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Insects Affecting Lodgepole Pine Productivity

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ABSTRACT

A variety of insects infest lodgepole pine and are capable of limiting productivity during each stage of tree development. Of these, insects of seeds and cones do not appear to be a major factor affecting lodgepole pine management. Insects, such as the lodgepole terminal weevil, that infest and kill terminal shoots cause deformed and multistemmed trees of lower merchantable value. Defoliating insects, such as the pandora moth and the needle miner, may kill some trees, but they primarily slow tree growth, which results in lengthened rotation periods. Bark beetles, particularly the mountain pine beetle, are the most serious threat to lodgepole pine management. The beetle periodically kills most of the large diameter trees in a stand. Development of large beetle populations depends upon large trees that have thick phloem, which in turn depends upon good tree vigor. Consequently, stands of large numbers of fast-growing trees will be the first to reach conditions conducive to buildup of beetle populations. Management methods currently offer the best opportunity for regulating beetle populations.

INTRODUCTION

Lodgepole pine, *Pinus contorta* Douglas, like most trees, provides suitable 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, fundamental knowledge is lacking on the significance of most insect damage in terms of productivity. Waters (1969) recommends that life tables for forest stands 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.

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.

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.

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.

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. The greatest effort has been placed on the mountain pine beetle because of interest generated by severe, almost continuous losses of lodgepole pine in Utah, Wyoming, Idaho, Montana, and Oregon during the last decade. For more detailed descriptions and life histories and for broader coverage of insect species affecting lodgepole pine, you are referred to Keen (1952), now under revision by Robert Furniss, consulting forest entomologist, Portland, Oregon. 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 CONES AND SEED

The cones of lodgepole pine appear to be almost free of insect damage, according to Keen (1958); Parker (1972) found an average of only 2 percent infested by insects in 1971.

Moths reported working in green cones of lodgepole pine are *Dioryctria abietella* (D. and S.) (Lepidoptera: Phycitidae); *Eucosma recissoriana* Heinrich (Olethreutidae); and *Laspeyresia* sp. (Olethreutidae). Larvae of the first two species bore through both scales and seed destroying them in the process (Fig. 1). The last species is associated with pith of the cone axis and with seed.

Stark and Borden (1965) reported that reproductive structures of lodgepole pine in California are a major feeding site for larvae of *Choristoneura lambertiana* subspecies *subretiniana* Obraztsov (Lepidoptera: Tortricidae). They found that cones were often completely excavated.

Although a number of animal and weather factors may destroy cones, these factors have a negligible silvicultural effect on cone crops (Tackle 1961). The closed-cone habit of lodgepole pine is at least partially responsible for the negligible effect of seed-destroying forces; in stands of lodgepole pine where the closed-cone habit prevails, millions of viable seed may be stored per acre for many years (Lotan and Jensen 1970). Following fire or cutting, this seed then is available for seeding the area. However, in stands where the closed-cone habit is limited, seed

[1] Persons considering applied control of forest insects should obtain the latest recommendation from the Forest Service, USDA, Division of Pest Control, at the nearest regional office.

Figure 1. Lodgepole pine cone destroyed by *Dioryctria* sp. (Courtesy of W. H. Klein)

losses could have a significant effect on attempts to generate a new stand.

At the present time, loss of cones and seed to insects does not appear to be a major threat to lodgepole pine productivity.

INSECTS OF SEEDLINGS AND SAPLINGS

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

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 (Fig. 2). Previously, damage by insects that affects young trees has not been considered to be of much 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 thinned stands and in plantations attest to this.

SHOOT INSECTS

The lodgepole terminal weevil, *Pissodes terminalis* Hopping (Coleoptera: Curculionidae), probably is the most important insect affecting young lodgepole pine. Adult weevils usually oviposit in elongating terminal leaders, which are killed when larvae mine through the phloem, sapwood, and pith (Salman 1935, Stark and Wood 1964). The terminal weevil was reported to be particularly destructive to open-grown lodgepole pine in California (Salman 1935). More recently, damaging infestations of this weevil were observed in Idaho (Klein and Knopf 1969) and Colorado (Cahill and Lister 1971). In one area of Idaho, over 80 percent of the pine was damaged at one time or another (Klein and Tegethoff 1970).

Figure 2A. Insects cause tree deformity: larva of lodgepole pine weevil in shoot. (Courtesy of W. H. Klein).

