Silvicultural Control of Mountain Pine Beetle: Prescriptions and the Influence of Microclimate

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In a recent *American Entomologist* article, Malcolm Furniss (1997) described the profound impact that one insect, the mountain pine beetle, *Dendroctonus ponderosae* Hopkins, had on the establishment of forest entomology in North America. Unlike other classical examples of depredations by one insect profoundly impacting American entomology (e.g., the Rocky Mountain grasshopper [Walsh] and applied entomology, see *An In-Depth Look at the Life and Times of C. V. Riley*, Smith and Smith 1996), the interest in, and importance of, the mountain pine beetle has remained undiminished during the century following its original description in 1902. The reason for this sustained interest is multifaceted. First, unlike most insects, and even most bark beetles, the mountain pine beetle usually kills its host to reproduce successfully. Second, unlike the Rocky Mountain grasshopper, this widely distributed insect remains very much extant. Mountain pine beetle outbreaks rank among the most impressive of naturally occurring entomological events (Fig. 1). During the last great epidemic in forests of lodgepole pine, *Pinus contorta* Douglas, from 1979 to 1983, over four million acres per year were infested. These outbreaks resulted in mortality of over 15 million trees each year during the five-year period (McGregor 1985). The resulting fuel loads contributed in large part to a subsequent, equally spectacular, episode of wildfires (Roe and Amman 1970, Brown 1975), including the 1988 Yellowstone fires. Hence, for both economic and ecological reasons, the mountain beetle has remained the subject of intensive

Fig. 1. A 1980 aerial photograph of Adair Ridge in Glacier National Park, MT, showing damage from a massive mountain pine beetle outbreak. All of the red trees in the photograph were killed during one season.

Fig. 2. A mountain pine beetle egg gallery. The female excavates a characteristic "J" shaped gallery. As she excavates the gallery, eggs are deposited in niches chewed in the gallery sides. Larvae hatch and begin feeding perpendicular to the original gallery, thereby girdling and killing the tree.

research and management since it was first described by Hopkins.

As with many economically important insects, the mountain pine beetle spends most of its life in a protected environment. The female initiates attack on apparently healthy trees.[1] If enough beetles attack the tree to overcome its substantial defenses, the females (who are soon joined by males attracted by pheromones) begin excavation of egg galleries in the phloem tissue and initiate oviposition (see Hopkin's drawing in Furniss 1997, and Fig. 2). The girdling effect of larval feeding (also restricted to the phloem), perhaps in consort with the action of introduced fungi, eventually kills the tree, although for all practical purposes the tree can be considered dead once dry-boring dust (Fig. 3) is evident around the base of the tree. Throughout this interaction, the tree remains far from a passive victim. Rather than quietly awaiting the *coupe de grais*, host trees (which essentially include all members of the genus *Pinus)* have evolved effective chemical defenses to beetle attack. This interaction has been characterized elsewhere (Furniss 1997, Logan et al. 1998) as a small, weak predator attacking a large, dangerous prey. To overcome the inherent disadvantage of a small, weak predator, the mountain pine beetle has co-evolved an elegant chemical communication system (Pitman and Vité 1969, Ryker and Rudinsky 1982, Borden and Lacey 1985). Utilizing a combination of host- and beetle-produced compounds, the initially attacking females attract large numbers of both female and male beetles to simultaneously attack the targeted tree. At sufficient population levels, host defenses are overwhelmed by the number of attacking beetles and the tree is killed. As beetle

Fig. 3. Boring dust around the base of a mass-attacked tree, a sure sign that the mountain pine beetle has won this encounter with the host.

[1]During endemic population phases, most successful colonization occurs in trees weakened by root disease or other factors. During an epidemic, however, any tree of sufficient size is susceptible to attack

numbers inhabiting the tree increase, antiaggregation pheromones begin to predominate over attracting pheromones (Rudinsky et al. 1974, Borden et al. 1987, Lindgren and Borden 1989) and attack is shifted to nearby trees (Geiszler and Gara 1978, Bentz et al. 1996). This switching from the initially attacked focus tree to nearby trees first serves to focus attacking beetles on one victim and, then, secondarily, to avoid over-exploitation of a limited food resource (Berryman et al. 1984). Thus, the life cycle of the mountain pine beetle, and in particular its interaction with host forests, is a complex interaction involving both host condition and a co-evolved predator/prey relationship.

