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Topics

Key Points

- Use hazard rating to set treatment priorities
- Prevent outbreaks by regenerating mature lodgepole
- Thinning can help
- High value trees are afforded temporary protection using pesticides

Management Guide for

Mountain Pine Beetle

Dendroctonus ponderosae Hopkins

Most frequently killed hosts in the Northern and Central Rocky Mountains:	• Lodgepole pine • Ponderosa pine • Whitebark pine • Limber pine • Western white pine	The mountain pine beetle is the most aggressive, persistent and destructive bark beetle in the western United States and Canada.

Manage by suppression and prevention

Because outbreaks usually develop in mature to over mature forests, especially in lodgepole pine, large reserves of these forests pose a constant hazard in areas climatically favorable for the mountain pine beetle (MPB). Thus, "storing" mature/over mature trees on the stump should be discouraged, or at least the risk of such should be realized. In addition, management plans for reserved areas, such as parks and wildernesses, should consider the need for protection against destructive outbreaks. The economic impact of tree mortality is largely dependent on the effects of epidemics on allowable cut, regeneration of affected areas, and increased fire.

Management must focus on forests and not MPB. Management should alter stand conditions that favor buildup of beetle populations. However, alternative strategies for reducing losses from MPB must emphasize biologically sound silviculture that includes concern for other resource values.

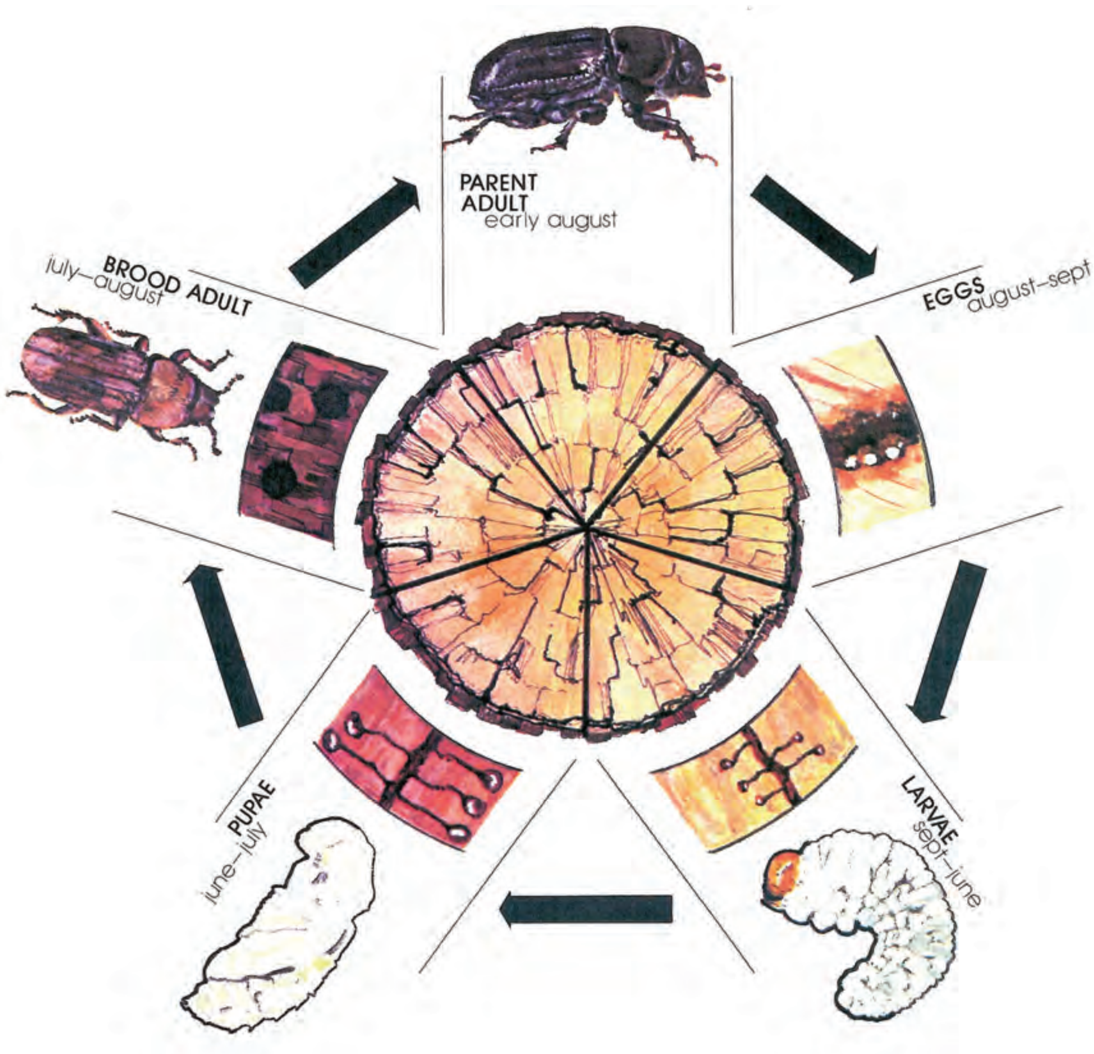
Basically, there are two approaches to reducing losses from MPB in pine forests: (1) long-term (preventive) forest management, and (2) direct control.