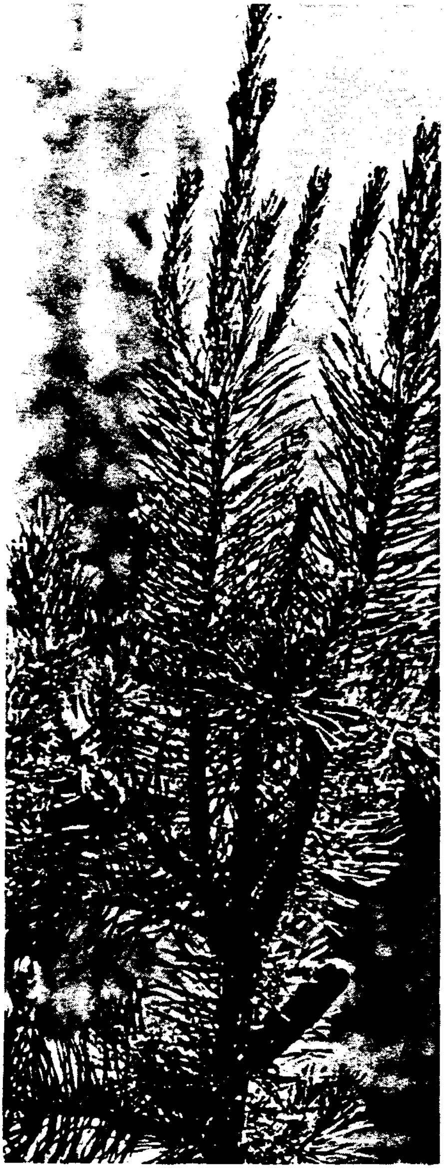

Figure 2B. Insects cause tree deformity: double-stemmed lodgepole caused when insects killed terminal shoot. (Courtesy of W. H. Klein)

Because terminal-feeding weevils seem to do less well under shaded conditions (Salman 1935), close spacing during early years of tree growth of a partial overstory offer possibilities for minimizing damage. However, the amount of stocking or shading will be a compromise between that yielding rapid growth and that reducing insect damage to an acceptable level.

STEM INSECTS

A weevil, *Hylobius warreni* Wood, has caused extensive damage to lodgepole pine, particularly in Canadian plantations. Adult weevils feed on terminal shoots and needles and cause negligible damage. However, larvae girdle roots and portions or all of the root collar, which weakens or kills the tree (Warren 1956a).

Silvicultural methods offer the best opportunity for control of *H. warreni*. Warren (1956b) found that weevil damage was more common on wet sites than on dry sites. Cerezke (1970) observed that year-to-year damage was correlated within weevil-infested stands, an indication that certain stands are subject to continual infestation. Nonhost trees could be used as a control measure 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. 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 subject to infestation.

The larva of the pitch nodule moth, *Petrova albicapitana* (Busck) (Lepidoptera: Olethreutidae), bores into both the new and old growth of stems, twigs, and branches. Larval presence is recognized by a nodule of pitch and frass where the larva entered the bark. Attacks usually are at nodes or whorls of branches; trees seldom are girdled. However, the weakened portions frequently are broken by wind or snow (Keen 1952).

Another moth, the sequoia pitch moth, *Vespamima sequoia* (Hy. Edw.) (Lepidoptera: Aegeriidae), was reported to be a pest of lodgepole pine as early as 1914 when serious infestations occurred over 90,000 acres of lodgepole pine in Montana (Brunner 1914). Larvae usually feed around the root collar causing growth reduction and even death of some trees. A recent outbreak of the insect in over 400 sapling-size pines near Trout Creek, Montana, was associated with pruning and thinning operations; many trees were nearly girdled at the root collar (Tunnock 1967). Pruning and thinning after moth flight probably would result in less infestation.

NEEDLE INSECTS

Adults of another weevil, *Magdalis gentilis* Leconte, made feeding punctures that resulted in needle losses on young trees in Montana; the adults were attracted to stands where thinning operations were being conducted. Timing of thinning operations, to be carried out when adults are not present to be attracted into the area, should help reduce damage. Denser stocking could also reduce damage; more weevil damage occurred where trees were widely spaced (Fellin and Schmidt 1966, Fellin 1973).

