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Gene D. Amman
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the species and its management
SYMPOSIUM PROCEEDINGS

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Compiled and Edited By:

DAVID M. BAUMGARTNER, Washington State University, Pullman, Washington, USA

RICHARD G. KREBILL, Intermountain Forest and Range Experiment Station, Missoula, Montana, USA

JAMES T. ARNOTT, Pacific Forest Research Centre, Victoria, British Columbia, Canada

GORDON F. WEETMAN, University of British Columbia, Vancouver, British Columbia, Canada

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INSECTS OF LODGEPOLE PINE: IMPACTS AND CONTROL

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ABSTRACT

Of approximately 240 species of insects that feed on lodgepole pine, 35 are considered pests or potential pests. Nine insect species cause serious damage in periodic, local infestations and one species, the mountain pine beetle, causes catastrophic losses in repeated outbreaks over most of its distributional range. Stand management offers the best possibility for reducing losses. Seed and cone insects do not extensively affect seed production; nursery stock can be protected through cultural practices and pesticide treatments. Several insects affecting young stands cause reduced height growth and permanent crooks in stems. Defoliating insects, such as the lodgepole needle miner and pine sawflies, usually infest trees of all ages and cause growth loss and some mortality during severe outbreaks. Bark beetles, especially the mountain pine beetle, pose the most serious threat to lodgepole pine management.

INTRODUCTION

Lodgepole pine, *Pinus contorta* Douglas, like most trees, provides habitat for a variety of insect species throughout its development. These range from moth larvae that feed on seed and cones to bark beetles that cause widespread mortality of mature trees.

Although we know which insect species most commonly affect different stages of stand development, we lack fundamental knowledge of the significance most insect damage will have on final harvest. The life table approach for forest stands (Waters, 1969) could be used for an integrated analysis of forest stand productivity and an assessment of important agents affecting productivity, including insects.

Generally, insects affect productivity in four ways, as illustrated by the following examples:

1. *Understocking.*—Even though large amounts of seed are produced and large numbers of seedlings emerge, insects that destroy seed and seedlings can reduce productivity; losses during early stages of stand development can result in an understocked stand at the time of tree harvest. (fig. 1A).
2. *Reduction in merchantability.*—Insects that kill terminal leaders can cause deformed or multistemmed trees that yield less merchantable wood at time of tree harvest. Following harvest, merchantability can be further reduced by insects that bore holes into the wood unless logs are processed promptly (fig. 1B).
3. *Growth reduction.*—Insects that remove large amounts of foliage or those that partially girdle trees reduce growth and productivity because a longer time is required for a tree to reach merchantable size (fig. 1C).
4. *Direct killing.*—Bark beetles cause large losses in productivity by killing merchantable trees and by reducing numbers of merchantable trees to the point that harvest of residual trees cannot be accomplished profitably (fig. 1D).

As the intensity of forest management changes, insect problems will change also. This fact is already apparent; several insect species previously considered to be innocuous under natural stand conditions have caused extensive damage when planting and thinning were attempted.

Insect species have been divided into groups that affect the different stages in the life of lodgepole pine trees. Only some of the more important species have been included. Nursery pests are not treated. These usually are general feeders and are covered in publications such as Sutherland and Van Erden (1980). The greatest effort has been placed on the mountain pine beetle because of interest generated by severe, almost continuous losses of lodgepole pine during the past 25 years. For more detailed descriptions and life histories and for broader coverage of insect species affecting lodgepole pine, you are referred to Furniss and Carolin (1977) and Evans (1982). Recommendations for control of insects by chemical insecticides are avoided purposely. Recommendations for use of pesticides change; some are no longer in effect, whereas improved materials and methods are being developed.[1]

INSECTS OF REPRODUCTIVE STRUCTURES

Although animal and weather factors may destroy a large proportion of lodgepole pine reproductive structures some years, these losses have a negligible silvicultural effect (Tackle, 1961). Studies of red pine cones suggest destruction of developing cones by insects may actually enhance flower primordia production and, consequently, the abundance of future feeding and breeding sites for cone insects (Mattson, 1978).

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[1]Insecticides used for direct control or preventive sprays are reviewed continually by the Environmental Protection Agency. Therefore, persons contemplating use of insecticides should ensure that the materials are currently registered for use.

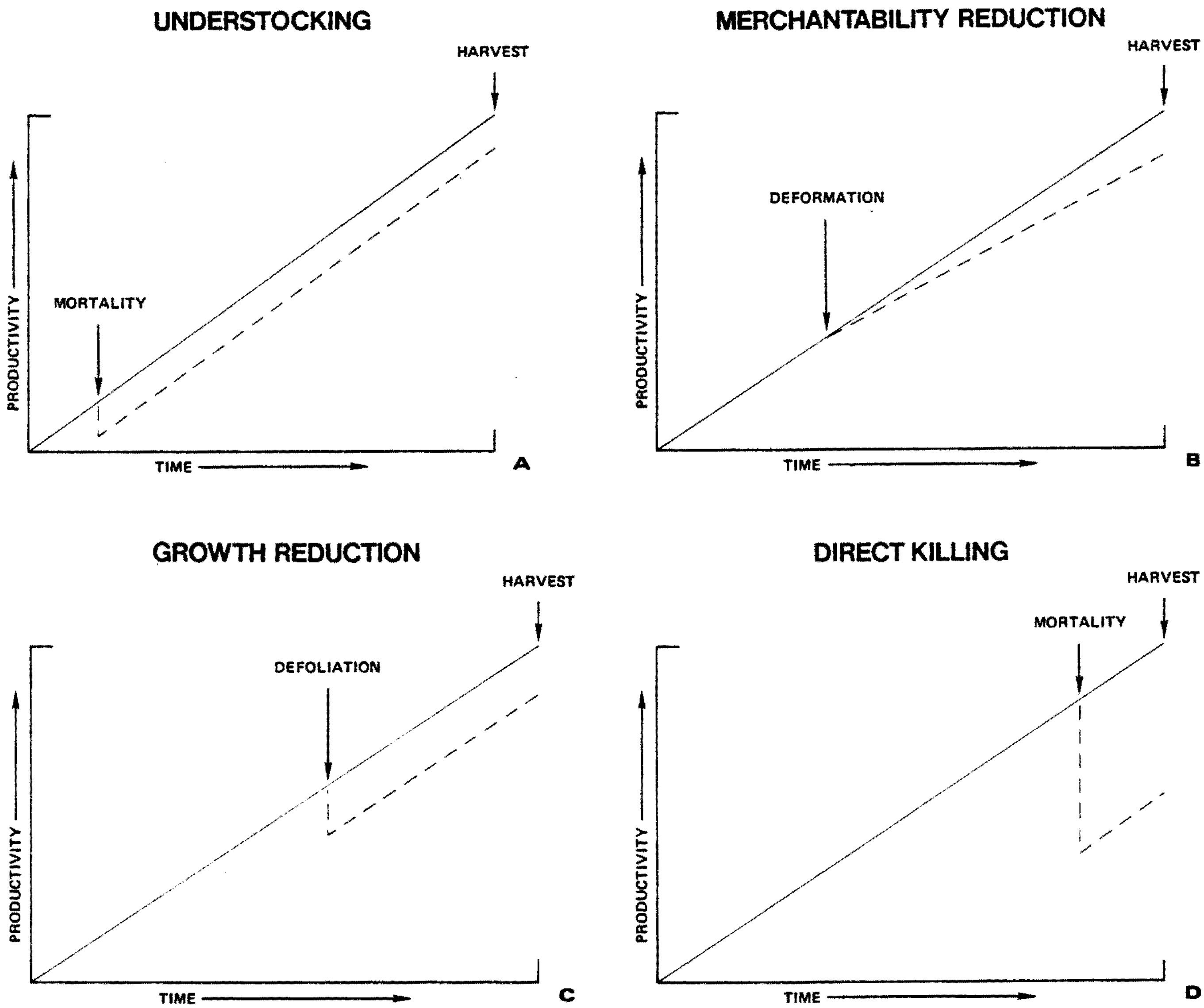

Figure 1.—A. Effect of stand understocking on productivity. B. Effect of reduction in tree merchantability on productivity. C. Effect of tree growth reduction on productivity. D. Effect of merchantable tree mortality on productivity.

