciduous tree and leaf cover also reduces bird densities, which require cover from predators provided by deciduous leaves. Birds are a positive, density dependent factor limiting insect pests in stands (Felton et al, 2010). Riparian reserves also benefit from leaf cover provided by deciduous trees. Shading, and leaf litter are both important ecological considerations in riparian management (Felton et al, 2010).

4.4 Pest Management

4.4.1 Detection and monitoring

Forest tent caterpillar can be detected and monitored using several methods. Aerial photography can be used to map landscape level outbreaks of tent caterpillar (Natural Resources Canada, 2016). In order to prevent large caterpillar outbreak, understanding the biology of the tent caterpillar can help isolate possible attack centers. Studies conducted in Quebec, where hardwood species are economically important, found that low-lying areas were prone to higher frequency and duration of attack than higher elevation regions (Cooke & Lorenzetti, 2006). Furthermore, tent caterpillar return approximately every 10 years, however these estimates of population cycles are not accurate, and vary depending on region (Cooke & Lorenzetti, 2006). Forest managers have an approximate time frame of when to expect tent caterpillar cycles, but ground inspections are important. Identifying egg clusters on trees above a certain threshold may indicate a possible attack cluster (Cooke & Lorenzetti, 2006).

4.4.2 Hazard rating and prioritization

Hazard rating can be conducted by ground identification, which requires mapping areas with high volumes of egg clusters. Once egg clusters are identified, it is important to understand the extent and spatial pattern of the egg clusters (Cooke & Lorenzetti, 2013). Areas in higher elevations would receive a lower hazard rating as attacks are less frequent and severe (Hogg et al., 2002). Hazard rating is important, as it allows forest managers to prioritize management of tent caterpillar populations in the most severely affected stands.

4.4.3 Tactics to minimize damage

The biological pesticide, *Bacillus thuringiensis* (BT) is an effective bacterial strain that affects the life history of *M. disstria*, and other lepidopterans, but does not affect other species (Bjornson & Oi, 2014). This may be sprayed from an airplane and can cover large areas of aspen and birch stands. This pesticide is effective; it is biodegradable, and as efficient as chemical sprays (Sanahuja et al, 2011). A disadvantage of BT is that it is quickly inactivated by sunlight, heat, and abnormal pH . Wind and rain can remove BT from the leaves that, rendering it ineffective in areas with variable weather patterns (Sanahuja et al, 2011). BT also requires several reapplications to be effective (Sanahuja et al, 2011). Furthermore, many lepidopterans can become resistant to BT over time (Sanahuja et al, 2011). A major criticism of BT, has been its effect on non-target, beneficial insects (Vojtech et al, 2005). Many lepidopterans are suseptible, and are either killed by BT, or their development is suppressed (Vojtech et al, 2005). Further research in BT applications are required to understand the full ecological consequences of removing non-target species.

In high hazard areas where egg clusters are localized, branches can be removed in the winter and burned (Wood, 1992). This method is inefficient and would not be applicable at the landscape level. At the landscape level, the most effective method is to apply BT despite its shortcomings.

5 Spruce Beetle

5.1 Introduction

D. rufipennis is naturally present in Northern BC and affects mature spruce stands. The *D. rufipennis* carries the blue stain fungus (*Leptographium abietinum)* which disrupts the food and water distribution in the tree, starving the tree of nutrients (Humphreys & Safranyik, 1993). Though *D. rufipennis* have historically been kept at low population levels by both biotic and abiotic factors, changing climate and forestry practices have allowed populations to increase in size (Werner et al., 2006). Management of spruce beetle requires a strategy that may range from reducing beetle populations to increasing the resistance of the host. Outbreaks in the past have often been associated with wind thrown trees, drought, or from slash and log residues from harvesting (Industrial Forest Service Ltd., 2008).