Two sucking insects (Homoptera: Diaspididae) reported from lodgepole pine are the pine needle scale, *Phenacaspis pinifoliae* (Fitch), and the black pine leaf scale, *Aspidiotus californicus* Coleman. The pine needle scale is usually a pest of young trees in low vigor. However, Pierce (1969) reported a severe infestation on mature trees in the Lake Tahoe area in 1968. The scales suck sap from the needles. On severely infested trees, foliage turns yellow or becomes mottled and eventually drops from the tree. Infestations gradually kill branches and sometimes entire trees.

The black pine leaf scale is commonly associated with the pine needle scale. The black scale, as its name implies, is black and easily distinguished from the pine needle scale, which has a whitish covering. It also injures trees by removing sap and, when present in large numbers, can kill them. This scale is usually sociated with conditions that are harmful to the host tree. Such conditions include smelter fumes, smog, smoke, and dust (Struble and Johnson 1964), which could increase in the future. 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.

The spruce spider mite, *Oligonychus ununguis* (Jacobi) (Acarina: Tetranychidae), reportedly killed large numbers of lodgepole pine trees in Oregon in the 1930's (Doane and others 1936). The mites have sucking mouthparts that they insert 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 have been 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.

Specific insecticides for control of mite populations exist. Their use is usually unnecessary or impractical under most forest conditions but outbreaks in nurseries may require attention.

INSECTS OF POLE AND MATURE TREES

At this stage in the life of the stand, tree loss or reduction in growth is likely to substantially affect productivity.

DEFOLIATORS

Although defoliating insects occasionally cause widespread mortality, they most consistently affect productivity through reduction of tree growth. Death of trees (Fig. 3) is most likely to occur when complexes of several species of defoliating insects eat both old and new needles and complete defoliation results.

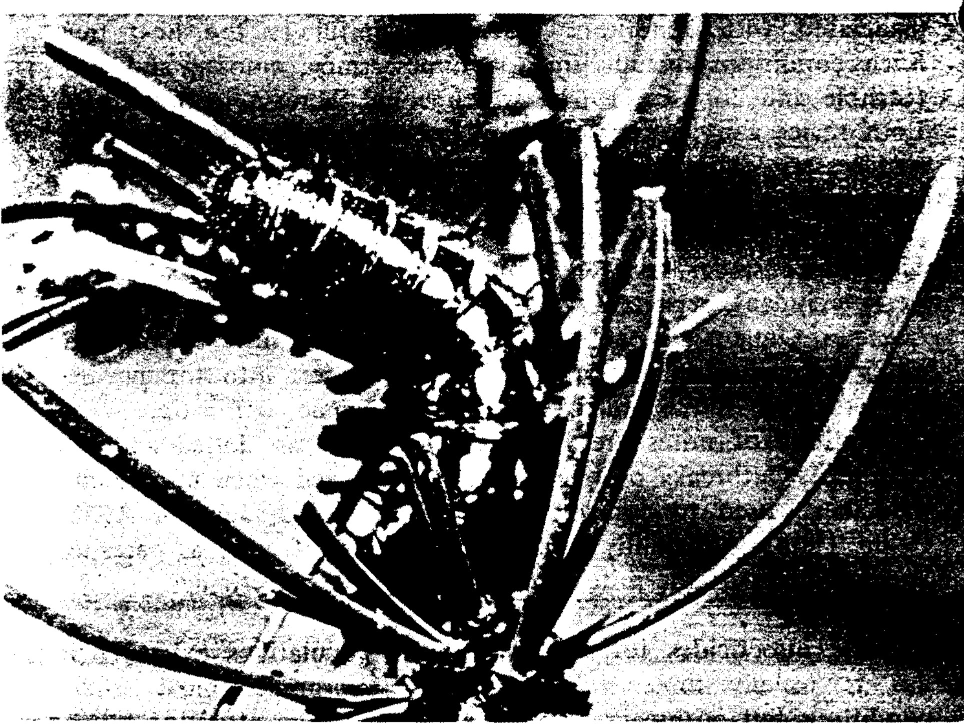

Figure 3A. Defoliation by insects causes growth reduction and possibly death of trees: larva of pandora moth.

The lodgepole pine sawfly, *Neodiprion burkei* Middleton (Hymenoptera: Diprionidae), is probably the most frequently encountered sawfly on lodgepole pine. 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. Larvae usually feed gregariously, consuming most of the needle.

Recent reports indicate that small infestations of sawflies frequently occur in lodgepole pine forests (Washburn and Terrell 1961, Cahill and Lister 1971, Ciesla and others 1972). Most such infestations decline without causing much damage. A viral disease was credited with reducing one infestation in Yellowstone Park

Figure 3B. Defoliation by insects causes growth reduction and possibly death of trees: lodgepole pine defoliated by pandora moth.