The closed-cone habit of lodgepole pine is at least partially responsible for the negligible effect of losses. In stands of lodgepole pine where the closed-cone habit prevails, millions of viable seed may be stored per hectare for many years (Lotan and Jensen, 1970). Following fire or cutting, this seed then is available for seeding the area. In stands where the closed-cone habit is limited, however, seed losses to insects could have a significant effect on attempts to generate some stands. In addition, some of these insects could become major factors when superior tree and seed selection programs for lodgepole pine are initiated.

Since the Lodgepole Pine Symposium in 1973, a number of additional species have been reported feeding on the reproductive structure of lodgepole pine (Furniss and Carolin, 1977), and perhaps the reason damage has been considered low (Keen, 1958) is that few studies of only short duration have been conducted. A study of lodgepole pine cones in 1971 found only 2 percent infested by insects (Parker, 1972). Larvae of the moths (Lepidoptera) are the most common insects infesting lodgepole pine reproductive structures.

Lodgepole pine cone borer, *Eucosma rescissoriana* Heinrich (Lepidoptera: Olethreutidae), larvae tunnel in second-year cones and feed on the scales and seeds, consuming the softer parts of cones, leaving the woody veins and paper-thin layers at the surface of the cone scales. Larval mines are packed with fine-grained dark brown frass pellets. Damaged scales may fail to open at cone maturity, trapping sound seed within the cones (Hedlin *et al.,* 1981). The proportion of damaged cones is usually low, but is found to increase with spacing in western white pine plantations in Idaho (Ollieu and Schenk, 1966).

The adults, which have tan forewings with rust-red markings, emerge and lay eggs on cone scales. Larvae hatch from the eggs in about a week and tunnel between cone scales into the seed, where they feed on seeds and scale tissue. The dirty white larvae may damage more than one cone in completing development (Hedlin *et al.,* 1981). They drop to the forest floor to spin cocoons and pupate in September and October. There the pupae overwinter and development is completed in the spring.

Laspeyresia toreuta (Grotê), one of the seedworms (Lepidoptera: Tortricidae), is associated with seed, upon which the larvae feed almost exclusively. Cones of pines are infested during the second year of development. The cones show no external evidence of damage. Upon hatching, the larva bores between cone scales, enters a seed, and consumes it, then moves on to the next seed, leaving frass and a silk-lined tunnel. When fully developed, the cream-colored larva tunnels into the cone axis, where it overwinters. In the spring, development is completed and the adult emerges to lay eggs on the cones (fig. 2) (Hedlin *et al.,* 1981).

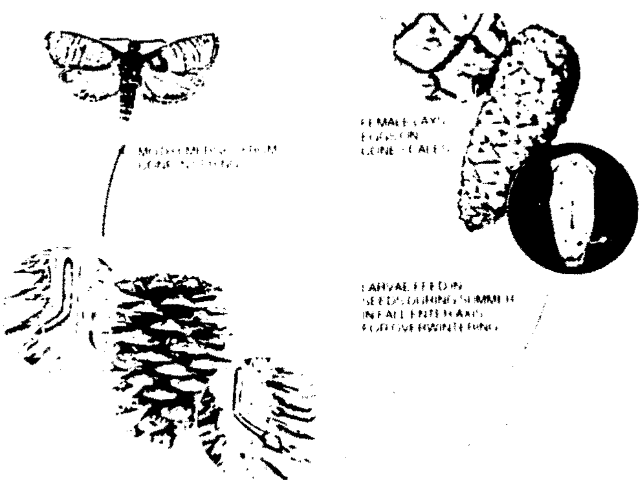

Figure 2.—Life cycle of a seedworm, *Laspeyresia* sp. (Hedlin *et al.,* 1981).

Dioryctria abietivorella (Grotê), the fir coneworm, feeds on the cones of lodgepole pine, leaving conspicuous frass and webbing on cone surfaces. Boring larvae riddle the cones. Some larvae pupate in the ground in late summer; adults emerge shortly after to lay eggs which overwinter. Other larvae overwinter in cocoons, then complete development in the spring. Adults emerge and lay eggs in May and June (Hedlin *et al.,* 1981).

The reproductive structures of lodgepole pine are a major feeding site for larvae of *Choristoneura lambertiana* subspecies *subretiniana* Obraztsov (Lepidoptera: Tortricidae), one of the budworms (Stark and Borden, 1965). Cones are often completely excavated.

When the budworm larvae hatch in late summer, they may feed on the needles, and defoliation is the most conspicuous indicator of the insects' presence. But, if male and female flowers and cones are present, those may be preferred feeding sites. External frass and webbing are signs of infestation. Flowers may be completely consumed and holes bored into the developing cones (Hedlin *et al.,* 1981).

Adults emerge in mid-to-late summer and lay eggs that are flattened and overlapping in long masses on the needles. When the larvae hatch in late summer, they molt once, without feeding, and overwinter in small webbed tents called hibernacula. In the spring, the larvae mine old needles or buds and flowers. Then they feed on new foliage and in some cases the cones. Pupation occurs on the tree about midsummer.

The ponderosa pine cone beetle, *Conophthorus ponderosae* Hopkins (Coleoptera: Scolytidae), considered potentially the most damaging insect in seed orchards and seed production areas (Dale and Schenk, 1978), also feeds on lodgepole pine cones. Second-year cones are attacked in late spring or early summer by adult female beetles, severing conductive tissue at the cone base. Dead cones appear as shriveled brown cones on the tree or as partly developed cones that fall to the ground. The beetles enter through the cone stalk or side of the cone near the base. Eggs are laid in a gallery made in the cone. Larvae complete development in about a month, pupate, and then become adults. The adults may overwinter in the dead cone, or leave and enter shoots or conelets where they feed and overwinter. A single generation is produced each year.

The western conifer seed bug, *Leptoglossus occidentalis* Heidemann (Hempitera: Coreidae) feeds by piercing the cone scales into developing seeds. When feeding occurs before the seedcoat hardens, the contents of the seed are removed and the seedcoat collapses. If the seedcoat has hardened, the seedcoat does not collapse (Krugman and Koerber, 1969), even if the contents have been removed. When adults first emerge from hibernation in the spring, they feed on developing male flowers, causing them to be stunted or deformed. The pollen sacs are pierced and pollen dissolved, causing necrotic areas around the feeding site and thus reducing pollen production.

The bug has one generation per year, laying eggs on needles. When nymphs hatch from eggs in May to early July, they feed upon developing cones and seeds. The nymphs mature by August but continue to feed on seed until cold weather arrives, when they seek sheltered locations for hibernation.

Xyela alberta (Curran), the pine catkin sawfly (Hymenoptera: Xyelidae), feeds in developing male flowers. The flowers may be obviously deformed by effects of oviposition and flecked with resin. Larvae feed on pollen, moving from sac to sac. When grown, they drop to the soil where they pupate, remaining there for one to two seasons (Hedlin *et al.,* 1981). The pine catkin sawfly probably is not of much importance in the forest; however, they could reduce pollen significantly from particular clones used in artificial breeding.

INSECTS OF SEEDLINGS AND SAPLINGS

Some of the insects mentioned in this section also can extensively damage pole and mature trees. Likewise, some insects mentioned in the section dealing with pole and mature trees can damage younger trees. For convenience, discussion is limited to the period in the life of the tree when damage is likely to be most significant.

Previously, damage by insects that affects young trees has been considered of little economic importance, but Fellin and Schmidt (1966) warn that this type of damage can be expected to increase as forest plantations and naturally regenerated stands increase in acreage. Recent observations of damage in young lodgepole stands throughout much of the lodgepole pine type gives credence to their statement. The principal problem presented by insects affecting young trees is the killing of the terminal, which may result in a crooked or multistemmed tree and a reduced amount of merchantable wood at maturity. In addition, insects can have a devastating effect on lodgepole grown for Christmas trees.

Shoot Insects

The lodgepole terminal weevil, *Pissodes terminalis* Hopping (Coleoptera: Curculionidae), occurs throughout the range of lodgepole pine and probably is the most important insect affecting young lodgepole. In Alberta, weevils are most common in the central and southwestern regions (Johnson *et al.,* 1971). Adult weevils usually feed and oviposit in elongating terminal leaders during June and July. The current year's terminal growth is killed when larvae mine through the phloem, sapwood, and pith (Salman, 1935; Stark and Wood, 1964). Occasionally, lateral terminals are infested. Infestation causes reduced height growth, permanent crooks in stems and, in severe cases, "stag-headed" crowns.