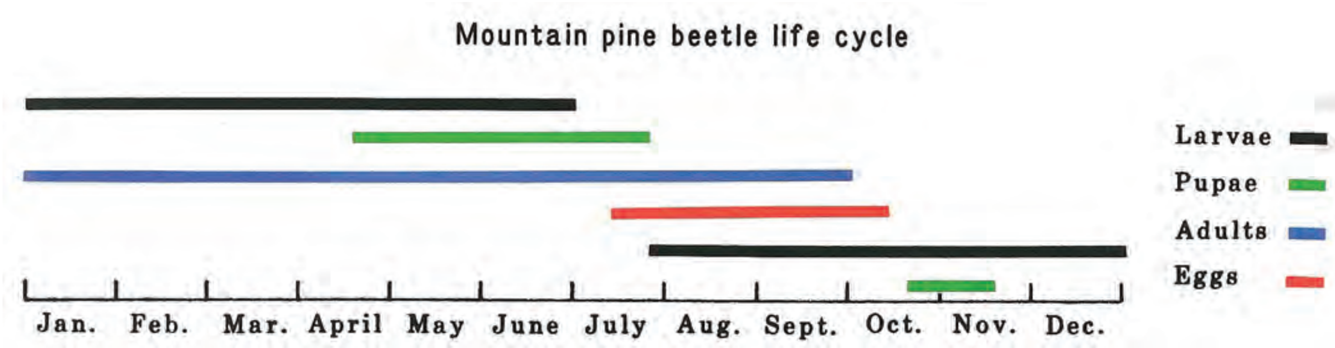
The strategy of preventive management is to keep beetle populations below injurious levels by limiting the beetles' food supply through forestry practices designed to maintain or increase tree/stand resistance. Preventive management addresses the basic cause of epidemics, which is stand susceptibility, and is considered the most satisfactory long-term solution. It includes a combination of hazard rating, priority setting, and silvicultural manipulations. protection costs. Situations where MPB instead of forest managers set priorities and dictate management options should be avoided. In contrast, suppression of MPB populations, that is killing them by various methods of direct control; treats only one symptom of the problem (too many beetles). Effects are usually, therefore, only temporary. When proper1y used, direct control might be effective both in reducing the rate of the spread and intensification of infestations; but should be considered only a "holding action" until susceptible stands can be altered silviculturally.

Life History

Mountain pine beetle over winters mostly as larvae beneath (or within) the inner bark of host trees. Occasionally, pupae and callow adults may also overwinter. In most lodgepole and ponderosa pine stands, larvae pupate at the ends of their feeding galleries in late spring. Adults emerge and attack from about early July through August depending on elevation and temperature. Egg galleries are more or less straight and vertical and may be up to 30 inches long. Eggs are laid along each side of the gallery in individual niches. Both niches and egg galleries are tightly packed with partially digested woody particles, or frass. Eggs hatch and larvae feed until freezing temperatures cause dormancy. Larvae go through four instars before pupating (Amman and Cole 1983).

Mountain Pine Beetle Life Cycle





Controlling MPB in lodgepole pine

Suppression

Direct Control

Direct control is expensive in time, effort, and resources. In spite of its long history, there is no general agreement among scientists and foresters regarding its effectiveness in reducing losses. Operational activities in Canada indicate that direct control can be a temporarily sound strategy and that tactics can be developed to implement it.

Since direct control is expensive, it is usually prohibitive to treat all infestations. Therefore, susceptible lodgepole pine stands need to be prioritized on economic, or other criteria; and control applied only to the most valuable stands. These stands must be resurveyed yearly, and as soon as newly attacked trees are discovered, a decision made on the feasibility of control action. If control action is feasible, direct treatment is applied involving sanitation cutting, controlled burning, single-tree treatment, or a combination of these methods (Safranyik 1982).

In order to be effective, suppression should be based on the following principles:

1. Early detection and control action over the entire infested area within one to two years.
2. Continue control work as long as necessary.
3. Thorough treatment and follow-up surveillance

Methods to kill beetles under the bark:

1. Pesticides (systemic, bark-penetrating) on unbaited or pheromone-baited trees. Chemical control by spraying standing and/or fallen trees provides only a holding action at best until the highly susceptible trees can be removed. Tree mortality will probably result despite any immediate success of direct control measures. Because stand susceptibility is not changed by this management option, reinfestation will occur (Cole and Amman 1980). This type of treatment might be more suitable for treating isolated spot infestations, especially in remote locations or in areas where logging is not possible.
2. Heat (burning, solar).
3. Mechanical (debarking process).
4. Water (sprinkling, submersion).

