

THE MOUNTAIN PINE BEETLE— IDENTIFICATION, BIOLOGY, CAUSES OF OUTBREAKS, AND ENTOMOLOGICAL RESEARCH NEEDS

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The mountain pine beetle, *Dendroctonus ponderosae* Hopkins, is the most important native insect that is infesting lodgepole pine, *Pinus contorta* var. *latifolia* Engelman, and ponderosa pine, *P. ponderosa* Lawson. The beetle was described by Hopkins in 1902 from specimens collected in the Black Hills of South Dakota. The name *Dendroctonus* means "tree killer" and this bark beetle is truly worthy of the name. During endemic periods, only an occasional tree can be found infested by the beetle. Then, within a period of 5 to 10 years, from 25% to almost 80% of the trees having a DBH of 4 inches and larger will be killed by an epidemic of beetles. In 1970, the mountain pine beetle accounted for almost 80% of lodgepole and ponderosa pine timber loss (over 6 billion board feet) in the Rocky Mountain States alone. Contrast this with the total harvest of 11 billion board feet in all of the United States during 1970. In 1976, infestation of mountain pine beetle occurred on many national forests, with 3 million lodgepole pines being killed on a single national forest (the Targhee).

We generally equate infestations with losses in timber values. However, there are other impacts; for example: the reduction in the quality of recreational sites and the cost of cleanup; the loss of ornamental trees around permanent residences and summer homes; and the probable effects on the wildlife and on the water quantity and quality. Not all effects of infestations are bad. A study in Colorado showed a large increase in forage production within a couple of years following the loss of ponderosa pine. Therefore, the seriousness of the impact depends upon the management's objectives.

The epidemiology of the beetle, covering the period from the start of the population buildup through the epidemic, has been studied in considerable detail in lodgepole pine. However, there are still important gaps in our knowledge concerning epidemics. In addition, the endemic, or low population, period is an area in need of research. Studies during the endemic period should reveal factors that keep the beetle population at low numbers for many years and then suddenly allow release of the population. Important means of preventing losses to the mountain pine beetle should come from studies of the endemic period.

BIOLOGY AND ECOLOGY

Distribution and Host Trees

The mountain pine beetle can be found throughout pine forests from about 56° north latitude in British Columbia to northern Mexico and from the Pacific Ocean on the west to the Black Hills of South Dakota on the east. Elevationally, the beetle occurs from about sea level in British Columbia to 11,000 feet in Colorado.

The most important hosts of the mountain pine beetle, based on commercial value and intensity of beetle epidemics, are: lodgepole pine; ponderosa pine; western white pine, *P. monticola* D. Don; and sugar pine, *P. lambertiana* Douglas. Other pines within the beetles' range are also infested and killed.

Occasionally, native nonhost trees (such as Engelmann spruce, *Picea engelmanni* Parry; grand fir, *Abies grandis* (Douglas) Lindl.; and incense cedar, *Libocedrus decurrens* Torrey) are infested, but usually little or no brood is produced. Some exotic trees, such as Scots pine and Norway spruce, also are infested and killed.

Life Cycle

The mountain pine beetle usually completes a single generation per year. Beetles mature in July; adults reach sizes up to 0.25 inch (6.4 mm) long and are dark brown to black in color. Prior to emergence, new adults feed within the bark to complete maturation. The feeding adults obtain fungal and yeast spores, which become packed into a special structure on the head. This structure is called a mycangium and is used to transport the spores to the new tree.

The emergence and flight of new adults usually begin after several days of relatively high temperatures. Beetles emerge only during the warm part of the day, starting when temperatures reach about 60°F (15.5°C) and ceasing in the afternoon when temperatures drop to about the same level. Maximum flight activity occurs between 11 a.m. and 6 p.m. in both lodgepole and ponderosa pine forests.

Although emergence may be spread over a period of a month or more, about 80% of the beetles usually emerge in a 1- to 2-week period. Large numbers of beetles emerging over a short period appear to be important for the beetles to attack and kill the most vigorous trees in the forest.

Emerging adults select and infest living trees. In lodgepole pine forests, the beetles are strongly oriented to large diameter trees, and vision is believed to play a strong role in final tree selection. Once the female starts boring into a tree, she produces a pheromone—that is, a chemical messenger—that attracts other beetles to the tree. When the number of attacks reach a certain density, a second pheromone signals the newly arriving beetles not to attack the tree, thus preventing overcrowding. These beetles infest adjacent trees. Attacks on an individual tree are usually completed within 48 hours.