Larvae usually complete development by late August and overwinter in the shoot (Stevens and Knopf, 1974). Some individuals overwinter as pupae (Evans, 1982), however, while others develop to adults and emerge in the fall (Stark and Wood, 1964; Drouin *et al.,* 1963). These adults may overwinter in the forest floor. Overwintering larvae complete development in the spring and emerge in June and July, completing the single generation per year.

Large percentages of trees in some stands have been infested at one time or another; for example, in two stands in Idaho, 50 percent (Stevens and Knopf, 1974) and 80 percent (Klein and Tegethoff, 1970) of the trees had been infested, and in two stands in central British Columbia, 40 percent and 50 percent top kill occurred (Johnson *et al.,* 1971). Stevens and Knopf (1974) felt that fairly heavy weevil activity could be tolerated in stands managed for poles and sawlogs because severely damaged trees could be removed in thinning at age 30. After age 30, very little weevil infestation occurs. In addition, most trees outgrow the effects of weevil infestation.

Salman (1935) wrote that terminal-feeding weevils do less well under shaded conditions. Attacks are most commonly confined to the leaders of vigorously growing trees, and maximum damage occurs in open stands 1.5 to 5.0 m (5 to 16 ft) high (Drouin *et al.,* 1963; Stevenson and Petty, 1968). Significantly higher damage levels occur in thinned than unthinned stands of lodgepole pine (Bella, in press). Nevertheless, Stevens and Knopf (1974) did not believe that the weevils preferred open stands. These differences in weevil response may be related to geographic location. Additional work is needed to determine if controlled stand density would be worthwhile in minimizing damage by the terminal weevil. The degree of shading through controlled stocking will be a compromise between stocking that yields rapid growth and stocking that reduces weevil damage to an acceptable level. Weevils in Christmas tree plantations would probably require control by chemical insecticides.

The western pine shoot borer, *Eucosma sonomana* Kearfott (Lepidoptera: Olethreutidae), also infests the shoots of lodgepole pine. Although the effects of shoot moths on lodgepole have not been assessed, loss in average annual height increment of infested ponderosa pine is estimated at up to 25 percent of height increment for uninfested trees (Stoszek, 1973).

Moth activity on lodgepole pine is probably similar to that reported on ponderosa pine. The shoot moths lay eggs in early spring, with larval hatch occurring with start of bud elongation. Larvae bore into the pith of expanding buds, the shoot apex apparently being preferred. The feeding tunnel is confined to the pith region; it is straight and filled with compacted frass (fig. 3). Mature larvae leave the shoot, drop to the soil, and pupate. More infested leaders occur on dry sites than wet sites. No control is recommended at this time. Additional work is needed on shoot borer damage in lodgepole pine.

The European pine shoot moth, *Rhyacionia buoliana* (Schiffermuler) (Lepidoptera: Olethreutidae), is potentially one of the most damaging shoot-boring insects of lodgepole pine. This introduced species now is established in various locations in British Columbia, Washington, and Oregon, mostly on ornamental and shelterbelt pine trees (Harris and Ross, 1973; Furniss and Carolin, 1977). Naturally growing lodgepole pine are also susceptible to damage. Trees from seedling size to about 7.5 m (25 ft) tall are most susceptible to injury. Damage is caused by the larvae mining the buds and shoots. Trees are most seriously affected when the terminal shoot is infested, resulting in reduced height growth and forked, multiple, or crooked stems. Young trees are sometimes killed.

Figure 3.—Terminal shoot of lodgepole pine is killed by *Eucosma sonomana* larva feeding within the shoot.

The European pine shoot moth has one generation per year. Adults moths fly in midsummer (active at dusk), and eggs are laid on twigs, buds, and needles. Larvae mine into nearby needles and later move into buds to overwinter. The following spring, the dark brown larvae mine buds and new shoots, reaching 10 mm (0.4 inch) in length when mature. Pupation occurs in a mined shoot about mid-May (Evans, 1983; Furniss and Carolin, 1977).

The distribution of the moth is generally limited above snowline by minimum temperatures of -29°C and lower. Prevention of the movement of infested stock, coupled with control of local infestations, are the most effective measures in containing the spread of the insect into uninfested areas. Insecticides are effective when applied April to mid-May to kill active larvae, and mid-June, after egg hatch and before the larvae burrow too deeply into buds. In addition, clipping and burning of infested shoots in gardens and nurseries help prevent the spread of infestations.

Pine gallmidges, *Cecidomyia* spp. (Diptera: Cecidomyidae), are widely distributed throughout the range of lodgepole pine. Several types of damage are described from British Columbia (Evans, 1983): crooked shoots occur principally on lodgepole pine, and twig swelling and pitch blisters occur mainly on shore pines. Damage is most commonly associated with young trees and frequently occurs on leaders.

The adults are fragile insects, approximately 2 to 5 mm (0.08 to 0.20 inch) long, have nearly clear wings, and resemble mosquitoes. Their coloration varies from pale brown to pink and black, depending on species and sex. Eggs are pink or brown, and the larvae and pupae (about 2.5 mm = 0.1 inch long) are pinkish-orange when mature. Adults fly during late spring and the females lay eggs on the scales of young shoots. Larvae bore into the plant tissues, feed, and overwinter there.

Crooked shoots are caused by larvae feeding inside the ends of needles near the bases of shoots. More than 40 percent of the shoots on a tree may be affected (Evans, 1983), and shoot mortality is about 12 percent. Twig swelling, which occurs mainly in pine reproduction, is caused by larval feeding in pitch blisters in the bark of last year's leader growth. The feeding activity causes swelling of the shoot and frequently is followed by mortality.

Outbreaks by *Cecidomyia* spp. in young lodgepole pine stands developed in four areas in the Prince Rupert Forest Region of British Columbia during 1972-73. Up to 40 percent of the leaders were killed. Control has not been attempted.

Stem Insects

A weevil, *Hylobius warreni* Wood (Coleoptera: Curculionidae), has caused extensive damage to lodgepole pine, attacking healthy trees from a few years old to maturity. Adult weevils feed on terminal shoots and needles and cause negligible damage. Larvae feed on phloem and cambial tissues, however, girdling roots and portions or all of the root collar, which causes reduced radial and height increments (Cerezke, 1972) or kills the tree (Warren, 1956a). Wounds may serve as entry points for root and stem diseases (Cerezke, 1971).

Tree mortality is most common in stands less than 30 years old. Weevil attack preference was found to be directly related to tree size and age and the thickness of the duff, and inversely related to stand density (Cerezke, 1970). The highest weevil populations tend to occur on the better pine sites at lower elevations. A method for estimating abundance of the weevil and its damage has been developed (Cerezke, 1970). In natural stands, the kill rarely exceeds 5 percent (Cerezke, 1974). In eastern Canada, pine plantations tend to be more heavily attacked (up to 63 percent mortality) than natural regeneration (Cerezke, 1971). In artificially regenerated lodgepole pine stands, weevil impact has not been adequately assessed. In one study from central British Columbia, estimated mortality from the root collar weevil in eleven 7-year-old plantations ranged from 2 to 13 percent (Herring and Coates, 1981).

H. warreni lays eggs in small niches chewed in the outer bark at the base of main lateral roots of healthy pines. The young larvae feed in the living phloem and cambium of the root-collar zone below the surface of the forest duff. They pupate in chambers composed of bark and humus. Up to 2 years may be required to complete development. Silvicultural methods offer the best opportunity for control of *H. warreni.* Weevil damage is more common on wet sites than on dry sites (Warren, 1956b) and year-to-year damage is correlated within weevil-infested stands, an indication that certain stands are subject to continual infestation (Cerezke, 1970). Nonhost trees could therefore be grown on susceptible sites. Pines appear to be preferred hosts, although white spruce is readily infested also (Warren, 1956a).

In the process of reforestation, logging debris should be burned or removed, including all advanced pine and spruce regeneration. Cerezke (1971) noted that clearcutting in large blocks, followed by scarification, will probably provide control of the weevil and prevent damage to regeneration in the clearcut blocks. Weevils have a high moisture requirement (Warren, 1956a; 1956b), so trees in the new stands that have a layer of moist humus at their bases are more subject to infestation.