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 other defoliating insects.

Needle miner populations, *Coleotechnites milleri* Busck and *C. starki* (Freeman) (Lepidoptera: Gelechiidae), frequently erupt into large infestations that result in much growth reduction and may kill many trees. Infestations covering thousands of acres have been reported in California (Koerber and Struble 1971) Idaho (Washburn and Terrell 1961), Oregon (Dolph 1967), and national parks of western Canada (Stark and Cook 1957).

Larvae mine the needles in which they are relatively protected. 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).

Defoliation alone often kills trees. In addition, weakened trees may be attacked and killed by the mountain pine beetle, *Dendroctonus ponderosae* Hopkins, in California (Struble 1973). However, no increase in bark beetle activity occurred in Canada during an outbreak of the needle miner that severely weakened and killed some trees (Stark and Cook 1957).

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.

Direct control of the moths by insecticides proved to be successful and long-lasting (Struble 1973). However, larval control was not effective 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 completely destroyed on trees of all ages, sizes, and crown classes within heavily infested areas, trees under 30 feet 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 (Klein and Tegethoff 1970).

The pine tube moth, *Argyrotaenia pinatubana* (Kearf.) (Tortricidae), is another defoliator that occasionally reaches epidemic proportions. For example, an infestation in Idaho covered 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 current year's growth (Burke 1932).

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

Infestations may last 6 to 8 years, but occur only every 20 to 30 years. Outbreaks 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; consequently, defoliation is light during the first year when larvae are small, and heavier defoliation occurs the second year when larvae reach maturity (Carolin and Knopf 1968).

Wygant (1941) reported an infestation that covered 100,000 acres in Colorado; more than 4,000 trees were killed and many others were weakened. More recent outbreaks have occurred in Oregon (Pettinger and others 1972) and Utah (Washburn and Terrell 1961).

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 15,000-acre infestation of the pandora moth in Utah (Washburn 1962). Initial 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 pine tube moth and the lodgepole pine sawfly was especially damaging in the Upper Madison River Valley of Wyoming and Montana from 1921-1925. Larvae of the moth fed on current needles and those of the sawfly on old needles, which resulted in total defoliation of many trees (Burke 1932). In combination, they caused widespread mortality; singly, neither seems to be very destructive in terms of tree mortality. However, reduced tree growth undoubtedly occurs.

A complex consisting of the pine tube moth, the jack pine budworm, *Choristoneura pinus* Freeman (Tortricidae), and the pine needle sheath miner, *Zelleria haimbachi* Busck (Yponomeutidae), caused widespread defoliation in the Intermountain area (Washburn 1965, Klein 1967). Other complexes involving some of the same species were reported for Montana and Idaho in 1968 (Honing 1969) and Montana in 1970 (Ciesla and others 1971).

Most defoliating insects can be controlled by aerial applications of chemical insecticides. However, much work needs to be done on the economic and environmental feasibility of such operations.

RK BEETLES

The most serious insect threat to growing lodgepole pine is posed by the bark beetles (Coleoptera: Scolytidae) (Fig. 4). 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.

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. However, they also are capable of killing large trees that have been weakened by some other cause.

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 trees (Evenden and Gibson 1940).

The lodgepole pine beetle, *Dendroctonus murrayanae* Hopkins, also may be ranked as a secondary beetle. It develops in the bases of weakened trees and in freshly cut stumps, but, following cutting operations, it may kill some residual trees. In addition, this beetle can so weaken trees that they die from other causes.

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 operations or windthrow and breakage. When adequate slash is not present to accommodate the emerging population, standing trees may be infested, especially during warm dry years (Sartwell and others 1971). *Ips* is less likely to build up after

Figure 4A. Bark beetles are a serious threat to growing large lodgepole pine: adult.

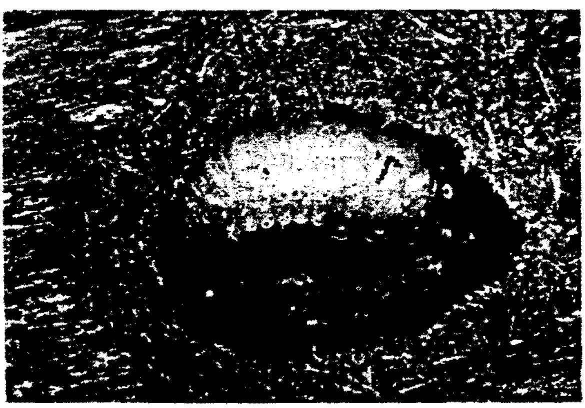

Figure 4B. Bark beetles are a serious threat to growing large lodgepole pine: larva of the mountain pine beetle.