Evidence of beetle infestation consists of: pitch tubes where beetles have entered the tree; and boring dust in the cracks and at the base of the tree. Although pitch tubes may be absent, orange-brown

boring dust around the base of the tree is a sure sign that the tree has been killed.

The adults bore through the outer bark into the phloem-cambial layer where they construct vertical egg galleries. The late July attack period corresponds well with the beginning of a seasonal decline in tree resistance, as determined by the tree's response to inoculations of blue-stain fungi.

Fungal and yeast spores and bacteria, carried by the beetles, commence growth in the living tissues of the phloem and xylem soon after the beetle starts its gallery. Although the role of all of these is not completely known, the blue-stain fungi: invade and kill cells; aid in killing the tree by interrupting water conduction; and cause a rapid reduction in moisture of the sapwood.

Eggs are laid singly in niches, alternating in groups along the sides of the gallery. They hatch within a week or so, and the larvae feed in the phloem, usually at right angles to the gallery. The larvae become dormant for the winter in late October and November and begin to feed again in April, completing their development in the latter part of June to mid-July.

The beetle generally has one generation per year; however, there are exceptions that are primarily dependent upon weather and climate. One exception is that the parents may establish two broods in some warm years. After completing an egg gallery in one tree, adults emerge and attack a second tree. Another exception is that 2 years may be required for the beetle to complete a generation at high elevations. Cool temperatures during the summer delay development of and emergence of beetles.

Infested trees can be detected by aerial surveys after the foliage has dried and changed color. As the foliage dries, it turns from green to pale green in the spring, then light orange, and finally a bright orange by July. The presence of emergence holes through the bark at this time signifies that the brood has left the tree to infest green trees.

Factors Affecting Brood Survival

During almost a year that the beetles are developing within the tree, many factors of mortality are reducing their numbers. These factors consist of: competition among the larvae; parasites and predators; pathogens; cold temperatures; drying of the

bark; and pitch. Several comprehensive life table studies of the beetle and its mortality factors, including a 13-year study, showed that none of these factors, either individually or in combination, regulate the beetle population. Survival of beetles during the epidemic period is more closely correlated with the diameter of and the phloem thickness of the trees than any other factors.

The numbers of new beetles produced is directly related to: the thickness (quantity) of the inner bark (phloem) layer, the food of developing larvae; and the rate of phloem drying, which is slower in larger trees. The phloem layer, also, is generally thicker in large-diameter trees and is related to tree growth.

CAUSES OF BEETLE OUTBREAKS

Although we know a great deal about the biology and ecology of the mountain pine beetle in lodgepole pine, we still do not know what triggers an outbreak. The classical theory for bark beetle outbreaks emphasizes some form of tree stress, decline in vigor, or tree injury to which beetles are attracted. Some possible stressing agents are drought, tree competition for moisture and sunlight, insect defoliation, fire, mechanical injury, and tree diseases such as commandra rust, dwarf mistletoe, and the root rots. However, none of these has been studied in depth to provide a definitive answer of the role of stress in triggering outbreaks of mountain pine beetle.

My studies suggest that mountain pine beetle outbreaks are related to physiological changes of the tree associated with good vigor—not stress. There are four main conditions that must be met for epidemics of the beetle to occur—sufficient numbers of large-diameter trees; thick phloem in many of the large trees; optimal age of trees; and optimal temperature for beetle development.

Effect of Tree Diameter

The mountain pine beetle usually selects the largest trees in the stand to infest, at least immediately preceding and during a major epidemic. These usually are the most vigorous trees in the stand. Please keep in mind that I am referring to unmanaged lodgepole pine stands. We don't know how the mountain pine beetle will respond to managed lodgepole pine stands.

The preference of the beetle for large-diameter trees is apparent when the percent loss is calculated for each diameter class for an entire infestation. In two stands in northwest Wyoming, trees killed by the beetles ranged from 1% of the 4 inch (10 cm) trees to 87% of the trees having a DBH of 16 inches (41 cm) and larger. Other observations, particularly in Montana, show that losses are greater in each diameter class than observed in Wyoming, with 100% of the trees over 12 inches DBH being killed in some stands.