The pitch nodule moth, *Petrova albicapitana* (Busck) (Lepidoptera: Olethreutidae), is distributed throughout the northern States and in Canada. In Alberta, the moth is most common at elevations less than about 900 m (2,953 ft) (Drouin, personal communication, 4/84). This insect usually attacks young lodgepole pine to the sapling stage, but it is also common on mature trees. The damage is caused by the larvae feeding on the bark, phloem, cambium and, to a lesser extent, on the sapwood of both the new and old growth of stems, twigs, and branches. Larval presence is recognized by nodules of pitch and frass where the larvae entered the bark (fig. 4). Attacks usually are at nodes or whorls of branches. These weakened portions frequently are broken by wind or snow (Keen, 1952; Drouin and Kusch, 1981).

The pitch nodule moth requires 2 years to complete its life cycle. Eggs are laid on needles or at the base of the needle sheath from early June to mid-July. The larvae feed in the terminals, creating small circular excavations in the cortex. These are covered with silk and pitch. As they feed, larvae create nodules. With the onset of cold weather, larvae become dormant. In spring, larvae leave the overwintering nodules and move along branches toward the tree trunk. Larvae resume feeding at crotches on the main stem or on a branch, forming new nodules about 2 cm (0.8 inch) in diameter. The larvae spend the second winter in these nodules. In early spring, the larvae feed a short time, then pupate. Adults emerge in June to mid-July (Turnock, 1953).

Trees between 0.3 to 1.5 m (1 to 5 ft) tall are most susceptible to infestation. A significantly higher percentage of trees are damaged in thinned than unthinned lodgepole stands (Bella, in press).

Nurseries and Christmas tree plantations may require protection with chemical insecticides. Control of 67 to 71 percent was achieved during a test of dimethoate used as a soil drench (Drouin and Kusch, 1981). No chemicals are registered for control of the pitch nodule moth.

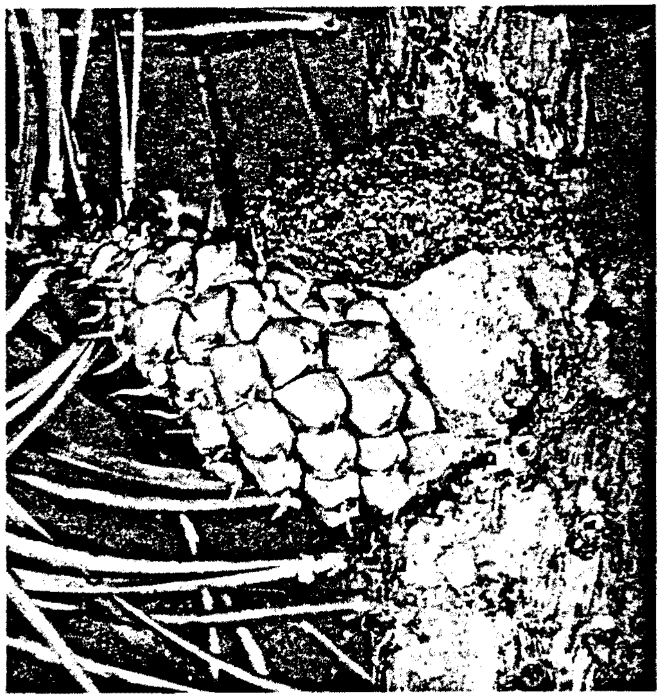

Figure 4.—Pitch mass is formed during feeding by pitch nodule moth larva, *Petrova* sp. Stems are weakened and subject to wind breakage. Courtesy H. F. Cerezke.

Another moth, the sequoia pitch moth, *Synanthedon sequoiae* (Hy. Edw.) (Lepidoptera: Sessidae), was reported to be a pest of lodgepole pine as early as 1914, when serious infestations occurred over 36,422 ha (90,000 acres) of lodgepole pine in Montana (Brunner, 1914). Larvae usually feed around the root collar or near the base of branches. Larval feeding in the cambium causes massive pitch flow (fig. 5), growth reduction, and even death of some trees. The lack of frass particles in the pitch helps distinguish pitch moth infestation from that of bark beetles. The pitch moth prefers open stands and dry, sunny slopes. The life cycle requires 2 years. The adult moths are black with yellow markings, and have clear wings with a span of 25 to 30 mm (1 to 1.2 inches). The moth, which resembles a hornet, lays eggs on the trees during early summer. Eggs hatch and larvae enter the bark before winter. The larvae overwinter twice, pupating in late spring of the second year of the life cycle. An outbreak of the insect in over 400 sapling-size pines near Trout Creek, Mont., was associated with pruning and thinning operations; many trees were nearly girdled at the root collar (Tunnock, 1967). Pruning for fuel breaks in California attracted the sequoia pitch moth, which infested mostly the largest, most vigorous trees (Powers and Sundahl, 1973). The large resin masses associated with infestation are deemed a hazard when using prescribed fires to maintain a fuel break because they readily ignite. Adverse appearance of *S. sequoiae* attacks affects the esthetics, particularly along roadsides (Powers and Sundahl, 1973). Pruning and thinning after moth flight so moths are not attracted probably would result in less infestation.

Figure 5.—Feeding in the bark by larvae of sequoia pitch moth, *Synanthedon sequoiae*, causes large pitch masses to form and may completely girdle trees.

Needle Insects

Adults of the weevil, *Magdalis gentilis* LeConte (Coleoptera: Curculionidae), make feeding punctures that cause defoliation of young trees; the adults are attracted to stands being thinned. Habits of larvae are unknown. Damage to young trees is most severe when thinnings are made prior to late July; therefore, conducting thinning operations after July, when adults are not present to be attracted into the thinning, should help reduce damage (Hamel and McGregor, 1974). Denser stocking could also reduce damage; more weevil damage occurred where trees were widely spaced (Fellin and Schmidt, 1966; Fellin, 1973).

Sucking insects (Homoptera: Diaspididae) commonly found on lodgepole pine are the pine needle scale, *Chionaspis* (*Phenacaspis*) *pinifoliae* (Fitch), and the black pine leaf scale, *Nuculaspis* (*Aspidiotus*) *californicus* Coleman. In Canada, areas where repeated infestations occurred are the Okanagan and East Kootenay of British Columbia. In the United States, notable infestations occurred at Cashmere and Spokane, Wash.; The Dalles, Oreg.; and several areas in California. The pine needle scale is usually a pest of young trees in low vigor. Nevertheless, a severe infestation developed on 500 ha (1,236 acres) of mature trees near Lake Tahoe, Calif. (Pierce, 1969). On severely infested trees, foliage turns yellow or becomes mottled and eventually drops from the tree. Infestations cause growth loss and may gradually kill branches and sometimes the entire tree.

Young pine needles scales are pale brown and about 1 mm (0.04 inch) long; the scale covering the mature, wingless female is white, flat, narrow, and about 3 mm (0.12 inch) long. They occur on needles and stems. In the cold interior climate, the scale overwinters only as eggs, but in the warmer maritime climate, both eggs and adults overwinter. Eggs overwinter under the body of the female and in the spring hatch into briefly mobile nymphs. Usually there is one generation a year (Evans, 1982).

The black pine leaf scale is commonly associated with the pine needle scale. The black scale (about 2 mm = 0.08 inch long), as its name implies, is black or dark grey and easily distinguished from the pine needle scale, which has a whitish covering. There may be one or more generations per year. This scale is usually associated with conditions that are harmful to the host tree, such as smog, smoke, dust, and smelter fumes (Edmunds, 1973; Struble and Johnson, 1964).

Both scales can be controlled by insecticides. Spraying is usually unnecessary or impractical under most forest conditions, but may be necessary in nurseries and young plantations. An outbreak of the pine needle scale at South Lake Tahoe was thought related to mosquito fogging that killed parasites and predators which had kept the scale under control (Luck and Dahlsten, 1975).

Actebia fennica Tauscher (Lepidoptera: Noctuidae), the black army cutworm, normally an occasional pest of agricultural crops, is now recognized as a serious pest of newly planted conifer seedlings, including lodgepole pine (Ross and Ilnytzky, 1977). In British Columbia, epidemics occur at about 10-year intervals and major epidemics last up to 4 years.