Figure 4C. Bark beetles are a serious threat to growing large lodgepole pine: lodgepole pine killed by mountain pine beetle.

clearcutting than when other harvest methods that shade slash are used. Slash exposed to direct sun dries rapidly. In addition, developing brood may be killed by high temperatures (Reid 1957). Losses to *Ips* are usually in diameter classes of less than 10 inches (Evenden and Gibson 1940); however, at high elevations, this beetle may kill much larger trees.

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 and others 1971).

The mountain pine beetle is the most aggressive bark beetle attacking lodgepole pine. Periodically, it kills most of the large, vigorous trees in a forest before the beetle population subsides. Frequency of infestations on a given area of forest appears to range from 20 to 40 years, depending upon how rapidly a stand grows into conditions conducive to buildup of beetle populations (trees of large diameter that have thick phloem).

The mountain pine beetle is food-limited in those stands of lodgepole pine where developmental temperatures are optimum (Cole and Amman 1969); only trees that have a certain thickness of phloem 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 the beetle population declines.

The thickness of phloem depends upon tree vigor; the most vigorous trees are the fastest growing and have the thickest phloem.[2] Consequently, the rate of tree growth will determine when the stand will be subject to an epidemic beetle infestation. In contrast to this type of food limitation, which is dependent upon characteristics of the host tree itself, other bark beetles, such as the secondaries, are dependent upon factors that weaken the host tree (for example, tree competition, injury, and attacks by other insects). Consequently, their populations are more regulated by these factors than by food supply as are mountain pine beetle populations.

The dependence of brood production in bark of varying thickness was illustrated when the numbers of emergence holes

[2] Dennis M. Cole. Phloem thickness relationships in lodgepole pine trees. USDA For. Serv. Res. Pap. INT- (in preparation).

made by emerging brood adults ranged from none for bark 0.06-inch thick to 120 per square foot for bark 0.20-inch thick (Fig. 5). Although these figures are for total bark thickness, phloem generally increases as total bark thickness increases (Amman 1969, D. M. Cole[3]). Further evidence that brood production is dependent upon phloem thickness has been furnished from laboratory studies (Amman 1972).

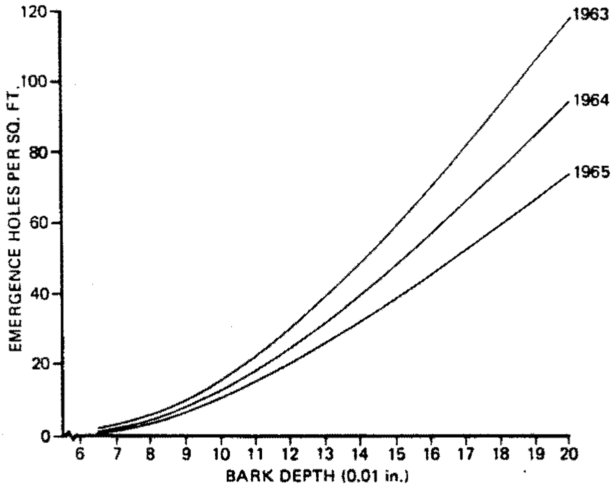

Figure 5. The number of emerging brood adults of the mountain pine beetle is directly related to thickness of the bark measured in bark grooves (Amman 1969).

Reid, Whitney, and Watson (1967) proposed that infestations of the mountain pine beetle in Canada are dependent upon trees that cannot resist attack. Trees they consider to be resistant respond to beetle attack by producing resinous compounds in the sapwood and phloem adjacent to the attack. When resin production is slight, insects and fungi are able to overcome the tree. Response of the tree could be initiated by an artificial inoculation of blue stain fungus, *Europhium clavigerum* Robinson and Davidson, normally carried by the beetle. This response

[3]Ibid.

resembled the tree's response to insect attack. They believe that this technique could be used to determine the susceptibility of a stand of lodgepole pine to mountain pine beetle infestation.

Response to fungal inoculation indicates that 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 attack have the fastest growth rate and the thickest phloem (Shrimpton 1973). Paradoxically, these are the trees that our observations indicate the beetle must attack in order to increase or maintain large populations. However, it is possible that the beetle-tree relationship in the United States and in Canada differs because of location and accompanying climatic differences.

