MOUNTAIN PINE BEETLE LITERATURE REVIEW

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1. INTRODUCTION

In order to understand the potential for the control of the mountain pine beetle through environmental management, it is necessary to understand the life habits and environmental requirements of the beetle and its host. Detailed information on the ecology and interrelationship of the beetle and lodgepole pine is presented in the body of the report. Management options for control by exploiting weak links in the beetle's population dynamics are discussed.

1.1 BEETLE ECOLOGY - GENERAL

The mountain pine beetle is a small (0.5 cm), inconspicuous black beetle. The beetle exists at low population levels in all lodgepole pine forests. They beetle larvae feed on the inner bark of mature pine trees, girdling the trees and killing them. The host trees must be sufficiently large and have thick inner bark for the beetles to reproduce successfully enough reach epidemic populations. When food supplies over a sufficient area and climatic conditions over a sufficient period of time are favorable, the small endemic populations undergo explosive growth and beetle epidemics result. Epidemics end when the desirable food supply of large lodgepole pine trees is no longer continuous enough to support the population or when climatic conditions become unfavorable for the beetle. Climatically ended epidemics will reoccur after a period of favorable weather allows populations to rebuild.

The beetle is a naturally occurring part of the lodgepole pine forest ecology. Lodgepole pine has been a pioneer species after fires in pure or near pure stands since the glaciers left, and the beetle has been killing mature stands for just as long. In mixed species stands, other tree species will assume dominance in the forest tree community after a beetle epidemic has killed most of the pine. In areas where lodgepole pine forms pure stands, a dramatically thinned pine forest will be left after an epidemic with many standing dead trees. Pine will regenerate the holes in the stand over time. The beetle killed snags will eventually fall down and either decompose or provide fuel for an intense stand replacement forest fire. Such fires the forest successional clock back to the beginning of the cycle with an even aged lodgepole pine stand.

1.2 CONTROL OPTIONS - GENERAL

The pine beetle occupies a niche in the pine forest ecosystem. It is not going to go away and it cannot be exterminated. To quote Hector Richmond, former Chief Entomologist for the B.C. Ministry of Forests,

> *The eradication of any native species of forest insect is impossible. They are as much a part of the forest as the trees themselves. They have been there as long as the trees have, and will continue to be so until the end of time.*

The beetles activities are acceptable from an ecological standpoint, but conflict with the interests of modern man in that they destroy desirable timber resources. Because of this conflict, the forestry establishment has demanded "control" of the beetle and draws up "battle" plans to "combat" infestations and "salvage" timber by cutting it down before the beetle has a chance to kill it. Yet endemic populations of beetles still exist in every pine stand, waiting for favorable conditions to increase their population, while nothing is being done to mange the forests to prevent future epidemics.

The only hope for long term control of the pine beetle population lies in managing the forest in such away that habitat conditions never become favorable enough for epidemic populations to build up, and/or epidemics occur in geographically isolated pockets that will not spread extensively because the food supply is not continuous. This is the aim of a wholistic pest management program, and of wholistic forestry in general.

A wholistic approach to pest management recognizes:

1. That there will be timber losses that will not be recovered. Rational levels for maximum acceptable losses must be established per management unit based on the full spectrum of resources of an area.
2. That long term management plans must be developed to reduce losses to the beetle now and over following rotations.
3. That contingency plans must be developed to deal with situations where losses exceed or are expected to exceed the standards set in 1.

The rational objective in this situation is to develop a forest land use and pest control program that is directed by long term resource management goals and not by the breeding success of an insect. Such a plan must recognize the rights and aspirations of all resource users and the silvicultural and ecological implications of forest management practices.

2. LIFE CYCLE AND ECOLOGY

The following life cycle description applies to the epidemic population phase of the mountain pine beetle.