The black larvae with two double white lines on both sides of the body (fig. 6) are usually seen feeding during May and June and attain a length of about 4 to 5 cm (1.6 to 2.0 inches) upon maturity. In cool weather, the larvae may be active all day but later in the year they tend to hide in the soil during the warmest part of the day and feed mostly at night. Pupation occurs in the soil and, in central British Columbia, the blackish-brown moths, wingspan about 4 cm (1.6 inch), emerge during July and August. Female moths are strongly attracted to new clearings and recently burned areas where they oviposit in the soil. Cutworms overwinter mainly as young larvae.

Complete or nearly complete defoliation of lodgepole pine seedlings usually causes mortality, especially when flushing of the seedlings occurs prior to or during the feeding period of the larvae. The following guidelines (Ross and Monts, 1976) are effective in reducing damage:

1. Do not burn slash on sites to be planted before or during periods of expected or existing cutworm epidemics. A synthetic pheromone is available for trapping male moths for predicting which areas may become infested the following spring.
2. During outbreak years, plant infested sites after June, when cutworm feeding is completed for the year.
3. Treat infested, recently planted sites with an approved pesticide in the spring immediately after larvae become active.

Figure 6.—Larvae of the black army cutworm, *Actebia* fennica, defoliate and kill seedlings.

The spruce spider mite, *Oligonychus ununguis* (Jacobi) (Acari: Tetranychidae), reportedly killed large numbers of lodgepole pine trees in Oregon in the 1930's (Doan *et al.*, 1936). The mites insert sucking mouthparts into the needles to withdraw fluids; injured needles become chlorotic. When populations of mites are large, most needles are killed and the trees die. Outbreaks of this mite have occurred when insecticides were used to control insects (Burke, 1932; Johnson, 1958; Fellin, 1968). Apparently, such natural control factors as parasites and predators of the mite are reduced by the insecticides.

Although miticides for control of mite populations exist, their use is usually unnecessary or impractical under most forest conditions. In nurseries, such outbreaks may require miticidal treatments.

INSECTS OF POLE AND MATURE TREES

At pole stage and beyond, tree loss or reduction in growth is likely to substantially affect stand productivity.

Defoliators

Although defoliating insects occasionally cause widespread mortality, they usually reduce tree growth. Trees are most likely to die when several species of defoliating insects at once eat both old and new needles, resulting in complete defoliation.

Sawflies, *Neodiprion* spp. (Hymenoptera: Diprionidae), are semicolonial defoliators of both young and mature trees. The larvae (fig. 7) feed on old foliage; therefore, damage usually consists of growth loss rather than tree mortality. Occasionally, outbreaks occur over large areas and may last 1 to 3 years. The sawflies derive their name from the toothed lancet used by the female to make an incision in the needle into which an egg is oviposited.

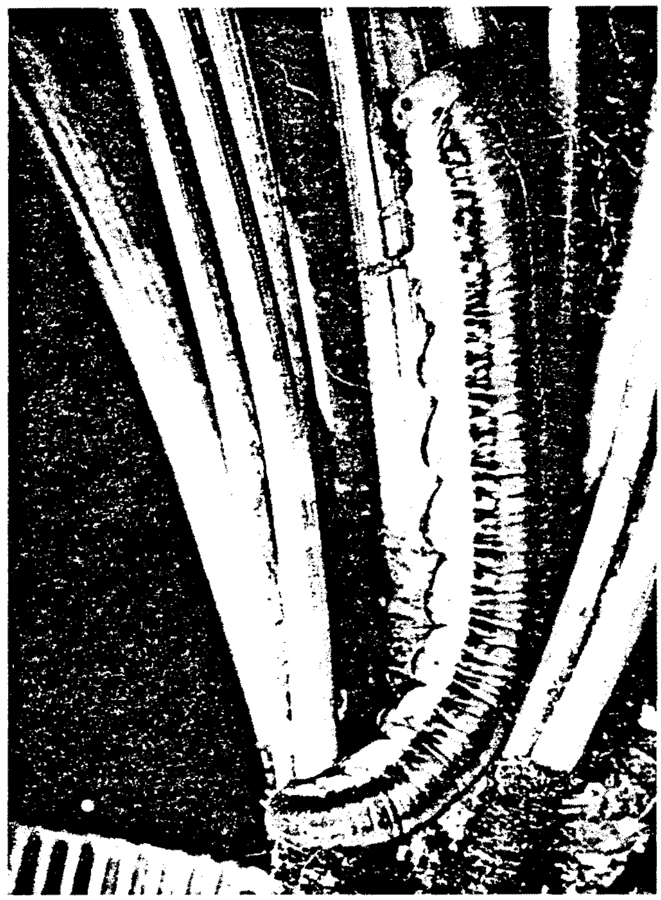

Figure 7.—Sawfly larvae (*Neodiprion* sp.) are common defoliators of lodgepole pine, causing growth reduction.

The lodgepole pine sawfly, *Neodiprion burkei* Middleton, is probably the most frequently encountered sawfly on lodgepole pine. It has one generation per year, but part of each generation remains as prepupal larvae in cocoons on the ground for 2 to 4 years. The sawflies overwinter as prepupal larvae in cocoons in litter on the forest floor. In the spring, development is completed and the adults emerge to oviposit in needles. Larvae usually feed gregariously, consuming most of the needle.

Another sawfly, *Neodiprion nanulus contortae* Ross, also feeds on lodgepole pine, and some tree mortality has been attributed to it. In British Columbia, it is the most damaging of the sawflies (Evans, 1982). This sawfly also has one generation per year, with winter usually passed in the egg stage within the needles, but prepupae may also overwinter. Larvae feed in June and July on old needles. Mature larvae are about 20 mm (0.8 inch) long, have shiny black or brown heads, and longitudinal, shaded green stripes. The mature larvae then drop to the litter and construct cocoons in which they pupate. Adults (6 mm ½ 0.25 inch long) emerge from the cocoons in mid-September to mid-October to lay eggs (Ciesla, 1976).

Most sawfly infestations decline from natural factors before causing much damage. A viral disease was credited with reducing one infestation in Yellowstone Park in 1956 (USDA Forest Service, 1957). However, the large infestation recorded by Burke (1932) indicates the sawfly's potential for damage, particularly when associated with another defoliating insect.

Examples of damage by *Neodiprion* spp. in British Columbia include the outbreaks during the mid-1970's that covered 92,000 ha (227,000 acres) in shore pine on the outer islands near Prince Rupert, and an outbreak of over 9,700 ha (24,000 acres) in lodgepole pine along the Thompson River. The outbreak near Prince Rupert caused considerable mortality after 2 years of heavy defoliation.

Owing to the nature of larval feeding and the short duration of outbreaks, control usually is not required in natural stands, but may be needed in plantations and other high value stands, such as Christmas trees.

The lodgepole needle miner, *Coleotechnites milleri* (Busck) (Lepidoptera: Gelechiidae), and the northern lodgepole needle miner, *C. starki* (Freeman), cause severe defoliation of lodgepole pine during periodic outbreaks in the southern and central Sierra Nevada and the Rocky Mountain Parks region of western Canada, respectively. The most severe outbreaks tend to occur in extensive, mature lodgepole pine stands. Cumulative defoliation by *C. milleri* may cause extensive tree mortality; prolonged defoliation by *C. starki* weakens the tree, but its main effect is growth loss.

Both species have a 2-year life cycle. Adults emerge during midsummer and eggs are laid on the bases of needles. Each larva bores into a needle, feeds, and overwinters there. In the spring, the larva completes excavation of the first needle, emerges, and enters a second needle on new growth and overwinters again. The following spring, the larva enters a third needle, completes development, and pupates (Evans, 1983; Koerber and Struble, 1971). *C. milleri* and *C. starki* fly in odd- and even-numbered years, respectively. The adults are slender moths, light grey to brownish grey, with an average wingspan of about 11 mm (0.4 inch) and strongly fringed hindwings. The mature larva is about 5 mm (0.2 inch) long and has a black head; *C. starki* larvae are dull green; *C. milleri* larvae very in color from yellow to orange, pink, and red (Furniss and Carolin, 1977).

After several successive years of infestation by the miner, trees are weakened and growth essentially stops (Struble, 1973). About 40 percent defoliation is needed before growth reduction can be detected; annual production of new foliage exceeds that consumed by the needle miner when defoliation is less than 40 percent (Stark and Cook, 1957; Cook, 1961). Cumulative effects of defoliation often kill trees. In addition, weakened trees may be attacked and killed by the mountain pine beetle, *Dendroctonus ponderosae* Hopkins (Struble, 1973).