Individual Tree Protection

Preventative sprays can protect high-value trees in campgrounds, picnic areas, visitor centers, around permanent and summer homesites and administrative areas.

Shade and aesthetics can be protected for up to 2 years with one application of water-based carbaryl spray prior to beetle flight (Gibson and Bennett 1985)

Shore and Safranyik Hazard Rating System

Has three distinct facets:

- a susceptibility index,
- a beetle pressure index,
- a risk index.

Risk index is a combination of ***susceptibility index*** and ***beetle pressure index*** and is a measure of a stand's relative likelihood of sustaining damage from beetle attack in the near future. Risk index is a number, between 0 and 100. Higher numbers, represent higher probability of infestation.

Methods to protect trees from fatal attacks

1. Lethal trap trees baited with pheromone and treated with insecticide.
2. Protective chemicals. Although carbaryl treatments provided the standard preventive measures for more than 25 years, and was the only chemical registered for most of that time; pyrethroid insecticides have been recently tested and registered, and now provide an alternative to the use of carbaryl.
3. The anti-aggregative pheromone, verbenone, has been tested and registered as a preventive treatment. Results have not been as reliable as chemical insecticides, but may be a reasonable alternative in some situations.

Prevention

Management objectives should be directed toward preventing, or at least substantially mitigating, development of epidemic beetle infestations. Once populations increase to an epidemic status and outbreaks become as large as experienced during the 1970's and early 1980's, management of beetle populations, as well as other resources, becomes more complicated.

Hazard rating:

Recurrent depredations by MPB allow the forest manager less than a 50 percent (perhaps as low as 25 percent) chance of growing lodgepole pine to a 16-inch diameter in unmanaged stands. Two commonly asked questions are: (1) which lodgepole pine stands are most susceptible to mountain pine beetle outbreak, and (2) how many trees will be killed, or how much volume loss will occur, if a stand becomes infested?

Susceptibility of stands to MPB depredation is determined by hazard and risk rating stands. Generally, "hazard" is defined as the likelihood of an outbreak within a specific time period and is a function of stand conditions. “Risk" defines expected loss should an outbreak occur and is determined by proximity to beetle populations.

To date, several hazard rating systems have been developed based on climatic, tree, and stand variables that have significant effects on both beetle survival and distribution. That is, tree age, size, stand structure, phloem thickness, climatic conditions, and tree growth all determine stand susceptibility. Such site factors influence amount of tree and volume loss within stands.

The system formerly used in the Northern Region was developed by Amman and others (1977) and involves a 3-point rating of each of three factors: (1) climate (elevation/latitude), (2) average age of lodgepole pine in the stand, equal to or greater than 5 inches d.b.h., and (3) average d.b.h. of the lodgepole pine in the stand, equal to or greater than 5 inches d.b.h. Currently in our Regions, we most often recommended a hazard-rating system developed by Shore and Safranyik (1992). Similar in some respects to the one described by Amman, and others (1977), it is more definitive in its use of more detailed stand information, and it incorporates data relative to nearby beetle populations.

Calculating the Stand Susceptibility Index

To determine a stand's *risk index*, determine first its *susceptibility index* using stand data in the following relationship: The *susceptibility index* will range from 0 to 100. Highest values indicate the most susceptible stands.

Susceptibility Index (S) = P x A x D x L where:
P = Percent of susceptible pine basal area
A = Age factor
D = Stand density factor
L = Location factor

P is calculated: Average basal area per hectare of LPP > 15 cm d.b.h. x 100
Average basal area per hectare all species ≥ 7.5 cm. d.b.h.
(Note: Metric units must be used in formulas to assure appropriate table values are obtained.)

Susceptibility index is a measure of stand characteristics which describe their attractiveness to beetles and is based on four variables:

1. Susceptible host basal area (as percent of stand basal area),
2. Age of dominate and codominant host,
3. Stand density, and
4. Location (latitude, longitude and elevation).

Age factor from table:

Age of dominant or co-dominant LPP	Age Factor
< 60 years	0.1
61-80 years	0.6
> 80 years	1.0

Density factor from table:

Stems per Hectare (all species ≥ 7.5 cm d.b.h.)	Density Factor
≤ 250	0.1
251-750	0.5
751-1,500	1.0
1,501-2.000	0.8
2,001-2,500	0.5
> 2,500	0.1

There are three possible location factors, based on a combination of longitude, latitude and elevation. Location factor is determined from the formula Y = [24.4 longitude] -[121.9 latitude] -[elevation (in meters)]+ 4545.1. For most areas on a District, and perhaps over a Forest, the location factor, once determined, will remain constant.