Although thickness of phloem is the most important variable affecting brood production that we have measured to date, the beetle selects trees to be attacked on the basis of size. For each increase of one 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 4 inches in diameter at breast height (dbh) to about 87 percent of those 16 inches dbh and larger (Fig. 6) (Cole and Amman 1969); however, these figures vary considerably with elevation.

Loss of merchantable trees (9 inches dbh and larger) to the mountain pine beetle ranged from 73 percent at low elevations to 25 percent at high elevations in the Teton-Targhee area. By far the heaviest loss was observed by Evenden and Gibson (1940) in stands around the Big Hole Basin in Montana where 84 percent of the trees 9 inches and larger were killed by the mountain pine beetle. When losses due to other causes were added, 93 percent of the trees 9 inches and larger were killed. Many trees in the smaller diameter classes survived because the beetle is usually unable to produce much brood in these trees.

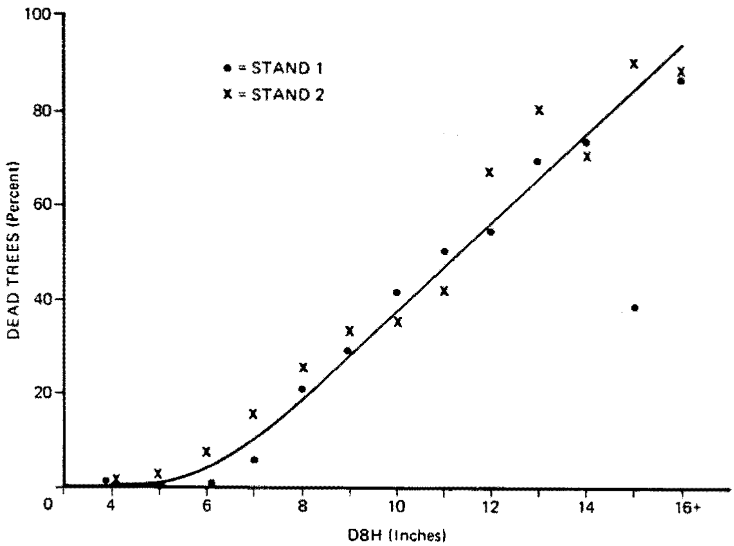

Figure 6. Proportions of trees killed by the mountain pine beetle are related to diameters of trees (Cole and Amman 1969.)

Shepherd (1966) indicated that the beetle has evolved a behavior for selecting large diameter trees. Our work shows that evolution of this behavior probably is related to generally thicker phloem in large trees (Fig. 7). Beetles that successfully attack large rather than small trees have a higher probability of encountering thick phloem and of subsequently increasing the beetle population.

Selection of large lodgepole pine trees that have thick phloem challenges the old premise that all bark beetles are dependent upon weakened, decadent trees; trees of good vigor have the thickest phloem and offer the greatest potential for population buildup of the mountain pine beetle. In fact, it is essential that such trees be infested in order for the beetle population to increase. D. M. Cole[4] measured the phloem of 392 trees and related it to a number of tree characteristics including radial growth, crown length, stand density, age, and diameter. His model accounted for 73.5 percent of the variance in phloem thickness and clearly demonstrated the relation of thick phloem to characteristics of good tree vigor.

[4] Ibid.

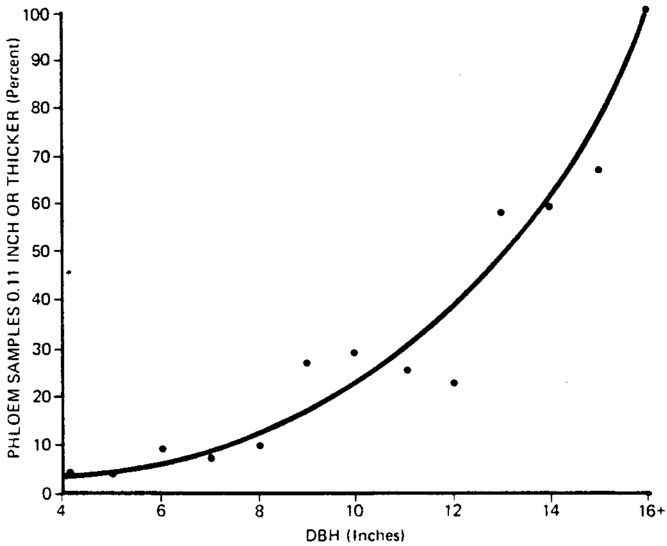

Figure 7. Phloem thickness of lodgepole pine increases as diameter increases (data collected from Warm River area, Targhee National Forest, Idaho).