The mountain pine beetle generally has a one year life cycle from egg to breeding adult. The beetle spends its life under the bark of a lodgepole pine tree except for a brief period when the adults emerge to fly and mate. Unmated females select a target tree and initiate an attack on the bole, boring into the bark with their powerful jaws. Beetles are strongly oriented to large trees and vision appears to play a major role in tree selection. As they attack, they release aggregating pheromones, chemical odors that attract males and other females to attack the same tree. This concentrates the beetles in the area on a single tree in what is termed mass attack (Amman and Safranyik, 1984). After a sufficient number of beetles have landed on a tree the rate of attack levels off, presumably in response to anti-aggregant pheromones. A few beetles will then land on neighboring trees. These are in turn almost immediately mass attacked (Gara et al., 1984).

The pine tree responds to this insect attack by attempting to drive out the invading beetles with pitch and resins, termed defensive allochemicals. If the tree is vigorous enough, and/or the number of attacking beetles is small enough, it will have sufficient carbohydrate reserves to manufacture enough chemicals to "pitch out" the attacking beetles. If the tree does not have enough stored energy, the beetles will gain entry (Waring and Pitman 1985).

The reproductive key for the beetle is to attack large desirable trees with thick phloem and the greatest potential for fostering large numbers of beetle larvae. These trees are also generally the most vigorous and resistant to attack. The best chance for overcoming this resistance is by concentrating all available beetles in a mass attack. Thus the beetle behavior is modified to overwhelm healthy trees, and form infestation centers from which to spread in the next year.

As soon as the beetle enters the tree it infects the living tissue of the tree with a complex of fungus, yeasts and bacteria that it has carried in a special mouth pouch from the tree where it was hatched. This mix, called "blue stain fungus" soon girdles the tree, staining the sapwood a prominent blue and clogging the tree's phloem. Phloem is the spongy plant tissue immediately below the bark, just on top of the first layers of wood. Phloem is the tree's water and food transport system - the corollary of our blood vessels. Phloem is the sole food of mountain pine beetles. Trees with thick, dense and not overly resinous phloem will produce much larger crops of beetles than trees with thin, spongy or resinous phloem. Exactly which environmental factor(s) cause the best phloem (from the beetle's point of view) to form or become accessible is a debated issue and will be dealt with later.

With its phloem clogged by fungus the tree soon dies, although the foliage does not discolor until the following spring. The beetle's relationship with the blue stain fungus is symbiotic. The stain kills the tree, halts its resin production and causes it to dry out quickly in the fall, but it retains moisture for a longer period in the following spring (Amman, 1976). Thus the blue stain fungus helps regulate the beetle's living environment. Excessive drying is fatal to beetle larvae and pupae.

Once under the bark, the female begins to bore an egg chamber, mates and starts to lay eggs. The female extends the egg chamber and lays eggs until halted by cold weather in the fall. A vigorous tree which failed to pitch out all the attacking beetles can still produce enough resin to flood the egg chamber and kill the eggs at this point, thus controlling the beetle population. Barring this, the eggs hatch into larvae which feed on the tree's phloem.

The larvae eat and grow as much as possible before winter sets in, constructing side galleries at approximately right angles to the main gallery. All eggs remaining unhatched when winter begins are killed. Small larva also have heavy mortality rates (Amman, 1973). The larvae stop feeding as temperatures drop, and overwinter. In spring they resume feeding, then pupate and change to adult beetles. The new adults spend some time feeding beneath the bark of the now dead tree, incidentally picking up the blue stain fungus, then emerge from the tree and begin the life cycle again.

At the extreme edge of the beetle's elevational and/or climatic range, completing the life cycle can take two years. The beetles cannot develop as speedily due to the short growing season and suffer increased predation due to their increased life span as well as cold mortality. Beetles in this situation are not overly successful breeders, and epidemic populations do not as a rule form. Epidemics that move into such regions usually die out (Amman et al., 1973).

The beetles' ecological niche is the inside of its host tree. The two factors which directly affect its environment are the local climate and the condition of the tree it lives in. The climate is not ours to control. Severe winter cold or cold snaps in early fall can decimate an epidemic population, but certainly cannot be depended on for reliable beetle control. The second factor, the condition of lodgepole pine trees, can be influenced by man. It is only by managing the lodgepole pine forest to produce conditions unfavorable to beetles that effective beetle control can take place.