Y	Location Factor
≥ 0	1.0
between 0 and -500	0.7
< -500	0.3

Calculating the Beetle Pressure Index

Beetle pressure index is related to the size and proximity of MPB population being rated. Determine first the size category from the following table:

Number infested trees outside stand (within 3 km)	Number infested trees inside stand < 10	10-100	> 1 00
< 900	Small	Medium	Large
900-9,000	Medium	Medium	Large
> 9,000	Large	Large	Large

Beetle pressure index
is related to size and proximity of nearest mountain pine beetle population. Both relative abundance of beetles and their nearness to the stand for which risk is being determined will influence that stand's likelihood of being infested.

Now, use following table to determine **beetle pressure index**:

Relative Infestation Size	Infestation Within Stand	Distance to Nearest Infestation (km) 0-1	1-2	2-3	3-4	4+
		Beetle Pressure Index (B)				
Small	0.6	0.5	0.4	0.3	0.1	0.06
Medium	0.8	0.7	0.6	0.4	0.2	0.08
Large	1.0	0.9	0.7	0.5	0.2	0.10

Risk Index:

Having determined both *susceptibility index* (S) and *beetle pressure index* (B), we can now calculate *risk index* (R) from the relationship:

$$R = 2.74\,[S^{1.77}e^{-0.0177S}][B^{2.78}e^{-2.78B}]$$

Where:
e = Base of natural logarithm = 2.718
B = *Beetle pressure index*
S = *Susceptibility index*

Alternatively, *Risk index* can be found in the table on page 6. *Risk index* will be a number between 0 and 100. The highest numbers represent stands that would receive the most damage from beetles in the near future

Risk Index Table

Based on Susceptibility Index (S) and Beetle Pressure Index (B)

S	***Beetle Pressure Index (B)***									
	0.1	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1.0**
10	<1	<1	2	3	5	6	7	8	8	8
20	<1	2	6	10	14	18	20	22	24	24
30	<1	4	10	17	24	30	35	39	40	41
40	1	6	14	24	33	42	49	54	56	57
50	1	7	18	30	42	52	61	67	70	71
60	2	9	20	34	48	61	70	77	81	82
70	2	10	22	38	53	67	78	85	89	91
80	2	10	24	40	56	71	82	90	95	96
90	2	10	24	41	58	73	85	93	98	99
100	2	11	25	42	59	74	86	94	99	100

Risk index is a relative measure of a stand's likelihood of being infested in the near future -generally less than 3 years. Because it includes beetle pressure, a dynamic statistic, it should be updated every couple of years.

Models to predict stand losses

Risk index is not a predictive measure, per se, but does show a particular stand's likelihood of infestation relative to others evaluated. In a follow-up study, Shore, and others (2000) developed a predictive model that could be used to estimate percent basal area killed, based on stand *susceptibility index*. Their model is expressed as:

Percent basal area killed = 0.68 x stand *susceptibility index*

As an alternative, stands determined to be of highest risk could be subjected to analysis using the Rate of Loss Model (Cole and McGregor 1983) to determine an approximation of loss should infestation occur. This model predicts tree and volume loss over time and helps set priorities for entering high-risk stands. The model is available as part of the FINDIT program (Bentz 2000), and is also a subroutine of the Forest Vegetation Simulator (FVS).

Data used in determining stand susceptibility and risk may be obtained from surveys designed specifically for determining stand susceptibility, timber inventory, or regular stand exams.

Rate of Loss Model

To approximate mortality in high-risk stands:

- Available as part of FINDIT program
- Subroutine of the Forest Vegetation Simulator.

Silvicultural Alternatives: Even-aged lodgepole pine stands

Shortened rotation is a viable option when lodgepole pine is the desired species and a smaller tree size can be grown which would still satisfy product requirements and economics of the operation

Type conversion:

Type conversion can be an attractive choice when most objectives of management can be met equally well with different forest types. Even though the mountain pine beetle appears to infest the lodgepole component of mixed stands as readily as pure stands, the overall stocking and wood production would be higher. Achieving a mosaic of age classes and tree species in stands creates a minimum area susceptible to the beetle, making fast removal and/or application of direct control action more feasible. This operation takes careful long-range planning, good roads, markets, and above all, time.