Needle miner populations are usually regulated by weather conditions (Stark, 1959; Struble, 1973). Populations at high elevations and those in valley floors are most likely to be killed because average temperatures are consistently colder than temperatures on midslopes. Also, variation in resistance of foliage to infestation by needle miners was observed in Oregon (Tigner and Mason, 1973). The degree of resistance is probably determined by a feeding deterrent in the foliage.

Direct control of the moths by insecticides proved to be successful and long lasting (Struble, 1973). Larval control was not effective, however, because larvae are protected within needles during most of their development.

Larvae of another small moth, the sugar pine tortrix, *Choristoneura lambertiana* (Busck) (Lepidoptera: Tortricidae), destroy clusters of staminate flowers before new needles develop, and then move to the new needles. Although needles may be destroyed on trees of all ages, sizes, and crown classes within heavily infested areas, trees under 9 m (30 ft) tall appear to suffer heavier damage than larger trees. Larvae usually confine their feeding to new needles on terminal leaders of young trees when populations are small (Stark and Borden, 1965; McGregor, 1968).

Although several years of defoliation may not result in tree mortality, growth reduction can be expected. Feeding during several consecutive years can kill terminals and result in multiforked stems. The life cycle of the sugar pine tortrix was described in the section on insects of reproductive structures.

The lodgepole pine needletier, *Argyrotaenia tabulana* Freeman (Kearf.) (Tortricidae), is another defoliator that occasionally reaches epidemic proportions. For example, an infestation in Idaho covered 40,469 ha (100,000 acres); reproduction and young trees on cutover areas were damaged most severely (Washburn, 1963). The pest's name comes from the larval habit of webbing several needles together to form a tube lined with a papery white web. The larvae feed mostly on the current year's growth (Burke, 1932), maturing in August. They then drop to the ground and spin cocoons in the litter. There they pupate and pass the winter. The adult moths emerge in the spring to lay eggs on the needles.

The rusty tussock moth, *Orgyia antiqua badia* (H. Edw.) (Lepidoptera: Lymantriidae), is a multiple host species and commonly occurs throughout the northern United States and British Columbia. This insect feeds on all native species of pines in its range, but is most commonly found on lodgepole pine.

The adults emerge from mid- to late summer. The flightless female moths deposit eggs (200 to 300 eggs per mass) on their cocoons and winter is spent in this stage. The larvae, which are solitary feeders, complete development during early summer, then pupate in twig crotches and bark crevices. The male moth is rusty brown, has a wingspan of about 25 mm (1 inch) and two white dots on its forewings. The robust female is grey-brown and about 13 mm (0.5 inch) long. the larvae are hairy and strikingly colored; they have a brush of yellow hair in the middle and tufts of black hair at each end of the body. The mature larvae are about 25 mm (1 inch) long.

First signs of defoliation usually become apparent in the upper crowns of trees. Because the females are flightless, large larval populations tend to build up over small areas, causing severe localized defoliation. Rusty tussock moth populations rarely occur at outbreak levels and, when they do occur, are of short duration. Populations collapse naturally from nucleopolyhedrosis virus infection. An outbreak of the rusty tussock moth during 1975-76 in the Monte Hills region of southcentral British Columbia caused moderate to light defoliation over 3,200 ha (7,900 acres).

The need for controlling this insect has not been addressed. It appears that infestation in high value stands should be controlled. Application of nucleopolyhedrosis virus is effective in suppressing tussock moth populations.

The pine needle sheath miner, *Zelleria haimbachi* Busck (Lepidoptera: Yponomeutidae), is a transcontinental species and occurs commonly on lodgepole pine. The larvae are needle miners and defoliators; young trees, up to 5 m (16 ft) high, are infested most commonly. Severe defoliation during localized outbreaks causes growth loss, twig damage, and some tree mortality.

In general, there is one generation per year (Evans, 1982). Adults emerge during early summer to midsummer and lay eggs singly on terminal foliage. The first instar larvae bore into the needle and overwinter. The following spring, the larvae emerge from the needles and feed on new needles, chewing them off near the sheath. Each larva kills several clusters of needles. Pupation occurs during midsummer in silvery webbing in the foliage. The adults are slender, light brown moths with a wingspan of about 11 mm (0.4 inch); the forewings have wide, silvery median streaks. Mature larvae are about 10 mm (0.4 inch) long, slender and tan colored, with dull orange lines on their backs.

Two outbreak periods (1961-62, 1979-80) occurred in British Columbia, both on the Kamloops Forest Region. During 1961-62, from 85 percent to 100 percent of the current growth was destroyed in six areas ranging in size from 40 to 120 ha (99 to 297 acres), and in 1979-80 light to severe defoliation of the current growth occurred in nine areas totaling 5,400 ha (13,344 acres).

The largest of the defoliators that infests lodgepole pine is the pandora moth, *Coloradia pandora* Blake (Lepidoptera: Saturniidae). Adult moths have a wingspan of 7.6 to 11.4 cm (3 to 4 1/2 inches) and larvae are 6.4 to 7.6 cm (2½ to 3 inches) long when fully grown.

Infestations may last 6 to 8 years, cover thousands of hectares, and kill thousands of trees (Wygant, 1941). Infestations occur only about every 20 to 30 years, and can be found only where soils are loose enough to permit pupation of the larvae. Trees die from the direct effect of defoliation after 2 to 3 years; surviving trees show temporarily reduced radial growth. The moth has a 2-year life cycle. Defoliation is light during the first year when larvae are small, and heavier defoliation occurs the second year when larvae reach full size.

Moths emerge from pupal cases in the soil during June and July. Following mating, the blue eggs are laid singly or in clusters on needles, bark, litter, and understory brush. Larvae hatch from the eggs in August and feed in groups on needles at the branch tips until fall, then disperse and feed individually. Larvae overwinter at the base of needles, then resume feeding in the spring. Needles of all ages are consumed. During the last instar, a larva will consume five to eight needle bundles per day. When mature, larvae crawl down the tree trunk and pupate in the soil during July and August (Wygant, 1941).

Natural factors, consisting of predators, parasites, and wilt disease (probably a polyhedrosis virus), usually bring populations under control. A virus was credited with controlling a 6,070-ha (15,000-acre) infestation of the pandora moth in Utah (Washburn, 1962). Tests with the bacterium *Bacillus thuringiensis* offer some promise for control (Carolin and Knopf, 1968).

Defoliator complexes of several insect species are most likely to cause severe loss of foliage. An outbreak of the lodgepole needletier and the lodgepole pine sawfly was especially damaging in the Upper Madison River Valley of Wyoming and Montana from 1921 to 1925. Larvae of the moth fed on current needles; larvae of the sawfly fed on old needles. Almost all trees on 4,856 ha (12,000 acres) were totally defoliated and subsequently died (Burke, 1932). In combination, the insects caused widespread mortality; singly, neither seems to cause extensive tree mortality, but undoubtedly reduces tree growth.

Another complex consisting of the lodgepole needletier, the western spruce budworm, *Choristoneura occidentalis* Freeman (Tortricidae), and the pine needle sheath miner, *Zelleria haimbachi* Busck (Yponomeutidae), caused widespread defoliation in the Intermountain area (Klein, 1967).

Most defoliating insects can be controlled by aerial applications of chemical insecticides. Economic and environmental feasibility of such operations must be carefully evaluated before such control programs are begun.

Bark Beetles

Bark beetles (Coleoptera: Scolytidae) pose the most serious insect threat to growing lodgepole pine. Their capacity to kill trees ranges from that of the secondary beetles, such as *Pityophthorus confertus* Swaine, which can kill an occasional weakened or injured tree, to the mountain pine beetle, *Dendroctonus ponderosae* Hopkins, which can destroy almost all merchantable trees in a stand during a single infestation.

Much has been learned about bark beetles of lodgepole pine, particularly the mountain pine beetle, since the last lodgepole pine symposium 11 years ago. Much of this information has been published (Amman and Cole, 1983; Berryman *et al.*, 1978; Cole and Amman, 1980; Cole *et al.*, in press; Safranyik *et al.*, 1974).