In most reports of mountain pine beetle outbreaks in lodgepole pine, the stand is described as overmature. Consequently, overmaturity and beetle outbreaks are considered to go together. However, most trees, certainly those at low elevations where infestations are most intense, are within the age range for immature trees (40 to 120 years) given by Tackle (1955). Observations by Roe and Amman (1970) revealed that ages of green trees in two stands in the Teton-Targhee area that were undergoing beetle infestation ranged from 54 to 106 years (average 87) and from 33 to 113 years (average 76) for trees 4 to 16 inches dbh. In a third stand in northern Utah where an infestation had started to change from endemic to epidemic, trees ranged from 39 to 220 years (average 97) and from 6 to 20 inches dbh. Of the 124 trees measured in this stand, 85 percent were immature and only 6 percent overmature.

Mortality of lodgepole pine caused by the beetle differs among habitat types and elevations. Infestations were compared on three bitat types defined in the Teton-Targhee area (Roe and Amman 1970). The Douglas-fir/pinegrass type occurred primarily at low elevations; 64 percent of the stands showed evidence of having been infested and mortality of trees was moderate. The subalpine fir/*Pachistima* type occurs primarily at midelevations; 92 percent of the stands showed evidence of infestation and mortality was heavy. The subalpine fir/dwarf vaccinium type occurred primarily at high elevations; 44 percent of the stands had been infested and mortality was light.

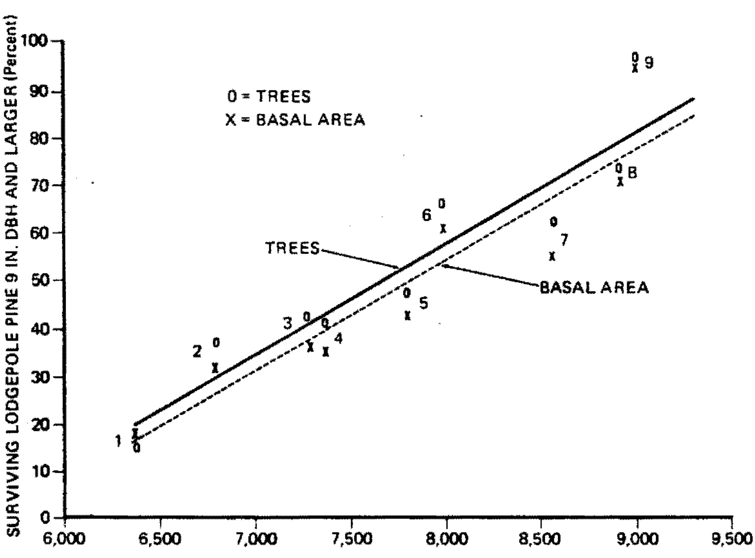

Figure 8. Fewer lodgepole pine trees are killed by the mountain pine beetle as elevation increases. 1. Indian Lake (Targhee N.F.); 2. Horseshoe (Targhee N.F.); 3. Pilgrim Mountain (Teton N.F.); 4. Hatchet (Teton N.F.); 5. Pacific Creek (Teton N.F.); 6. Spread Creek (Teton N.F.); 7. Spring Creek Park (Bridger N.F.); 8. Togwotee I; 9. Togwotee II (Teton N.F.).

Brood production in bark of a given thickness was found to be inversely related to elevation (Amman 1969); losses to the mountain pine beetle declined as elevation increased (Fig. 8) even in the presence of ample food supply in the Teton-Targhee area (Amman and Baker 1972) and northern Utah (Amman and others 1973). The reason for a decline in losses of lodgepole pine is related to the effect of weather on the life cycle and to the subsequent survival of the beetle. In the Teton-Targhee area, a portion of the population required two years to complete a generation at about 8,100 feet elevation, whereas the remainder required only one year. Most of the population required two years to complete their cycle above 8,700 feet elevation. During these long developmental periods, the result of consistently cool temperatures, beetle mortality was high and populations declined (Amman 1973).

It is interesting that two population-regulating factors operate within the same species and within a few thousand feet of each other: food regulation at lower elevations where developmental temperatures usually are optimum, and weather regulation at higher elevations where food is abundant.