5.2 Life History

In Interior BC, *D. rufipennis*'s host is White, Engelmann, and hybrid spruce, which the female adult beetle will bore into during May (Humphreys & Safranyik, 1993). The female will then release pheromones which attract both males and females, who aggregate and overwhelm the spruce tree's defences (Humphreys & Safranyik, 1993). Eggs are laid, and after hatching will bore horizontally together before commencing boring in individual galleries (Humphreys & Safranyik, 1993). This generation of *D. rufipennis* will overwinter in the host tree. The following summer, these larvae will pupate to become adults, and must overwinter again in the host tree before finding a new spruce host. Abiotic factors affecting the duration of the beetle life cycle is tied to summer temperatures, geographic location, and elevation (Humphreys & Safranyik, 1993). Anthropogenic climate change is increasing temperatures in BC (McMichael, 2003). The two-year lifecycle is becoming less common, as warmer winters mean *D. rufipenni*s can complete its life history within one year (Werner et al., 2006). *D. rufipennis* populations may increase to epidemic population sizes as temperatures rise above historic temperatures that once kept beetle populations in check (Werner et al., 2006). Furthermore, climate change is creating novel ecosystems and conditions that may have negative consequences for other biotic agents that control beetle populations, such as birds (Dale, et al., 2001). Forestry practices, such as leaving large woody debris on the landscape also creates habitats for spruce beetles, which can lead to population explosions (Tumquist & Alfaro, 1996).

5.3 Economic consequences

Northwestern BC witnessed an outbreak of spruce beetles in the 1940`s occurring over 375 km^2 and killing up to 90% of the mature spruce (Humphreys & Safranyik, 1993). This outbreak cost the province almost 900,000 cubic meters of timber. The Prince George forest region lost over 14 million cubic meters from 1961-1965 (Humphreys & Safranyik, 1993). Over a decade, from 1990 to 2000, Alaska witnessed *D. rufipennis* infestations that affected over 1.19 million hectares (ha) (Werner et al., 2006).

5.4 Pest Management

5.4.1 Detection and Monitoring

In order to map and isolate spruce beetle outbreaks, effective detection and monitoring is required. Detection can be done through aerial detection and ground reconnaissance. Ground reconnaissance includes inspecting individual trees for boring dust (Humphreys & Safranyik, 1993). Boring dust it found in the crevices of the trees, around roots, as well as on deciduous and shrub leaves surrounding the tree.

Boring dust is not an effective way of detecting spruce beetle signs alone, as boring dust disappears quickly and can be the result from other bark-mining insects (Humphreys & Safranyik, 1993). Pitch tubes are also symptoms of bark beetle activity. Pitch is used as a natural defence to expel the beetles from the tree (Humphreys & Safranyik, 1993). Woodpecker activity, such as holes in the bark of spruce, may indicate beetle infestations (Fayt et al., 2005). These methods of detection are most accurate when combined with several detection techniques. Ground reconnaissance can determine the percent of spruce trees attacked, the attack density, as well as the extent of the infestation

Aerial reconnaissance is a useful course filter survey system; it determines the scale of the infestation, and can be used to investigate the extent of beetle attacks (Hais & Kucera, 2008). Yellow needles in winter can easily be identified from the air and are a symptom of a spruce beetle attack from the previous summer (Holsten et al., 1999). Thermal remote sensing can also be used to detect infestations, as surface temperature of spruce stand infested by bark beetles increases following infestation (Hais & Kucera, 2008). Once potential areas of beetle attack are mapped aerially, it is important to verify that mortality was caused by beetles. This can be done by using multiple lines of evidence and identifying other signs and symptoms associate with spruce beetle infestation.

5.4.2 Hazard rating and prioritization

Spruce beetle infestations can be hazard rated in order to prioritize management strategies (Holsten et al., 1999). In BC, a formula for determining stand hazard exists: These variables include: site quality, location, proportion of susceptible basal area, age, and stand density (Holsten et al., 1999). Hazard ratings are important, as they set priorities for both surveys and treatment regimes. Risk ratings are important, as it describes the probability whether stands will be attacked in the near future, determined by proximity to other infestation centers. For example, stands adjacent to infested stands would have a high risk rating (BC Forests, Lands & Natural Resource Operations, n.d).