Pityogenes knechteli Swaine and *Pityophthorus confertus* Swaine are two small beetles usually associated with *Dendroctonus* and *Ips* beetles. They frequently are referred to as secondary bark beetles because they usually infest small, stagnated trees that are dying from the effect of tree competition, rather than healthy trees. They also are capable of killing large trees that have been weakened by other causes.

When large infestations of the mountain pine beetle end, secondary beetles that were sustained in the tops and limbs of trees killed by the mountain pine beetle no longer find such material to infest. Consequently, they attack and kill some remaining lodgepole pines (Evenden and Gibson, 1940).

At low population levels of mountain pine beetles, the role of the secondary bark beetles appears to reverse. The secondary beetles kill small-diameter, suppressed, and weakened trees; and the mountain pine beetle follows along, infesting the basal foot or two of the trunks of these trees. Thus, the mountain pine beetle is able to survive during endemic periods. Silvicultural practices that would eliminate at the pole stage trees that are suppressed or weakened by other causes might also eliminate secondary bark beetles and their mountain pine beetle associates from the stands (Richard F. Schmitz, personal communication, Intermountain Forest and Range Experiment Station, Ogden, UT 84401, March 19, 1984).

The bark beetles in the genera *Pityogenes, Pityophthorus,* and *Ips* have one to two generations per year in lodgepole pine, and parents may reemerge and establish a second brood, depending on elevation and latitude. Typically, males of these genera each excavate a nuptial chamber under the bark in the spring. Several females enter the nuptial chamber, where mating occurs; then each female bores a gallery and lays eggs along the sides (Schmitz, 1972; Wood, 1982). The larvae hatch and feed in the phloem tissue. When mature, the larvae pupate and then transform to adults. The adults emerge to start the second generation or drop to the ground, where they overwinter in the litter. When second broods are established, all beetles may not complete development before winter; therefore, larvae and adults may also be found overwintering under the bark.

Ips pini (Say) is a moderately aggressive beetle in lodgepole pine in the Northern Rocky Mountains, but is less aggressive to the south. Most losses attributed to *Ips* occur in conjunction with logging and thinning operations or windthrow and breakage. When slash is not adequate to accommodate the emerging population, standing trees may be infested, especially during warm dry years (Sartwell *et al.*, 1971). *Ips* is less likely to build up after clearcutting than when harvest methods leave standing trees to shade slash. Slash exposed to direct sun dries rapidly. In addition, developing broods may be killed by high temperatures (Reid, 1957). Losses to *Ips* are usually in diameter classes of less than 25.4 cm (10 inches) (Evenden and Gibson, 1940). At high elevations, where mountain pine beetle epidemics seldom occur and, consequently, trees live much longer and grow much larger, *Ips* kills large trees as they become decadent.

Another species, *Ips latidens* (LeConte), occasionally kills lodgepole pine. It usually infests weakened or dying pines, or tops and limbs of mature trees and the boles of pole-size trees. Under favorable conditions, it will kill trees, particularly those weakened by dwarf mistletoe or drought and, in some instances, healthy trees of small diameter.

Losses of lodgepole pine to *Ips* can be minimized best through such preventive measures as removing or burning large slash from logging operations or exposing small slash to direct sun for drying. Control by chemical insecticides usually is not recommended because populations soon decline from natural causes (Sartwell *et al.*, 1971).

The lodgepole pine beetle, *Dendroctonus murrayanae* Hopkins, and the red turpentine beetle, *D. valens* Le Conte, also are considered not very aggressive. They develop in the bases of trees and in freshly cut stumps, but, following cutting operations, may kill some residual trees. In addition, these beetles can weaken trees enough to be killed by other causes, especially other bark beetles.

The adults of *D. murrayanae* and *D. valens* emerge in the spring to infest host material. Attacks are recognized by their large pitch tubes. Characteristics of pitch tubes are related to the vigor of trees infested by each species. *D. murrayanae* infests trees of lower vigor than those infested by *D. valens.* Pitch tubes of *D. murrayanae* are a deep reddish color. They are smaller and contain more boring frass and less pitch than pitch tubes of *D. valens.* Pitch tubes of *D. valens* are more cream color because of the large amount of pitch compared to boring frass they contain. Galleries are made in the bark at the base of the tree and eggs are laid in elongate masses along the sides. Larvae feed side by side in the phloem tissue, killing patches of bark that vary from a few centimeters to more than 30 cm wide. These beetles overwinter as larvae and adults. The number of generations range from one in 2 years at high elevations to three generations at low elevations and southern locations for the red turpentine beetle (Smith, 1971), and from one to one and a half generations for the lodgepole pine beetle. No control of these beetles seems needed, except as described for *Pityophthorus* and *Ips* species to prevent harboring of mountain pine beetles in a stand.

Dendroctonus ponderosae Hopkins, the mountain pine beetle, is the most aggressive bark beetle attacking lodgepole pine (fig. 8). Periodically, it kills most of the large diameter lodgepole pines in a forest before the beetle population subsides. The mountain pine beetle usually has one generation per year. At high elevations where summer temperatures are cool, however, 2 years may be required to complete the life cycle.

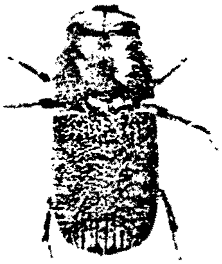

Figure 8.–The mountain pine beetle, *Dendroctonus ponderosae*, kills mature trees and is the most serious threat to growing large lodgepole pine.

All stages are spent under the bark of infested trees, except when adults emerge and fly to infest green trees in midsummer. Eggs are laid along the sides of straight, vertical, frass-packed egg galleries constructed by females. These galleries have a slight hook at the base and are mostly in the inner bark, but slightly score the sapwood. Galleries average about 25 cm (10 inches) long.

Larvae feed on the inner bark (phloem), constructing galleries that extend approximately at right angles to the egg galleries. Larvae overwinter and are very cold hardy. When fully developed, larvae excavate oval cells where they transform into pupae. Normally, pupae transform into adults by July, and adults usually leave the tree in late July and early August to infest green trees.

If the mountain pine beetle attacks are to be successful, the attacking insects, with their associated blue-stain fungi, must be present in sufficient numbers to overcome resistance of the tree. The mountain pine beetle uses a complex of three behavior-modifying chemicals, one a host tree monoterpene, Myrcene, and the other two are the insect-produced trans-verbenol and exo-brevicomin, to mediate mass attacks on host trees (Borden *et al.,* 1983). This process results in sequential colonization of nearby host trees and expansion of the infestation about the tree(s) which became attacked first. When beetles are not present in sufficient numbers, or when resistance is too high, trees may "pitch out" the beetles as they bore into the inner bark, or resin kills the eggs after galleries are made.

The blue-staining fungi that mountain pine beetles introduce into the trees at the time of attack form an integral part of the beetle's ecology (Shrimpton, 1978). Adults carry the spores on their bodies and in a special cavity inside their mouths. In successfully attacked trees, blue-stain fungi colonize and kill living tissues. This results in cessation of resin flow and, together with mining of the inner bark by beetle larvae, soon kills the trees.

Response to artificial inoculations of the fungi show that tree resistance reaches a maximum at the beginning of July and then decreases. Interestingly, the attack period of the beetle during late July and early August corresponds with decline in seasonal resistance (Reid and Shrimpton, 1971). Trees that are resistant to fungal inoculation have the fastest growth rate and the thickest phloem (Shrimpton, 1973). Paradoxically, these are the trees the beetle must overcome in order to increase or maintain large populations, beetle production being directly related to phloem thickness.

The first indication of beetle-caused mortality is usually discolored tree foliage. Needles on successfully infested trees start to fade and change color several months to almost a year after beetle attack. The sequence of color change is green to yellowish-green, then sorrel, red, and finally rusty-brown.

The mountain pine beetle is food limited in those stands of lodgepole pine where developmental temperatures are optimum. Only trees that have a phloem thickness of about 2.5 mm (0.1 inch) usually produce enough beetles to keep an infestation going. When beetles have killed most of the trees that have thick phloem, they attack smaller trees that have thin phloem and that dry excessively during beetle development. Consequently, beetle survival is low and the population declines. At high elevations and more northerly latitudes, populations are weather regulated (Safranyik *et al.,* 1975; Thomson *et al.,* in press).