Epidemics usually start in full-crowned trees (but not necessarily the oldest or biggest) located usually on the outer edge of the timber bordering open rangeland or lake and stream shores. In the more open portions of stands, the proportional losses of lodgepole pine are much greater.

Effect of Phloem Thickness

Trees on the edges of stands or in the more open stands are usually growing faster than those within stands and, consequently, have thicker phloem, resulting in high beetle production. This provides the impetus for starting an epidemic. Estimates of beetle production from trees in northwest Wyoming ranged from 300 for trees 8 to 9 inches in diameter to over 15 000 for trees 18 inches in diameter. 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.

Phloem thickness increases as diameter increases. Although this relation exists for all stands that we have measured, the phloem thickness for any given diameter will differ among stands, because of differences in stocking level and site quality.

Infested trees in dense stands produced fewer beetles than trees of the same diameter in more open stands. This is related to phloem thickness, which declines with increased stand density. Brood production from trees having thick bark in the least dense stands was over 4 times greater than in comparable-sized trees in the most dense stands.

Effect of Age

Age of host trees also is an important factor in mountain pine beetle infestations. Infestations seldom occur in lodgepole pine stands less than

60 years old and there is only moderate probability of infestation in stands 60 to 80 years old.

Although part of the beetle's selection of trees of older age may be associated with the generally smaller diameters of trees less than 60 years old, other elements also are involved. Phloem in young trees tends to be more spongy and resinous, probably because of more and larger cortical resin ducts. The blue-stain fungi, carried by the beetle and inoculated into such trees, do not establish well because of the greater resinous response of young trees. Although young trees are occasionally infested and killed, they tend to dry rapidly and few, if any, of the brood complete development. The average age and size of the trees infested by the mountain pine beetle at the start of an epidemic in northern Utah was 104 years and 13 inches DBH.

This apparent age requirement, essential for beetle epidemics, points to silviculture as a means of reducing losses to the beetle. Trees probably can be grown to a fairly large size under intensive management and be harvested at 60 to 80 years old without significant loss to the mountain pine beetle.

Effect of Climate

Although the diameter and the phloem thickness are major items involved in the dynamics of mountain pine beetle populations, epidemics can develop only in stands located where temperatures are optimum for beetle development. Climate becomes an overriding factor at extreme northern latitudes and at high elevations. At these extremes, beetle development is out of phase with winter conditions. Consequently, stages of the beetle that are particularly vulnerable to cold temperature enter the winter and are killed. Because of reduced brood survival, infestations are not as intense and fewer trees are killed as elevation and latitude increase.

These observations have been used to develop a stand risk rating system for mountain pine beetle in lodgepole pine. The factors used are: elevation-latitude of the stand; average age of the trees; and average DBH of the trees.

Looking at the overall relationship of mountain pine beetle and lodgepole pine, one cannot ignore the apparent coevolution of the two and the benefits to both. The killing of the largest trees in persistent and climax lodgepole pine stands, as they become mature or slightly before reaching maturity, provides a more

continuous supply of food, by breaking up the age and diameter structure of the stands. Infestations help maintain the vigor of the stand by eliminating some of the tree competitions, resulting in increased growth of residual trees.

In seral stands, lodgepole pine will be eliminated by climax species in the absence of fire. The large fuel loads that occur following beetle epidemics may result in fires that eliminate competing (climax) tree species and that perpetuate lodgepole pine. The serotinous cones of lodgepole pine open following a fire and the site is reseeded to lodgepole, thus assuring another generation of lodgepole pine and eventually food for the mountain pine beetle.

RESEARCH NEEDS

We know a great deal about the mountain pine beetle in lodgepole pine during epidemics, but keep in mind that, once an infestation reaches the epidemic stage, there is little that can be done to stop it. The entire epidemic for a given stand lasts 5 to 7 years. That simply doesn't give the land manager time to arrange a sale and to get the timber harvested before the beetle has killed most of the volume. Therefore, we believe the keys for minimizing losses to mountain pine beetle lie in the endemic, or low population level studies. Many of the entomological research needs listed by the research groups at Victoria and Ogden are similar. Some of the research needs are: outbreak prediction; the beetle blue-stain tree interaction; silvicultural strategies; control techniques; and beetle activity in ponderosa pine.