5.4.3 Tactics to minimize populations

There are a number of methods to reduce spruce beetle populations, including both direct and indirect control. Direct control methods include removing high stumps, windthrown trees, residue from logging, as well as removing infested trees (Humphreys & Safranyik, 1993). Furthermore, sanitation harvesting, trap trees, and insecticide can be used to directly control beetle populations (Humphreys & Safranyik, 1993). Trees on cutblock edges are susceptible to windthrow, which may increase beetle populations. Disruptions in hydrological functions due to soil erosion may negatively affect nearby trees, and increase their susceptibility to beetle attack (Humphreys & Safranyik, 1993). Allowing trees to grow older through extended rotation periods creates stands that are susceptible to beetle infestation. Biotic controls may be to increase woodpecker populations, however this method has never been applied in BC. Many species live in BC forests year round, and population sizes are negatively correlated with *D. rufipennis* populations (Fayt et al., 2005).

5.4.4 Direct control

Sanitation harvesting provides the most effective management technique in reducing beetle populations on the landscape (Humphreys & Safranyik, 1993). In areas of high infestation, harvesting can remove entire stands that are infested (Humphreys & Safranyik, 1993). Processing must occur quickly, and bark must be burned immediately in order to remove beetles before they move to another stand. Forest managers can set cutting boundaries meant to target high beetle populations (Humphreys & Safranyik, 1993). Pre-flight baiting can be used to concentrate trees in a certain stand, which can then be harvested and processed. Effective hazard rating and prioritization is important, as areas with high beetle populations can be prioritized for harvesting (Humphreys & Safranyik, 1993).

Trap trees can be used to attract beetles to a certain area by using felled green trees used as bait prior to beetle flight (Humphreys & Safranyik, 1993). Felled trees can hold up to six times as many beetles as standing timber, as beetles will attack the entire felled tree. Standing trees are most often attacked around the lower regions near the ground (Humphreys & Safranyik, 1993). Lethal trees can also be used by applying insecticide such as monosodium methane arsenate (Humphreys & Safranyik, 1993). Insecticides is applied in notches made around the base of the tree before beetle flight in the spring. These trees are then cut down up to two weeks following insecticide application (Humphreys & Safranyik, 1993).

5.4.5 Indirect control

Indirect control can be beneficial, as management regimes may attempt to reduce the susceptibility of trees as a preventative measure, rather than a corrective treatment. Endemic populations of spruce beetle generally attack weakened spruce trees due to drought or windthrow (Christiansen et al., 1987). It is therefore important to maintain vigorous growth, as well as remove windthrow from stands.

Thinning and removing a proportion of trees in a stand allows for an increase in growing space. Increased growing space allows trees to invest energy to defence mechanisms that help to expel beetles (Fettig, et al., 2007). In dense stands with limited growing space, trees must prioritize respiration, root production, reproduction, height growth and diameter growth (Fettig, et al., 2007). Only once those requirements are met does the tree allocate resources in defence (Fettig, et al., 2007).

Reducing soil disturbance reduces disruption in subsurface water movement, which reduces disruptions to spruce moisture requirements, and reduces the susceptibility to drought, and beetle attack (Humphreys & Safranyik, 1993). Preventing windthrow on block boundaries is crucial, as windthrow is a common cause of population explosions (Humphreys & Safranyik, 1993). Selective cutting of large diameter spruce trees also reduces susceptibility, as spruce beetles have preference towards large diameter trees (Fettig, et al., 2007).

Woodpeckers naturally forage for *D. rufipennis* and can reduce populations (Fayt et al., 2005). Woodpeckers on the landscape reduce the risk of *D. rufipennis* populations increasing to critical biological thresholds which threaten healthy trees (Fayt et al., 2005). Woodpeckers are beneficial as a biotic control; populations are density dependent with *D. rufipennis* population fluctuations. A literature review conducted at the University of Joensuu, found that downy woodpecker (*Picoides pubescens*), hairy woodpecker (*Picoides villosus)*, and the american three-toed woodpecker (*Picoides dorsalis)*, increased in population by 30 times during infestations. These populations stabilized once *D. rufipennis* populations were at endemic levels (Figure 2) (Fayt et al., 2005. Furthermore, the Prince George TSA is a home to large woodpecker populations. (Humphreys & Safranyik, 1993).