A roadblock to developing effective beetle population controls which utilize forest ecology, tree physiology and beetle behavior to has been human bias and ignorance. Many humans look down on and/or intensely dislike insects. To many humans, "bugs" are stupid, crawly things. This viewpoint is inaccurate and reduces our chances of achieving a workable relationship with insect pests. A more accurate view of insects would be as small, finely programmed microcomputers. They can assimilate data in the form of radiation readings (heat, light, ultraviolet, sound), chemical traces (pheromones, food and host tracking) and climatic variables (air pressure, photoperiod, windspeed) and analyze the data in their central processors to come up with responses which, on average, will result in propagation of the species.

As all computer users know, computers are extremely literal and are not capable of working or "thinking" beyond their programming or instructions. Insects are very similar. No insect has ever had a flash of inspiration. Tremendous potential for biological control exists through modifying habitats so that they appear unsuitable or are unusable for the target insects, or through confusing agents which will derail the insects programming. By accepting that insects are complex life forms we can better deal with managing their activities within the forest.

3. POPULATION PHASES

The mountain pine beetle exists in two distinct population phases: the endemic and the epidemic. The different population phases have very different life habits. The behavior of epidemic beetle populations has already been described. The behavior of endemic and transitional populations follows.

3.1 ENDEMIC

The endemic beetle population is the small number of beetles that exist in all lodgepole pine stands. They live a marginal existence in small, weakened and stressed trees, often in conjunction with Ips spp. and Pityophthorus bark beetles. The other beetles infest the host stem first, weakening it so that the mountain pine beetles can gain entry. Mountain pine beetles have also been observed infesting porcupine damaged stems in the endemic phase. The behavior of attacking injured or weakened trees or those of low resistance apparently allows the beetles to maintain their populations at low levels while the main stand is growing into a condition that will support an epidemic population (Amman 1978, Amman and Safranyik 1984, Shrimpton and Reid, 1973)

3.2 TRANSITION

Understanding how the transition from endemic to epidemic population occurs is of paramount importance for beetle control strategy.

Schmitz (1993) postulates the following scenario for the jump from endemic to epidemic populations. As noted above, the endemic populations of mountain pine beetle depend on the activities of other beetle species to weaken trees so they can successfully invade the bark without being pitched out. However, the associated beetles prefer small diameter stems, and mountain pine beetles have low breeding success and low brood production in such habitat. As the associated species deplete the available small stem habitat, they are forced to invade larger stems. This reduces their population health, resulting in declining populations of the associated beetle species, but allows a window of opportunity for the mountain pine beetles to increase their breeding success.

Schmitz hypothesizes that each endemic population group of mountain pine beetles may get only one or two chances to make the leap from endemic to epidemic. Many factors come into play:

1. The associated beetle species must attack a sufficiently large and healthy tree to produce large broods of mountain pine beetles.
2. The mountain pine beetle broods from the marginal host tree much hatch and fly at the same time, in order to successfully mass attack a healthier, larger diameter pine tree where their breeding success rate will increase.
3. Weather conditions must be favorable for the small beetle population to increase.

Schmitz believes that an endemic mountain pine beetle population must reach epidemic proportions and be able to mass attack relatively resistant trees before the associated beetle population dies out due to lack of suitable habitat, taking with it the endemic mountain pine beetle population.

The transitional populations and large suitable stems must also be spatially arranged in such a way that:

1. Enough beetles from the endemic population can congregate on a single desirable large stem to overcome its resistance, and;
2. The resulting brood can concentrate on a small group of large stems in the area around the brood tree, overcome host tree resistance, and continue to increase.

The beetles must attack in sufficient numbers to overcome a large tree. On the average, the number of beetles produced in small trees is less than the number of parent beetles that killed the tree. In contrast, a large surplus of beetles is usually produced in large trees. Therefore, once the beetles make the first population jump to establish an initial successful infestation in large trees in a susceptible stand, an epidemic is usually well under way (Amman 1981).