The relationship between pine forests and the mountain pine beetle has co-evolved over countless millennia. In pre-European times, this relationship most likely was characterized by what Mattson (1996) has termed a "normative outbreak," a term which he used to describe outbreaks of a native insect that are "part and parcel of the normal plant biology." Post-European emphasis on the economic production of western forests has altered this normative relationship in two important ways. First, through interference (e.g., fire suppression) with natural, co-evolved disturbance regimes, forest landscapes have been altered dramatically from their pre-European condition. These changes in forest ecosystem structure and function have created conditions that seriously debilitate the capacity of the host to defend itself. Second, for various reasons, post-European forest management often has attempted to maintain a status quo of current stand conditions that extends beyond the natural cycle of forest regeneration and renewal. The result of both management practices has been the same—large acreages of forests that are highly vulnerable to mountain pine beetle attack.

Confounding the changes that have occurred in forest landscapes during the past century are the unique aspects of insect management in natural resource systems. The concepts of Forest Pest Management (FPM) have evolved largely in consort with, or as a subdiscipline of, Integrated Pest Management (IPM) (Waters et al. 1985), the dominant paradigm of applied entomology. And yet, there are inherent aspects of forest systems, particularly in the West, that are vastly different from the typical IPM agricultural setting. The temporal (decades to centuries) and spatial (continental) scales are much longer and larger, respectively, than the typical IPM setting of the farm. The structure of the landscape of interest is extremely heterogeneous, and, in fact, maintaining or regaining heterogeneity is often a high priority management objective. Forested systems in the West are imbedded within the fastest growing and most rapidly changing sector of American society. These changes are altering the way we view natural resource systems and the perceived values they represent. As a result, instead of the unambiguous objectives in crop production, management objectives in natural resource systems are multifaceted and, often, may be in direct conflict with one another. Given this intractable combination of large expanses of high vulnerable landscapes and inherent complexity, it is little wonder that attempts at directly controlling mountain pine beetle outbreaks have met with little success.

Recommendations for control of the mountain pine beetle in ponderosa pine, *Pinus ponderosa* Lawson, were started by Hopkins in 1905. Hopkins recommended cutting infested trees and debarking them and suggested burning or scorching the infested trees to kill beetles in the bark (Fig. 4A and B). The first recorded control project was initiated in the Black Hills National Forest in 1906. This effort involved an expenditure of $2,700 in an attempt to check an epidemic of the Black Hills beetle (i.e., mountain pine beetle) (Craighead et al. 1931). Between 1906 and 1930, more than 100,000 acres were treated for bark beetle problems at an expenditure of $1,000,000.

With the advent of modern chemical pesticides, attempts once again were made to control outbreaks over large acreages involving most of the western forests. These were massive efforts (Fig. 4C). For example, the project on the Targhee National Forest in southeastern Idaho started in 1964 and ended in 1970. During that period, over 1.5 million infested trees were treated at a cost of over $8,000,000 (Klein 1978). Although these efforts reduced tree killing in some areas, and slowed infestations in others, they had little overall impact on mountain pine beetle populations (Amman and Baker 1972, Klein 1978), not unlike conclusions reached by Craighead et al. (1931) almost 50 years earlier.

By the early 1970s, it had become apparent that control of mountain pine beetle outbreaks by directly killing beetles was not working. The inescapable conclusion was that as long as forest conditions remained unchanged from their vulnerable condition, large-scale outbreaks were going to occur and their extent was going to be determined largely by the