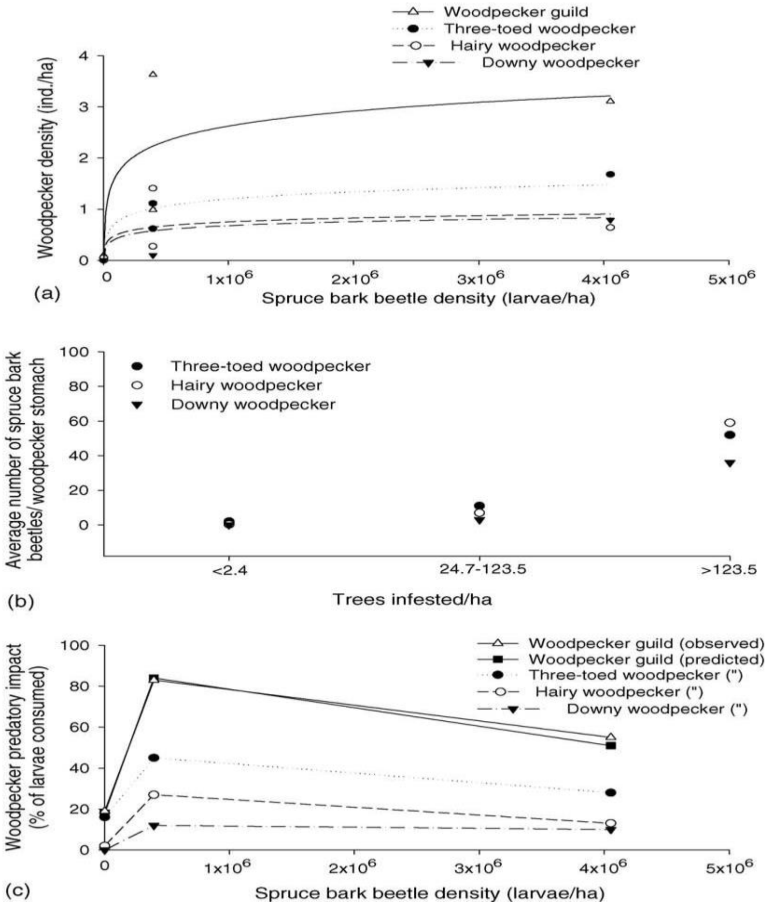

Figure 2 a) Density response b) Food availability c) Impact of predation with changes in density Retrieved from Fayt, et al., 2005

6 Conclusion

BC forest management in the future must address adaptive management to reduce insect damage to forests. Management approaches must focus more on preventative measures, rather than concentrate on corrective actions. Many of the pest species mentioned above can be effectively controlled by reducing the susceptibility of stands by changing harvesting practices, removing damaged trees, as well as changing species compositions. These preventative actions focus more on controlling endemic populations, and reducing the probability of these populations reaching epidemic sizes. Preventative management requires effective detection and monitoring on the landscape level. This can be aided by frequent aerial surveying, as well as training forest workers how to identify and map signs and symptoms of insect attacks. This paper has focused only on three species relevant in BC, however there are many species affecting BC's forests such as: the western spruce budworm (*Choristoneura occidentalis),* gypsy moth (*Lymantria dispar),* and warrens root collar weevil (*Hylobius warren).* Global shipping must aim to reduce alien insect species such as asian gypsy moth (*Lymantria dispar asiatica)* that enter BC by mistake. These insects are not native, and local ecosystem have no evolutionary resistance. Shipments of wood products must be highly regulated in order to prevent invasive alien insects.

The first step in successful adaptive management against biotic disturbance agents, is to change the paradigm of forest management in BC. It is impossible to continue managing forests for economic interest alone. Other values to manage for include: species composition, multiple age class structure, natural disturbance cycles, as well as enhancing landscape to promote wildlife populations. It would be inefficient and short sighted to manage for just a single disturbance agent. Specific management techniques may be impossible to predict due to climate change, however increasing forest resilience may be an effective first step. Resilience is important; if one species is removed, multiple other species remain on the landscape. This is important to both ecological and economic function.

Currently, licensees have little incentive to alter management strategies that reduce potential risks in the future. Working under a volume-based tenure agreement, licensees may not be inclined to change management methods. The consequences of short-term, economic focused planning compromises forest resilience. Many of the management regimes discussed in this report would be effective if tenure holders were operating in a regulated, area-based tenure agreement, where it would be in the best interest of the licensees' to managed trees through a full rotation.

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