Clearcutting in small- to moderate-sized blocks creates age and size mosaics within extensive pure even-aged stands and is a highly recommended practice (Amman 1976). Timely surveys and maps of stand growth and volume, site quality, and other risk-related factors such as phloem (inner bark) thickness, elevation, latitude, stand structure and form, composition, and forest type are essential for clearcuts to be effective. Schedules for clearcutting as a preventative measure should be coordinated with other multiple-use management objectives. In areas where probability of loss is high, future damage can be reduced by directing regeneration to alternating species among blocks or to mixed species within blocks (D. M. Cole 1978, Cole and Amman 1980, McGregor and Cole 1965).

Salvage and sanitation cutting:

In practice, salvage and sanitation logging is favored over individual tree treatment because it is more cost effective. Also, salvage operations utilize infested timber and reduce both the number of beetles and their potential food source. Individual tree treatments do not yield any salvage value and it is difficult to thoroughly treat large areas (Safranyik 1982).

Salvage and sanitation cutting should be adjusted either directly by timber economics or indirectly through protection of other resources to qualify as loss reduction practices (D. M. Cole 1978). Salvage cutting should be carefully planned and administered as a conscientious silvicultural practice to protect other resource values. Time between tree killing and salvage cutting should be minimal to prevent wood deterioration. This should be done before beetle flight or it won't be effective in protecting trees in the cutover adjacent stands.

Sanitation cutting

of highly preferred large-diameter, infested trees from high-hazard stands may slow rate of mortality. However, sanitation cutting will not significantly alter stand structure, and beetles will seek out and infest residual, preferred large-diameter lodgepole pine unless all preferred trees are cut or the stand structure is altered. Surveys to inventory stand structure, diameter-phloem distribution, and growth of residual lodgepole pine may permit successful cutting; and prevent, or greatly reduce, beetle infestation for several years. Sanitation cutting is expensive and must be carefully coordinated to prevent spread of beetles into other stands along haul roads or from infested log decks at sawmills. Sanitation cutting must also take into account the presence of dwarf mistletoe or cutting may leave too many infected residuals. Salvage, or a combination of sanitation/salvage, should be used with caution in some stands. Residual stands should be managed to meet objectives for growth, maximum stocking levels, and species composition. Salvage works best where epidemics are in early stages, in well-stocked stands with a relatively minor component of host species, and generally confined to operable ground with access in place.

Stocking control:

This is extremely important in pure, even-aged lodgepole pine stands. It allows maintenance of good stand vigor and the direction of stand growth toward moderate tree sizes and rotation objectives (D. M. Cole 1978).

Stocking control by age 25 (preferably by age 15) to a spacing of about 10 by 10 feet results in culmination of mean annual increment on medium to good sites at about age 80 with average stand diameters of about 20 inches d.b.h. Additional thinning (commercial thinning would prolong the culmination of CAI/MAI from about 80 years to probably 120-130 years. Growth decline and MPB infestation could probably be prolonged for a number of years through early thinnings.

Through stocking control, diameter/phloem thickness distributions could be managed to favor those not preferred by MPB. Alternatively, early stocking control and managed practices for increasing rate of growth (thinnings, genetic improvements, and fertilization) could increase tree vigor so that present age/size limits of tree susceptibility would not be restrictive (Safranyik 1982).

Photo of stocking control by thinning can make a stand less attractive to MPB.

Silvicultural Alternatives

Pure, uneven-aged lodgepole pine stands and mixed-species stands

Stocking control, clearcutting, and salvage cutting

For uneven-aged and mixed species stands preventive practices mentioned for pure, even-aged lodgepole pine stands are also feasible. For example, mature uneven-aged or mixed-species stands with a significant component of large lodgepole pine in the overstory can be clearcut. If already infested, mortality can be lessened by salvage logging.

Immature, uneven-aged, and mixed-species stands are candidates for stocking control with species discrimination possible in mixed-species stands (D. M. Cole 1978).

Species discrimination

In older mixed-species stands we can discriminate against lodgepole pine by cutting only the larger lodgepole. This can be considered a valid practice in regulated forests only if the residual stand is of sufficient vigor and stocking to maintain stand growth near the yield capability level of the site. However, value of the volume removed must exceed removal costs unless indirect benefits of beetle management warrant subsidization.

Partial cutting

Partial cuts can be used to advantage in order to reduce the losses from impending outbreaks through overwood removal, shelterwood, and group selection. This method is especially attractive when environmental and visual impacts preclude clearcutting. However, dwarf mistletoe infection and windfall susceptibility can be serious drawbacks on some sites (Safranyik 1982). Amman (1976) concluded that partial cutting is an option where timber values are primary, but applies only where:

- a small portion of the lodgepole pine have larger diameter and phloem thickness categories conducive to beetle population buildup,

(Continued on page 10)

Partial Cutting may be useful where:

- Clearcutting is not compatible with multiple-use objectives.
- Combinations of mature forest and openings are desired.
- Regeneration after clearcutting is difficult.