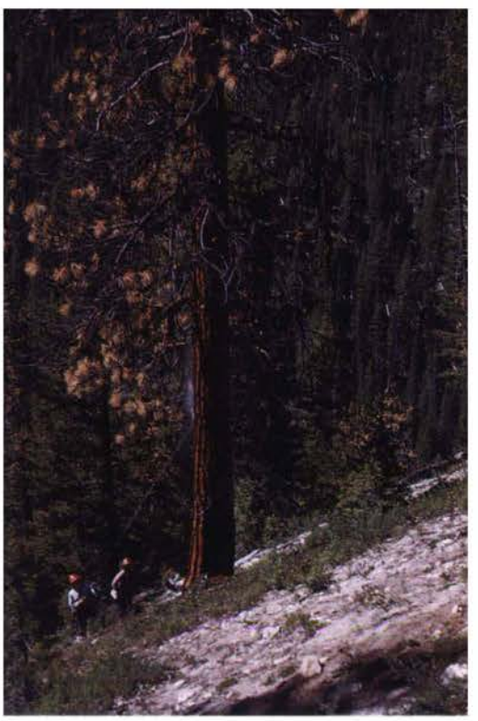

Fig. 4. (A) Scorching bark of an infested tree to kill mountain pine beetle larvae under the bark. Trees over extensive areas were treated in this manner, typically in the Winter or Spring during periods of low fire danger. (Photograph taken on the Targhee-Teton National Forest, 1946.) (B) Infested trees also were felled, stacked in decks, and torched to achieve the same ends. (Photograph taken on the North slope of the Uinta mountains, UT, 1963.) (C) Photograph of an Ethylene dibromide application for control of bark beetles in the Boise National Forest, 1950. Direct control of outbreaks typically met with limited success (see text).

extent of suitable habitat. As a consequence, research focus shifted from killing beetles to attempts at understanding the stand characteristics that led to vulnerability. Silvicultural or other vegetation management practices that focus on the precipitating causes of an outbreak rather than on increasing beetle mortality are the direct results of this research.

Silvicultural Control

Because of differences in infestation behavior between ponderosa and lodgepole pine, these hosts are discussed separately. Ponderosa pine generally grows at lower elevation habitats, which are warmer and dryer, than lodgepole pine. Therefore, not only do the hosts differ in the quality of the food resource, but the microhabitat is different. Even small diameter ponderosa pine have the potential for producing large numbers of beetles. In spite of this observation, outbreaks in ponderosa pine usually do not cause the extensive damage that is seen in lodgepole pine (McCambridge and Trostle 1970, Raffa 1988), and tree mortality tends to be spotty rather than the more continuous expression of mortality that is seen in lodgepole pine.

Tree mortality in lodgepole pine stands is tied more closely to stand dynamics than in ponderosa pine. In general, lodgepole pine has thinner phloem than ponderosa pine, and large diameter trees with thick phloem are needed to perpetuate an outbreak. In lodgepole pine, beetles kill a smaller percentage of small diameter trees, an observation most likely resulting from thin phloem and excessive drying in small trees (Cole et al. 1976). Although mortality in lodgepole pine is tied closely to size distribution of trees in the stand, infestations at the larger landscape level move through stands with few being spared.

To summarize the differences in expression of mortality, at the small scale of a spot or cluster, ponderosa pine are killed more uniformally, with even small trees being killed and producing relatively large numbers of beetles. However, at the landscape level, outbreaks in lodgepole tend to be uniform, with all stands experiencing more or less the same degree of intense mortality. The differences in the spatial pattern and intensity of epidemics suggests that factors other than food come into play to limit population growth in ponderosa pine stands.

Ponderosa Pine. Silvicultural treatments specifically directed at the mountain pine beetle in ponderosa pine began in 1938 with a crop-tree thinning experiment by Eaton (1941). Unfortunately, his experiment was destroyed by fire a few years later (Sartwell 1971). In 1961, Hall and Davis (1968, unpublished report) reported two small tests of one thinning level on the Modoc National Forest. The unthinned stand was "decimated" by mountain pine beetle, whereas mortality in the thinned portion of the stand was minimal during the first few years of the test.

Sartwell and Dolph (1976) reported thinning stands of ponderosa pine in eastern Oregon. They used four thinning levels between residual trees (i.e., 12 × 12, 15 × 15, 18 × 18, and 21 × 21 ft) and control stands. Five years later, mortality in the thinned stands had been reduced to 2.8 percent in the 12 × 12 ft treatment, whereas none occurred in the widest spacing. This was in comparison to losses of 6.8 percent in the control stands. During the 1976–1982 period, the experimental area was subjected to one of the largest beetle outbreaks of record. Thinnings that spaced trees 18 × 18 ft and 21 × 21 ft apart experienced little mortality (Dolph 1982). Treatments with closer spacing and controls suffered considerable mortality (no specific loss figures were given by Dolph).