In summary, the switch from endemic to epidemic populations depends on stand and climate conditions, coupled with a "chance" element - the habitat based relationship between mountain pine beetles and associated beetle species.

4. MANAGEMENT AND CONTROL OPTIONS - THEORY

Having examined the life cycle, behavior and limitations of the mountain pine beetle, one central question remains. Is there such a thing as a merchantable sized lodgepole pine forest that is pine beetle resistant? The answer, fortunately, appears to be a qualified "yes". Given enough beetles from infestation centers within a stand or from a neighboring stand, any tree will succumb. However, if we can control the number of attacking beetles and the stand microclimate and/or vigor, beetle resistant stands can be maintained.

McGregor, Amman, Schmitz and Oakes (1987, 1988, 1989) have found evidence which relates microclimate and pest dynamics. In their research, they oversaw partial cutting trials at various densities using diameter limit cuts and spaced thinnings in 76 and 102 year old pine stands in the northern U.S. There was an active beetle infestation in the study area. There was an instantaneous reduction in losses to pine beetle in the thinned stands. In a four year period when the untreated control stands in their two study areas suffered 73% and 93% losses, the treated stands suffered losses ranging from 4% to 39%. The 39% loss occurred in a very lightly thinned stand. If the 39% is disregarded the next highest loss is 17%. This is a dramatic reduction in beetle activity. To quote the researchers:

> *The results of our study demonstrate that partial cutting can be used to reduce tree losses to pine beetle. Our results show that properly spaced lodgepole pine of any size can be left in the stand, thus preserving the faster growing genotypes associated with large trees. ...When faced with an impending pine beetle epidemic, inclusion of partial cuts in the overall strategy appears to be a reasonable alternative to wide scale regeneration harvests (clearcuts) or extensive beetle caused mortality.*

The interesting point is that the "beetle proofing" of these stands occurred too soon after spacing to be attributable to any increase in vigor. The researchers concluded that it must be a result of the alteration of the forest microclimate caused by the reduction in crown closure. Amman et al (1988) state:

> *We believe alteration of stand microclimate is the key factor causing immediate reduction in tree loss to mountain pine beetle. Thinning results in greater insolation, light intensity, wind movement and reduction in humidity. Higher light intensity in thinned than in unthinned stands probably cause few beetles to stop in thinned stands and may cause beetles to avoid stands entirely. Therefore we offer the hypothesis that change in microclimate when thinning lodgepole pine is more important than tree vigor in reducing tree losses. When crowns of lodgepole increase in size following thinning, shade and accompanying microclimate slowly change to create an environment conductive to beetle infestation.*

Bartos and Amman (1989) conducted another research project into the effects of thinning on stand microclimate and beetle activities. They collected detailed microclimate data on two pine stands in Utah with very similar characteristics except that one stand had been reduced from 1090 st/ha to 707 st/ha. This is a very moderate thinning. The beetle population trapped using standard pheromone baiting in each stand was astonishingly different. An average of 8.7 beetles were caught per trap in the thinned stand versus 159.3 in the unthinned. Obviously, the beetles were not congregating in the thinned stands and/or could not find the pheromone baited traps. Among the important differences measured in the thinned stand compared to the control were greater insolation, higher air temperatures, higher stem and phloem temperatures and greater windspeed and air turbulence.