STRATEGIES FOR POPULATION SUPPRESSION

Knowledge of these basic aspects of mountain pine beetle ecology suggests some alternatives to the land manager for dealing with this pest.

PREDICTION

A method is needed that will enable the land manager to predict when a stand of lodgepole pine will reach a stage conducive to beetle infestation and what the losses will be should the beetle infest the stand.

Currently, W. E. Cole and A. R. Stage (Entomologist and Mensurationist, Intermountain Forest and Range Experiment Station, Ogden, Utah, and Moscow, Idaho, respectively) are developing infestation probabilities for stands growing under prescribed conditions and also estimates of tree losses. In addition, W. E. Cole and D. B. Cahill (Regional Entomologist, Forest Service, Rocky Mountain Region, Denver, Colorado) are preparing a method of estimating rate of spread of a beetle infestation and tree losses based on elevation and distribution of diameters and phloem thicknesses in Colorado stands. In both cases, the effects of timber harvest on subsequent losses to the beetle will be predicted.

CHEMICAL CONTROL

In the past, most land managers requested control projects that entailed the use of chemical insecticides to halt beetle infestations. However, recent comparisons of lodgepole pine stand structures where beetle infestations were complete showed that populations declined in about the same number of years and residual stand structures were about the same whether or not beetles had been treated with insecticides (Amman and Baker 1972). This does not mean that beetles were not killed in those trees that were treated, but rather that the area of infestation and numbers of trees involved were too large for all trees to be treated. Therefore, beetles from untreated trees kept the infestation active.

In view of these findings, chemical insecticides for mountain pine beetle control are not recommended at this time. When lodgepole pine forests eventually come under intensive management for timber products and the forest is broken up into an array of different age classes, only small portions will be conducive to beetle infestation at any one time. Under such conditions, chemical insecticides may have a place in control strategy. However, under intensive management, harvesting of trees for beetle control probably will prove to be more economically sound than chemical control.

It is recommended that no chemical insecticides for beetle control be used in forests (such as those in national and state parks and wilderness areas) where timber production is not a primary objective. The objectives of esthetics, watersheds, and wildlife habitat probably can be met by succeeding species and the remnants of the lodgepole pine forest as well as, if not better than, a pure lodgepole forest (Roe and Amman 1970, Amman and Baker 1972).

However, insecticides may prove useful as preventive sprays applied to trees in campgrounds and other high-use recreation sites. Tests conducted during 1972 were highly successful in protecting trees from beetle attack. Galen C. Trostle, forester, USDA Forest Service, Intermountain Region, Ogden, Utah, found that a single application well before beetle flight was effective throughout the flight period; none of the protected trees was attacked.

MANAGEMENT CONTROL

At this time, management practices offer the best solution for dealing with the mountain pine beetle and several possible practices have been presented by Roe and Amman (1970). By recognizing that the beetle concentrates heavily on trees of large diameter, land managers could break up continuous lodgepole forests into small blocks of different age and size classes, thereby reducing the area likely to be attacked at any one time. Then, if a small block were threatened by the beetle, trees on the entire block could be harvested immediately.

Mortality of lodgepole differs by habitat type and elevation; therefore, the manager could grow trees to larger size on some areas than on others with less risk of loss to the mountain pine beetle. He could select as an objective the smallest tree size that would fulfill product requirements and choose the shortest rotation to grow trees of this size.

Also, realizing that rapid growth, thick phloem, and beetles go together, he could employ controlled stocking to encourage a moderate growth rate, thereby assuring that a large number of trees would not develop thick phloem and trigger off a large beetle epidemic. A border planting of other tree species may be necessary; border trees usually grow more rapidly than trees within the stand and more quickly reach a stage susceptible to mountain pine beetle infestation.

Finally, stands that are particularly susceptible to damage by mountain pine beetle (for example, those at low elevations) could be converted to nonhost trees, such as Douglas-fir. In mixed species forests, the presence of nonhost trees will result in greater residual stocking should a beetle epidemic occur. However, the beetle appears to infest lodgepole in mixed species forests just as readily as in pure forests.

The practical difficulties of initiating some of these recommendations are readily apparent. However, if efforts to minimize losses to the beetle through management practices are postponed, conditions in stands recently subjected to beetle epidemics will again be conducive to beetle buildup. If this occurs, we again will experience an epidemic of beetles, the result of large acreages of susceptible host type.

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