Phloem thickness is highly correlated with tree diameter within any given stand. This strong correlation is probably involved in the beetle's behavior of selecting greater proportions of the large than small diameter trees. For each increase of 2.5 cm (1 inch) in diameter, Hopping and Beall (1948) showed a 5 percent increase in mortality in stands near Banff, Alberta, and Roe and Amman (1970) showed an increase of 8.8 percent on the Teton and Targhee National Forests in Wyoming and Idaho. Mortality ranged from about 1 percent of the trees 10.2

cm (4 inches) diameter at breast height (d.b.h.) to about 87 percent of those 41 cm (16 inches) and larger d.b.h. (Cole and Amman, 1969); however, tree losses very considerably with elevation. Frequency of infestations on a given area of forest appears to range from 20 to 40 years.

During low population levels (endemic), mountain beetles are difficult to find. They, as previously mentioned, have been found associated with secondary bark beetles in pole-size and larger trees. Just how the transition from endemic to epidemic populations occurs is unknown. Before an outbreak can occur, however, certain stand conditions conducive to buildup of beetle populations are essential. Those that have been identified for natural lodgepole pine stand are: (1) average diameter greater than 20.3 cm (8 inches) for trees 12.7 cm (5 inches) and larger d.b.h.; (2) average age about 80 years or older; and (3) climatic suitability for beetle development.

Several theories exist for the transition from endemic to epidemic populations in stands having these conditions. One theory is that stress of the trees or stand is necessary because the small numbers of beetles produced during endemic levels are unlikely to kill a vigorous tree in which beetle production would be large enough to start an epidemic (Berryman, 1978). A second theory is that small numbers of mountain pine beetles produced in association with secondary bark beetles during endemic levels infest a large vigorous tree when several of these infested trees are in close proximity. Thus, the small numbers of beetles produced per tree are attracted to and infest the same large, vigorous tree in which beetle production will be high (Amman, 1978). A third theory is that warm dry weather, beneficial to the beetles but adverse to the trees, allows the beetle population to increase (Thomson *et al.*, in press; Safranyik *et al.*, 1975). Although we cannot predict when outbreaks will occur, considerable progress has been made in developing stand hazard rating methods and models to predict rate and amount of tree loss, should a stand become infested.

Identifying stands having characteristics conducive to beetle infestation permits managing those stands before outbreaks occur. Several methods for rating the hazard to pine stands are available. These are based on characteristics frequently associated with epidemics. Models are available to predict losses to mountain pine beetles based on stand structure and habitat type.

Characteristics in high-risk lodgepole pine stands are: average age more than 80; average diameter at breast height more than 20.3 cm (8 inches) in the United States (Amman *et al.*, 1977), but closer to 25.4 cm (10 inches) in Canada (Shrimpton and Thomson, 1983); and suitable climate for development based on elevation and latitude. Good results have been obtained by using age, diameter, and elevation to hazard-rate stands in Montana (McGregor *et al.*, 1981). Tree characteristics conducive to outbreaks in many stands occur when current and mean annual increment culminate (Safranyik *et al.*, 1974). Culmination of current and mean annual increment came closer to predicting time of outbreak than other tree and stand measures in Canada (Shrimpton and Thomson, 1983).

Other hazard-rating methods recognize the importance of these tree and stand characteristics for an outbreak to occur, but use differing measures of tree stress to indicate stand susceptibility. These are periodic growth ratio (Mahoney, 1978); crown competition factor and percentage of basal area that is lodgepole pine (Schenk *et al.*, 1980); and growth efficiency (Waring and Pitman, 1980). Although these methods have not been tested extensively, their applicability appears to differ considerably by geographic location (Amman, in press; Shrimpton and Thomson, 1983). Further tests of all hazard-rating methods to determine geographic area of applicability are planned as part of the Canada/United States Mountain Pine Beetle Program (Anonymous, 1983).

A rate of loss model has been developed to estimate the amount of tree and volume loss per year and the length of a mountain pine beetle infestation (Cole and McGregor, 1983). Model predictions consider differences in mortality by habitat types. Another modeling approach uses a mountain pine beetle model coupled to a growth prognosis model (Crookston *et al.*, 1978) and is expected to be published in the near future. This model allows growth of a stand and calling of a mountain pine beetle model to predict tree losses at any time during stand growth.

Knowledge of mountain pine beetle ecology has led to the development of two basically different strategies for reducing losses: preventive management and direct control. Preventive management is based on manipulation of tree and stand conditions to reduce vulnerability to beetle infestation, and is the most satisfactory long-term solution. In contrast, direct control involves killing or repelling beetles. Because direct control treats the symptom (too many beetles) of the problem, its effects are apt to be temporary. However, when properly used, direct control may reduce spread and intensification of infestations, as well as provide a holding action until susceptible stands can be treated silviculturally. Control options depend somewhat on size of the outbreak, age of the stand, size of the trees, and stand growing conditions. Options that will prevent rather than control beetle outbreaks should be emphasized. Large outbreaks usually cannot be stopped before tree losses render stands economically inoperable.

Silvicultural control measures are the most efficient means of preventing outbreaks. Patch cutting can be used to create a mosaic of age and size classes that reduces the acreage highly susceptible to mountain pine beetles at one time.

Thinning stands to 247 trees/ha (100 trees/acre) in northwestern Wyoming (Cole *et al.*, 1983) or to 18.4 m^2/ha (80 ft^2/acre) in western Montana (Unpublished data, Intermountain Forest and Range Experiment Station, Ogden, UT 84401), regardless of residual tree size, reduced tree losses to mountain pine beetle. On the Shoshone National Forest in northwestern Wyoming, 1 percent of the trees in the stands cut to 247 trees/ha (100 trees/acre) was killed, compared to 5 percent of the trees in the untreated check stands. On the Kootenai National Forest in western Montana, only 9 percent of the trees were killed in the 18.4 m^2/ha (80 ft^2/acre) basal area cut, compared to 91 percent loss of trees in the check stands. Beetle pressure was extremely heavy.

Other thinning treatments used in these areas also reduced tree losses to the beetles but were not as effective as the 247 trees/ha (100 trees/acre) and 18.4 m^2/ha (80 ft^2/acre) of residual basal area treatments in their respective areas.

Selective harvest of the larger trees in which beetle production is usually high will help to reduce losses where clear or patch cutting is not recommended (Cahill, 1978; Cole *et al.*, 1983; Hamel 1978). Such situations include riparian zones and areas of visual concerns, such as road rights-of-way, campgrounds, and scenic vistas.

Salvage logging is a commonly used direct control method. Salvage operations can retrieve wood that otherwise would be lost, and removal of beetle-infested trees causes reduction in the beetle population. The following principles (Safranyik, 1982) must be followed if direct control is to be effective: (1) Infestations must be detected early and direct control must be applied to the infested area within 1 to 2 years; (2) Treated areas must be inspected annually and retreated if necessary. Once a large outbreak has developed, however, salvage logging of infested material usually will not reduce future timber losses.

Combining salvage or logging with the use of semichemicals offers considerable promise (Borden *et al.*, 1983). Semiochemicals are used to attract beetles to trees that are going to be harvested. These infested trees then are removed from the forest and processed so that the beetle broods they contain do not mature.

Direct control requires the combined efforts of all landowners within the designated control area. Individual tree treatments can be used to suppress small spot infestations, alone or in combination with salvage operations. Treatments used to kill beetles under the bark are: (1) Heat–fell deck and burn trees; burn standing trees; fell and expose trees to solar radiation; (2) Pesticides–bark penetrating on felled trees. When beetle outbreaks are large, direct chemical control may not be cost effective, because treatment costs may exceed the value of wood in the beetle-infested trees and in trees apparently saved by the treatment. Insecticides provide a temporary control measure that slows infestations, but will not stop nor prevent outbreaks as long as stand conditions favoring the outbreak are not altered.

Individual, high-value trees can be protected by insecticides. Spraying selected trees before beetle attack does not require united effort by forest landowners as does direct chemical control. A single application prior to beetle flight offers protection for 1, and possibly 2 years (Smith *et al.*, 1977). Periodic treatments will be necessary for the duration of an outbreak.

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AUTHORS

Gene D. Amman, Research Entomologist
Intermountain Forest and Range Experiment Station
Forest Service, U.S. Department of Agriculture
Ogden, Utah 84401

Les Safranyik, Research Scientist
Pacific Forest Research Centre
Canadian Forestry Service
Victoria, British Columbia V8Z 1M5