The authors observed that the differences between stands were often quite subtle, but caution that even minor changes in microclimate could have profound effects on the beetle. The high temperatures recorded on the south sides of trees could be a deterrent to beetle attack, although the north sides of the trees would be still be hospitable to beetles. However,

> *The effect of temperature could be more subtle than a direct inhospitable environment on the south sides of trees. Mountain pine beetle may have evolved behavior to avoid situations where their brood are not likely to survive (such as thinned stands). In thinned stands, where tree temperatures are a few degrees above those of trees in unthinned stands, the beetle larvae may proceed too far with their development before winter, thus entering winter in stages which are susceptible to freezing.*

Mountain pine beetle behavior could also be affected in thinned stands is by disruption of the pheromone communication system the beetles use to carry our mass attacks and congregate to breed. In closed canopy stands, most sunlight is intercepted and heat generated in the upper canopy. This produces a layer of warm turbulent air in the upper canopy, and a stable layer of cooler air beneath a temperature inversion in the lower canopy. Pheromone movement beneath a dense canopy on a sunny day is horizontally through the canopy. The periods of maximum beetle flight have been measured and correspond exactly with the periods of greatest air stability in the mid to lower forest canopy, and that beetles fly most in the midbole area in this stable air (Schmitz et al 1989). The beetles seem to be programmed to take advantage of conditions that are most favorable for their pheromone communication system which is the basis for their successful mass attacks and reproduction.

In thinned stands, the increased ground level insolation produces warm, turbulent air from the forest floor upward, and pheromone dispersal is vertical, up the stems of trees and into the upper air. This would play havoc with the beetles main communication system. Bartos and Amman (1989) state:

> *When mountain pine beetles do infest a tree in a thinned stand, usually only the single tree is infested, and occasionally a nearby tree when spacing is nor maintained. The openness of the stand causes convection currents created by solar insolation to transport the pheromone plume vertically out of the stand rather than horizontally. Thus, the infestation of other trees would be dependent on the degree of thinning.*

McGregor, Amman, Schmitz and Oakes believe that pine stands will be attacked again when the crowns close enough to create a cooler microclimate. They feel open stands must be maintained to preserve beetle resistant, which are by coincidence vigorous and healthy. The fact remains - it works.

Mark Znerold (1989) a forest silviculturalist with the U.S. Forest Service states that, "In ponderosa pine, lodgepole pine and Engelmann spruce, thinning is a very effective method of risk proofing the stand against beetle attack." Based on his experience thinning over many years, he recommends a 16 to 18 foot intertree spacing for lodgepole pine, which will hold the stand for from 40 to 60 years until a desirable rotation age of 120 to 150 years can be reached. One of his main objectives is to achieve the longer rotation to increase biological diversity. He also suggests the use of some small clearcuts (i.e. less than 4 ha) in order to further diversify the forest mosaic. He also points out that the National Forest Management Act in the U.S. prohibits any forest openings greater than 16 ha.

5. MANAGEMENT AND OPERATIONS STRATEGIES - APPLIED

5.1 FOREST MODIFICATION

The most basic step in mountain pine beetle management is to break up large, continuous areas of beetle habitat into smaller management units. This is done to quarantine beetle infestations and prevent or delay their spread over a large area, and to reduce the area susceptible to beetle attack at any one time. A mosaic pattern can be created through thinned stands, selectively logged blocks and residual forests. Naturally occurring young stands, water, nonforest areas, old clear cuts and old infestations can also be used in the mosaic to help geographically divide uniform pine types. A cutting pattern of this nature can have positive benefits for game and wildlife, and very few negative impacts. It also has the major positive benefit of providing good road access to all the residual blocks to facilitate silviculture and monitoring and/or control of beetle activity.

The unharvested stands in a cutting mosaic pattern are accessible for silvicultural treatments to improve resistance as outlined above. The main suggested treatment is stocking control at all age levels to maintain beetle resistance through high growth efficiencies and unsuitable stand microclimates. Fertilization could also be considered in exceptional cases but would not be a standard treatment due to cost (dollars and environmental) and the short term nature of its effects. The pest management objective would be to create pine stands vigorous enough to resist the start of an epidemic and with microclimates unfavorable to beetle activity with a sufficient buffer zone around them to prevent them from becoming infested en mass from outside.

Selection cutting in pine stands is difficult but not impossible. Windfirmness can be developed overtime and successive entries. Mistletoe problems can be managed with careful leave tree selection. Frequently, the main objective would be not timber production but to improve stand vigor and/or alter microclimate to improve beetle resistance. This would protect the other resource values in question and would remove likely initial infestation centers for beetle populations that would threaten other managed stands. Most areas likely to be considered for selection cutting also contain a spruce component which would be favored as a shade tolerant, beetle resistant species.