Working in the Black Hills, Sartwell and Stevens (1975) recommended thinning to 150 square feet of basal area to reduce mortality caused by mountain pine beetle.[2] This recommendation was based on measurements taken from infested groups of trees, using the apparent center of an infested group as the focal point for a variable radius plot estimate of basal area.

McCambridge and Stevens (1982) compared tree mortality in thinned and unthinned stands of ponderosa pine. In their three-year comparison, losses in thinned (45 to 89 square feet of basal area) and unthinned (163 to 201 square feet of basal area) stands averaged 3.4 trees and 10.4 trees per acre, respectively. Stevens et al. (1974) gave thinning recommendations for ponderosa pine on the front range in Colorado, including thinning to a growing stock level (GSL)[3] of 80. In a three-year study in the Black Hills, Schmid and Mata (1992) found no mortality in partial cut stands that had a GSL equal to or less than 100. In a seven-year study in 70 to 90 year-old second growth ponderosa pine on the Lassen National Forest in California, Fiddler et al. (1989) compared control stands that had 190 square foot basal areas to thinning treatments of 80, 100, and 140 square feet per acre. The 80 square foot treatments suffered no loss, and the 100 square foot and 140 square foot treatments had only light losses when compared to those of the control stands. Schmid and Mata (1992) estimated the critical threshold for mountain pine beetle outbreaks as 120 GSL in Black Hills Ponderosa pine. Based on a tree growth model, Schmid (1987) estimated the effect of thinning would last 40–50 years in stands that were thinned to a 40 GSL but less than 20 years in stands thinned to a 120 GSL.

Lodgepole Pine. Silvicultural control of the mountain pine beetle in lodgepole pine began in the late 1960s and early 1970s. Recommendations included patch cutting to create mosaics of age and size classes (to reduce the acreage of highly susceptible trees to future mountain pine beetle outbreaks), and conversion to later seral stands of nonhost spruce/fir (Roe and Amman 1970, Safranyik et al. 1974). Cole (1978) outlined several silvicultural practices for reducing losses to mountain pine beetles in lodgepole pine forests including: (1) stocking control in young stands; (2) block clear-cutting to create age, size, and species mosaics; and (3) salvage and sanitation cutting.

During epidemic periods, the mountain pine beetle is oriented strongly to large diameter trees (Evenden and Gibson 1940, Hopping and Beall 1948, Cole and Amman 1969, Roe and Amman 1970, Rasmussen 1972, Safranyik et al. 1974) but more so in lodgepole than in ponderosa pine. The positive correlation of tree diameter with mortality indicated that mortality could be reduced by removing large diameter lodgepole from stands.

When the mountain pine beetle does infest a tree in a thinned stand, usually only the single tree and, occasionally, a nearby tree are infested. Geiszler and Gara (1978) emphasized the importance of tree spacing in switching of attacks from a focus tree under attack to a nearby tree. If the distance is too great, infestation within the stand will not continue.

[2]Basal area is a standard measure of forest stand density. The larger the basal area, the more dense the forest. Units of measure typically are square feet per acre of stem cross section measured at breast height. Basal area for a stand is estimated in one of two ways: (1) tallying the size for all trees in a plot of fixed size (e.g. 1/5 acre), and (2) use of an angle gage or prism to select trees (based on tree size) that will be included in a standard conversion formula. The latter sampling method is not fixed to a specified plot size, hence the name "variable radius plot."

[3]Growing stock level and square feet of basal area essentially equivalent measures of stand density (Schmid and Mata 1992, Schmid et al. 1995). The choice of terms we used was dictated by that used in the original source cited.