Considerations for Partial Cutting in Lodgepole Pine Stands

Bollenbacher and Gibson (1986) have described additional conditions in which partial cutting may be desirable or preferable to regeneration harvests. If the decision has been made to conduct partial cuts, or "sanitation thinning," as a part of an overall management strategy, the land manager must choose stands where this technique will be most successful. Following is a list of site attributes and considerations to use when evaluating a lodgepole pine stand as a candidate for sanitation thinning.

1. Site productivity: A favorable soil moisture regime will likely add to the probability of an increase in growth and vigor of the crop trees.
2. Slope: Generally treat stands on tractor ground less than 35 percent to limit residual stand damage.
3. Average stand diameter: Choose stands where average d.b.h. exceeds 9 inches with less than 350 trees over 5 inches d.b.h. per acre. These stands will be more economical to log and will sustain less residual stand damage.
4. Age: Consider stands that are greater than 60 and less than 125 years old.
5. Current basal area: Stands should have at least 130 square feet per acre to be an economical logging chance.
6. Elevation: Consider only those stands lower than 6,000 feet. Stands at higher elevation (in northwest Montana) are generally lower risk due to a shorter growing season.
7. Wind firmness: In relation to topography, choose the most sheltered slope positions, as identified by Alexander (1975).
8. Present beetle infestation rate: Choose stands with a present infestation rate of 10 percent or less. Higher levels may result in excessive mortality in leave trees if logging is not completed prior to the next beetle flight.
9. Tree vigor: Choose stands with crop trees having a live crown ratio of 30 percent or greater.
10. Other resource objectives: Consider only those stands where other resource objectives may not be met through regeneration harvesting.

High windfall risk situations

- **Ridge top**
- **Moderate to steep middle south– and west-facing slopes not protected to windward, and all upper south-and west-facing slopes.**
- **Saddle on ridge tops.**

(Continued from page 9)

- residual trees would be numerically adequate and vigorous enough to maintain stand productivity.

Partial cuts in a mixed-species stand, just coming under attack, might be justified if removing high-risk lodgepole pine in mixed-species stands would protect adjacent, un-infested lodgepole pine stands. That might only be applicable in the situation where lodgepole pine in the mixed-species stand was of higher risk than that in the adjacent pure stand and infestation of the mixed-species stand posed an undue risk to adjacent stands of lower susceptibility (D. M. Cole 1978).

Windthrow in relation to prescribed cutting

Lodgepole pine is generally considered susceptible to windthrow, and the risk increases when stocking is reduced through partial cutting (Alexander 1975). Root system development varies with soil and stand conditions. On deep, well-drained soils, trees have a better root system than on shallow or poorly drained soils.

With the same conditions, the denser the stand, the less wind firm are individual trees because trees that develop together in dense stands over long periods of time, support each other and do not have roots, boles, and crowns to withstand exposure to wind if opened drastically.

The risk of windthrow is also greater on some exposures than others. The risk of windfall in these situations is increased at least one category by such factors as poor drainage, shallow soils, and defective roots and boles. All situations become high risk if exposed to special topographic situations such as gaps and saddles in ridges at higher elevations to the windward that can funnel wind into the area.

These guides should be carefully considered in assessing the efficacy of any intermediate or harvest cutting prescription for lodgepole pine stands, including those aimed at preventing or ameliorating mountain pine beetle effects.

Moderate windfall risk situations

- **Valley bottoms parallel to prevailing winds.**
- **All lower and gentle middle north- and west-facing slopes not protected to the windward.**
- **Moderate to steep middle south– and west-facing slopes protected by considerably higher ground not far to windward.**

Low windfall risk situations

- **Valley bottoms except where parallel to prevailing winds, and all flat areas.**
- **All low and gentle middle north- and east-facing slopes.**
- **All lower and gentle middle south- and west-facing slopes that are protected by considerably higher ground not far to windward.**

Semiochemicals and Baiting

Semiochemicals

Relatively recent developments by Borden, and others, (1983, 1986, 1987) have shown MPB semiochemicals ("message"-bearing chemicals) can be effectively used to augment silvicultural practices designed to reduce stand susceptibility. Semiochemicals are naturally occurring pheromones produced by attacking beetles, plus host-produced volatiles, which in combination result in mass attacks on individual trees. Taking advantage of this phenomenon, private industry has synthesized, packaged, and is marketing the complex of MPB semiochemicals in the form of aggregative “tree baits” (Phero Tech 1987).

Semiochemical tree baits are used in various strategies, in combination with logging, to essentially contain beetle populations in stands scheduled for harvest. Strategies vary with infestation intensity, size of infested stand, and susceptibility or infestation status of surrounding stands.