Outbreak Prediction

A method of predicting outbreaks far enough in advance that the land manager can take measures to minimize or prevent losses. This would give the land manager considerably more flexibility than it appears he now has. We have models that can predict losses when a lodgepole pine stand becomes infested (although these need to be refined for a wide range of habitat types and stand conditions), but we do not have a method of predicting when a beetle epidemic will start in any given stand of lodgepole pine. Some of the questions that need to be answered are:

1. Are there changes in beetle quality, including genetic changes that are important in allowing the population to become epidemic?

2. Likewise, are there changes in quality or quantity of blue-stain fungi that result in increased beetle survival?
 3. Do populations of natural enemies of the beetles decrease, thus allowing the beetle population to increase?
 4. And there is still the question of the role of tree stress or tree injury in triggering the epidemic. Do the beetles take advantage of such factors to increase their population to a level that any tree in the forest can be killed?
3. Cost-benefits for the various techniques need to be evaluated—not only for timber, but for other resource values.

Control Techniques

In the area of control, other than silvicultural practices, research is needed on host chemistry, as it relates to host selection by the beetle, and on behavioral chemicals produced by the beetle. Some of the questions that need to be answered are:

1. How does beetle dispersal relate to tree and stand characteristics and to the quality of the beetle population? Understanding dispersal characteristics may allow prediction of mass beetle movement and possible control through interception, decoy, and other disruptive treatments.
2. Are trees selected by the beetles on the basis of chemical composition? If so, can lodgepole be selected for particular chemical characteristics that would make it immune to beetle attack?
3. Can an effective attractant be developed? Some of the pheromone components have been identified, but others still appear to be needed before the synthesized pheromone can compete with natural compounds. An electro-antennogram approach through insect physiology offers promise of pinpointing specific compounds to which mountain pine beetles respond and which are important in their biology and ecology. A chemical bouquet that is competitive with natural chemical sources could provide the basis for trapping or decoying beetles, particularly at low population levels, thus keeping the beetle population at a low level indefinitely. Such compounds also could be used to monitor low level beetle populations in order to develop an index of outbreak probability.

The Beetle Blue-Stain Tree Interaction

Another area of research is the interaction of the mountain pine beetle with the host tree and with other species of bark beetles. Some of the questions that need research are:

1. How does the mountain pine beetle maintain a population when they are at very low levels and difficult to find?
2. What is the role of other less aggressive bark beetles, such as *Ips* and *Pityophthorus*, in maintaining these low level populations of mountain pine beetles?
3. What is the association of mountain pine beetles with diseased trees—diseases such as commandra rust, dwarf mistletoe, and the root rots?

Silvicultural Strategies

A third area of research is the improvement of development of silvicultural strategies to more effectively keep mountain pine beetle populations in check. Some of the questions are:

1. Is the mountain pine beetle dependent upon the secondary bark beetles in order to maintain a low level population? If so, can silvicultural practices be used to reduce or eliminate the suppressed, diseased or injured trees upon which such secondary beetles appear to depend?
2. Silvicultural methods presently being tested need to be extended and modified for different situations.

Beetle Activity In Ponderosa Pine

The last area in need of research that I'm going to mention is other pine hosts, particularly ponderosa pine. Unfortunately, what has been learned from research in lodgepole pine cannot be directly applied to ponderosa pine. The behavior of the beetle is different in ponderosa pine and is more variable

over the range of ponderosa than of lodgepole. For example, in eastern Oregon and westcentral Idaho, the beetles infest small-diameter ponderosa pine, in contrast to showing a strong preference for large, old-growth trees in northern Arizona and southern Utah. Therefore, we have much further to go in understanding the mountain pine beetle-ponderosa pine (MPB-PP) system than we do in lodgepole pine. Some of the research needs are:

1. Basic population dynamics studies to assess the role of natural enemies, phloem thickness, moisture, etc., and competitive insects—particularly the wood borer larvae.
2. Studies to identify the types of trees and

stands selected by mountain pine beetle over the range of ponderosa pine and to identify tree losses.

3. Models that link growth projections with mountain pine beetle population dynamics for predicting probability of infestation and expected tree losses.
4. Silvicultural practices modified to fit different site and stand conditions over the range of ponderosa pine.
5. Behavioral chemicals as a means of monitoring or trapping beetles for the prediction of impending outbreaks and for control purposes.