Cahill (1978) reported 2 percent mortality from mountain pine beetle in partial cut stands of lodgepole pine compared to 39 percent mortality in control (uncut) stands. McGregor et al. (1987) reported the results of a five-year study on the Kootenai and Lolo National Forests in Montana involving two diameter-limit cuts and three spaced-thinnings in lodgepole pine. The diameter-limit treatments were (1) removal of all trees greater than 10 in. diameter at breast height (dbh) and (2) removal of all trees greater than 12 in. dbh. Spaced-thinning treatments were designed to reduce basal area to (1) 80, (2) 100, and (3) 120 square feet of residual basal area. Tree losses in the two diameter-limit treatments were 6% and 8.6%, respectively, for the 10 and 12 in. limit cuts. Trees infested and killed in the successful thinnings occurred usually where spacing of trees was not maintained. Losses in the control stands were 70–94% of the trees that were greater than 5 in. dbh (McGregor et al. 1987). Tree losses to mountain pine beetle in spaced-thinning treatments were 10 and 15% in the 80 and 100 square foot treatments, respectively, but not significantly different from the control stands in the 120 square foot treatment. Apparently reduction of basal area to 120 square feet did not alter stand density enough to create the desired microclimate effect.

Cole et al. (1983) reported that thinning reduced losses to mountain pine beetle on the Shoshone National Forest of Wyoming. Treatments consisted of (1) removing all trees greater than 7 in. dbh, (2) removing all trees greater than 10 in. dbh, (3) removing all trees greater than 12 in. dbh, and (4) spaced thinnings leaving 100 trees per acre. Amman et al. (1988a) continued the Cole et al. study until beetle populations declined in 1985. Control stands sustained 26.5% mortality compared to 3% or less in all four of the thinning treatments (Fig. 5A and B).

Hamel (1978) attempted to reduce infestation of lodgepole pine in the Gallatin National Forest of Montana by removing trees with thick phloem. The test failed because the beetles were attracted to large diameter trees regardless of phloem thickness. Based on the work of Shepherd (1965), the propensity of beetles to be attracted visually to large vertical objects precluded the success of Hamel's experiment.

Stand Microclimate

Thinning operations have been assumed to decrease mountain pine beetle mortality by increasing tree vigor (Berryman 1978, Mitchell et al. 1983a). Undoubtedly, thinning does increase tree growth, but stands often require two to three years for expression of a growth response following thinning treatments (Amman et al. 1988b). Therefore, immediate decreases in tree mortality caused by mountain pine beetle following thinning are not explained fully by increased tree vigor. Change in microclimate, which occurs immediately after a stand is thinned, provides another explanation for the decreased mortality that has been observed (Bartos 1988, Bartos and Amman 1989). Safranyik (1978) has discussed more fully the role of climate and weather in determining the abundance and distribution of mountain pine beetle. Changes in microclimate that could influence mountain pine beetle behavior and, subsequently, stand susceptibility, include temperature, light intensity, and wind speed.

Temperature. Increased temperature in thinned stands have both direct and indirect effects on mountain pine beetle ecology. Schmid et al. (1991, 1992a) studied the direct effect of thinning on temperature in ponderosa pine. Between 1985 and 1992, they established 11 experimental replicates in the Black Hills of SD. Each replicate consisted of three thinning treatments (40 or 60, 80, and 100 GSL) and a control, unthinned plot. They selected two of these and compared the treatments to the controls. Temperatures were significantly different between the treatments and the controls, among the GSL treatments, and between sides of the trees across all plots. Temperature was inversely related to GSL. A mountain pine beetle epidemic subsequently occurred in one replicate of experimental plots. No mortality occurred in any of the treatments after thinning although substantial mortality (36 trees) occurred in the control plot during the same time period (Schmid and Mata 1992). Schmid et al. (1995) made detailed microclimate comparisons of one 80 GSL plot to its control. They found that south-side bark temperatures during midday hours, maximum difference between north-side bark temperatures and air temperature, maximum difference between south-side temperatures and air temperatures, and solar radiation were greater in the 80 GSL stand than in the unthinned control stand that was attacked successfully. Air temperatures and north-side bark temperatures were not significantly different. Schmid et al. (1992a) reported similar results for thinned and unthinned stands in Colorado and Wyoming.