Spot baiting

Developed to eliminate small "spot infestations of less than about 30 trees, spot baiting will hold beetles in the infested group until that group can be removed in a small patch cut Best used for isolated infestations, effectiveness of this strategy may be diminished if heavily infested stands are closer than a few miles. In this strategy, 2-3 susceptible trees are baited in the center of the group prior to beetle flight. Following beetle flight, the entire group of dead and currently infested trees is removed.

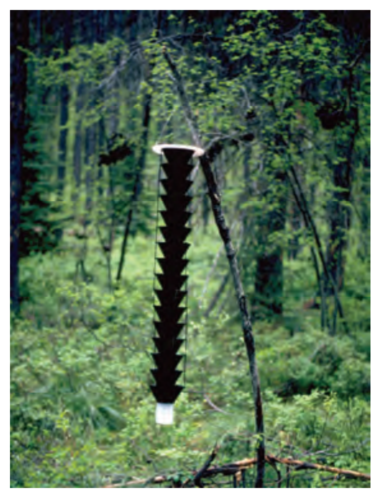


Photo displays a funnel trap containing aggregative semiochemicals provides a means to assess populations of MPB

Mop-up baiting

This strategy is used as a follow-up action where needed in an area previously treated. By baiting susceptible trees at a 2 ½- chain interval (165 feet) around the treated spot, and any susceptible trees left within the spot, beetles can be further concentrated and removed in a post-treatment operation.

Grid baiting

Grid baiting has shown good results in containing beetles in infestations up to 50 acres in size. With this technique, susceptible trees within the infested area are baited on a 2 ½-chain (165) feet) grid throughout the stand. Care should be taken to bait no closer to cut boundary than 165 feet to avoid beetle dispersal beyond cut-block borders. Once again, trees are baited before beetle flight and the entire stand is removed in a clearcut operation following beetle flight.

Additional research with semiochemicals has involved the use of anti-aggregative pheromones for stand protection, and a combination of attractive and anti-aggregative pheromones in "diversion" tactics. Though both strategies hold promise, we are probably a couple of years or more away from their operational use. The anti-aggregation pheromone, verbenone, has shown promise as a stand or individual tree protectant in recent tests (Bentz, and others, 2002).

Managing non-timber values

The do-nothing policy may be a viable option on forested areas not included in commercial timber production. As far as aesthetics are concerned, infestations (both far and close views) may have little impact on the viewer. However, dead timber can have an enormous impact on areas relative to recreation, wildlife, build up of fuel, fire hazard, and plant succession. Therefore, a fire management program utilizing prescribed fires in combination with some "safe" wild fires, may be more appropriate and ecologically more desirable than the no-action policy (Safranyik 1982).

Natural Control Factors

While beetles are developing within a tree, many factors of mortality are reducing their numbers. These factors consist of competition among 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 one 13-year study, showed that none of these factors, either individually or in combination, regulate beetle populations. Survival of beetles during epidemics is more closely correlated with tree diameter and phloem thickness of their hosts than any other factor.

In general, the number of beetles produced in any one tree is directly related to thickness and quality of phloem (food for developing larvae), and rate of phloem drying—which is lower in larger trees. Phloem layer is generally thicker in large-diameter trees and is a function of past growth.

Climate

Although tree diameter and phloem thickness are major factors involved in the dynamics of MPB 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.

Ponderosa Pine

General site characteristics and damage

High stand density is directly related to site quality, both of which are positively correlated with damage. Intensive competition between trees in dense stands and its effect on tree resistance to beetle outbreak in the history of a second-growth stand usually occurs between ages 50 and 100 years, depending upon site quality. Stands often sustain their first serious infestation between 50 and 75 years on better sites because they grow into a susceptible condition earlier. On poorer sites, trees are usually 75 to 100 years old when an outbreak first occurs.

Direct control

Most of the philosophies, methods, and materials used to suppress MPB in lodgepole stands can be used in ponderosa pine stands. Again, most direct control efforts should be considered a holding action until silvicultural treatments can be applied.

Hazard Rating Stands

Three stand characteristics affect susceptibility to attack: (1) stand structure, (2) average d.b.h. of ponderosa pine component, and (3) stand density as expressed by average basal area per acre (Stevens et at. 1980).

(1) Stand Structure

Single-storied stands are most susceptible to severe damage. They are most likely to become attacked first and to suffer greatest mortality. Such stands are given a hazard rating of (3). Two-storied stands are rated (2) since overstory trees are generally not as susceptible. Multi- storied stands have not been given a rating, but probably could be rated (1).

(2) Average Diameter

As mean stand diameter increases, stand susceptibility increases. Stands greater than 1 10-inch average d.b.h. are high hazard (3), those 6 to 10 inches are moderate (2), and those less than 6 inches are low (1). However, more trees in the 6 - to 12-inch d.b.h. size classes will be killed once an infestation starts.