Another means by which sound silvicultural practices might help to increase stand resistance is based on the cooperative relationship mountain pine beetles have with other beetle species in their endemic population phase. The Ips and Pityophthorus beetles usually live in suppressed or weakened stems in the stand, which the pine beetles also colonize after the other species. Removing these stems at the pole stage would decrease the endemic population habitat for mountain pine beetles, making it more difficult for them to successfully attack larger stems and start an epidemic population.

5.2 SALVAGE

The salvage of beetle killed timber is a desirable option where such activities do not adversely affect other resource values. However, the mere fact that a stand contains beetle killed trees does not automatically designate it for salvage logging in a wholistic forest management system. Some unrecovered timber losses are acceptable. Other resource values must be respected. Development of managed stands in a pattern and plan that will reduce beetle losses for all the rotations to come takes priority over chasing around the country behind the beetle. Prior to salvage operations, a land use plan, access plan and pest management plan should be developed. The purpose of all this paperwork is to identify stands where salvage logging is desirable and will not harm other resources and to identify access routes and coordinate access with future needs and other resource values.

5.3 DIRECT CONTROL

Direct control of the mountain pine beetle is aimed at the transitional population phase. Within a managed forest area it is used to prevent outbreaks from reaching epidemic population levels before harvest can take place or while other treatments are used to improve stand resistance. It is not a replacement for forest modification, but it is a vital tool in overall beetle management. Methods of direct control which do not involve pesticide use include:

1. harvesting and milling infested trees before beetle flight.
2. using pheromone lures to attract beetles to trap trees that are then felled and burned.
3. felling and burning infested stems in the stand.
4. heat (flame) treating infested stems on the stump.

Direct control is expensive, labor intensive and demands good access to the stand in question. It will also do no more than delay a beetle epidemic if stand and climate conditions are favorable for the beetle. It is a suitable emergency measure in areas where stand management is planned in the near future, and a vital part of beetle control in areas that are under management

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MOUNTAIN PINE BEETLE - SUMMARY

BIOLOGY

One year life cycle, its niche is the inside of host tree.

Exists at endemic levels in all pine stands.

Needs available food supply and favorable climate to switch from endemic to epidemic population. Susceptible to cold - winter kills all eggs and pupae, moderate cold kills small larvae, extended -40 c kills all.

Epidemics will end when food supply gone or when macro or micro climate no longer suited to beetle.

MYTHS

"Clearcutting pine stands will control the beetle." Wrong - the beetle will continue to evolve new epidemics in susceptible uncut stands <u>because it is already there</u>. Only modifying stand or tree conditions to varied age classes and species mixtures will prevent epidemics.

"Clearcutting will reduce beetle hazard" Only temporarily - the expanses of even aged, single species forest which (hopefully) regenerate following such a program will again be prime beetle habitat in 80 to 100 years, which is the short term in responsible forest management. Also, monocultures contain the lowest level of natural predators and other controls, and are most susceptible to all forest pests.

"The beetle will kill all our forests if we don't act." Unlikely - how did all those 140 to 250 year old pine stands live this long, given that they always have contained some beetles? It would appear that the beetle is climatically limited where the weather is too cold.

ALTERNATIVES

Develop a forest mosaic. A pattern of stands of various ages and species which will limit the amount of continuous food supply in any one place and maximize biological controls (predators, species diversity, travel distance to food supply).

Stand tending to improve vigor. Waring and Pitman have shown that vigorous pine trees have sufficient energy reserves to defeat attacking beetles with pitch flows.

No vigor = no energy reserve = no pitch = successful attack.

Stand tending to change microclimate. McGregor has found that thinned, open stands are beetle proof. The beetles are programmed not to attack such stands - unstable air, pheromone dispersal, unsuccessful breeding, lack of thermal cover = high winter mortality.