(3) Stand Density

The more dense the stand within a given average diameter, the more susceptible it will be to severe beetle-caused mortality. Hazard ratings for stands in which average d.b.h. is greater than 5 inches are: more than 150 square feet per acre = high (3); 80 to 150 square feet per acre = moderate (2); and less than 80 square feet per acre = low (1). This will vary with geographic area, with 120 BA/acre being high risk in some stands.

Computing a stand hazard category is similar to that described for lodgepole pine. The three numerical ratings above for stand characteristics are multiplied to obtain a stand risk value. The hazard value will then be assigned a rating as follows:

Schmid, and others (1994), confirmed Stevens earlier work and also demonstrated that stand hazard, a function of stocking, can effectively be reduced through commercial thinnings.

Estimating mortality

Loveless (1981) Mortality Risk Rating system to estimate anticipated mortality in ponderosa pine stands

Number of ponderosa pine killed in an infestation increases as:

- **Average d.b.h. decreases (down to about 6-8 inches),**
- **Site index increases,**
- **age increases.**

Stand Risk Value	Hazard Rating
2-6	Low
8-12	Moderate
18-27	High

Managing ponderosa pine to minimize losses to MPB

Year 1

- Determine boundaries of area to be included and arrange for handling as a unit.
- Salvage infested trees over entire area
- Locate areas in which thinning is needed (through hazard rating previously described). Begin thinning to BA of about 80 square feet per acre.

Year 2

- Continue salvage.
- Finish thinning.

Year 3

- Salvage

Year 4+

- Maintain surveillance and salvage as needed.

Year 10+

- Re-evaluate treated area. Thin where necessary to maintain low stand density.

Silvicultural Alternatives

Thinning of overstocked second-growth ponderosa pine stands can have a profound effect on beetle-caused mortality. An un-thinned stand stocked at a basal area of 152 square feet per acre had 8 percent of the stand killed by mountain pine beetle in a 5-year period. A similar stand, thinned to 15- by 15-feet spacing (80 square feet per acre BA) showed only 0.2 percent mortality in the same period. In addition to reduced mortality, thinned stands showed a net growth (Sartwell and Dolph 1976). Maintaining stand basal area below 150 square feet per acre has been effective in suppressing beetle outbreaks in the Black Hills (Schmid, and others, 1994). A cooperative FPM-Lolo National Forest study showed beetle-caused mortality was higher where stand basal area exceeded 120 square feet per acre.

Cautions are issued, however, where thinning is used to manage beetle populations. First, thinning has no application where trees are in a fringe area and widely spaced. Second, thinning in a small stand may not be successful if the stand is surrounded by un-thinned, infested stands. Finally, slash must be property disposed of, i.e., piled and burned or lopped and scattered to prevent population buildups of pine engraver beetles (*Ips* spp.). Where limbs or tops more than 3 inches in diameter are left, engraver beetles may develop and infest surrounding green trees.

Stevens, and others (1974), have outlined a management program to minimize losses. See the sidebar at right Using these guidelines, it may take at least 3 years to implement the program and significantly reduce mortality.

Natural control

The same factors that affect MPB in lodgepole pine pertain to ponderosa pine. However, severe low winter temperatures probably do not kill as many beetles in ponderosa pine because of its thicker bark.

Western White Pine

In the intermountain West, MPB is chronic in areas of residual mature western white pine. Trees over 90 years of age are susceptible and are frequently killed. Rarely does MPB attack a western white pine under 10 inches in diameter unless there are extenuating circumstances—such as blister rust infestation, extreme dry weather, or other stressing factor. Infestations in unmanaged pockets of mature western white pine usually do not spread into surrounding stands of lodgepole or neighboring ponderosa pine trees.

Surveys and observations over the years indicate that direct control, salvage logging, or partial cutting usually does not stop the beetle from killing residual mature western white pine in a stand.

Western white pine have not recently been intensively managed because of blister rust depredations; however, as rust-resistant plantations begin to mature, we may learn thinning to maintain low stand basal area will reduce mortality from MPB. At present, we recommend harvesting mature western white pine whenever feasible. It is a gamble to store such trees on the stump unless they can be salvaged easily.

Whitebark Pine

Although long known to be hosts of MPB, whitebark and limber pines have only recently begun to experience extreme amounts of beetle-caused mortality in the intermountain West. Currently, little is known about beetle life cycle at higher elevations. It may well be longer than one year.

Likewise, management efforts have been infrequently attempted on these sites. There is, however, increased interest in protecting seed-bearing trees because of their importance to wildlife species, and because of recent efforts to develop rust-resistant programs.

Mountain Pine Beetle can be devastating in dwindling white-bark pine forests.

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