Although beetles emerge at a greater rate from south than north sides of trees (Safranyik

Fig. 5. (A) Mountain pine beetle mortality in an unthinned control stand near thinning treatments, West Yellowstone, MT, 1979. (B) A thinned stand (removal of all trees ≥10 in. dbh) also near West Yellowstone. These photographs give an indication of reduced beetle mortality that can result from thinning.

and Jahren 1970), Bartos and Amman (1989) found north-side temperatures in thinnings would not have been a deterrent to beetle infestation. Additionally, south-side temperature may at times be high enough to impede mountain pine development [Powell (1967) reported subcortical temperatures were occasionally 95° F or higher on south sides of lodgepole pine trees in British Columbia]. Beetle attack densities are higher on north sides (Reid 1963, Shepherd 1965); also, when trees are strip-attacked, the attacks usually occur on north and east sides (Mitchell et al. 1983b). Apparently, the principle direct effect of the increased temperature that results from thinning is restricted to reducing habitat suitability on the south side of trees. These potentially deleterious impacts may result from temperatures high enough to interfere with developmental processes (Bentz et al. 1991) or from increased rates of drying that accompany higher temperatures.

Indirect effects of temperature are mediated through the physical characteristics of the stand. Bartos and Amman (1989) found that in lodgepole pine stands, ground temperatures and south-side tree temperatures were warmer

in thinned than in unthinned stands. Such temperature gradients could increase convection currents and turbulence as warm air rises. Convection currents also are created by solar energy penetrating through an open canopy to the forest floor. This solar input heats the ground and adjacent air increasing convection currents as the buoyant air rises through canopy openings (Rosenberg 1983), carrying pheromone and kairomone aerosols with it (Fares et al. 1980). In dense stands, sunlight is absorbed by the upper levels of the tree canopy that, in turn, heat the surrounding air. This results in a temperature inversion in the stem zone that is characterized by more stable air (Chapman 1967, Fares et al. 1980). Inversions tend to be more pronounced in dense stands than in sparse ones (Fares et al. 1980, Fritschen 1984). Aerosol movement below a dense canopy on a sunny day is trapped beneath the canopy until it flows to a point where the canopy is less dense or has an opening (Fares et al. 1980).

Light Intensity. Light intensity is another factor governing flight of the mountain pine beetle. Shepherd (1966) demonstrated under laboratory conditions that mountain pine beetles increased attempts to fly at high light intensities and increasing temperature, conditions that were found in thinned stands (Bartos 1988, Bartos and Amman 1989, Schmid et al. 1991, 1992a). Solar radiation in a 80 GSL plot in ponderosa pine generally exceeded solar radiation in the control plot (148 GSL) by 100 or more watts per 10.76 square feet, with specific hourly differences of 500 to 725 watts (Schmid et al. 1995). Significant differences in solar radiation also were observed between thinned and unthinned lodgepole pine stands (Bartos 1988, Bartos and Amman 1989).

Wind Speed. Wind can disrupt mountain pine beetle flight and disrupt pheromone and kairomone plumes that beetles follow in order to find their hosts and concentrate attacks. Gray et al. (1972) observed 59% of beetles flew with the wind but more flew against the wind when speeds were less than 3.1 miles per hour. No flight occurred at wind speeds greater than five mph.

Schmid et al. (1992b) compared horizontal wind speed, vertical wind speed, and wind direction in thinned ponderosa pine stands (one 60 GSL, and two 80 GSL) to an unthinned control (150 GSL). They found that horizontal wind speeds of 2–4 mph occurred more frequently in the thinned stands than the unthinned stand, although wind speeds greater than 5 mph occurred less than 11 percent of the time in all stands. Schmid et al. (1992b) also compared vertical wind speeds in two thinned stands (40 and 60 GSL) to respective controls (160 and 150 GSL). They found that upward wind speeds did not exceed 2 mph in any of the stands. Downward wind speeds exceeded 2 mph only in the 40 GSL stand. No statistically significant differences were found between any of the stands. They concluded that vertical wind speed probably would not be disruptive to the horizontal movement of mountain pine beetle pheromones. Any disruption probably would be caused by convection currents created by the greater, below-canopy heating of low GSL stands (Schmid et al. 1991). Schmid et al. (1995) concluded from their studies that of the variables they measured—air and bark temperatures, horizontal and vertical wind speeds, and solar radiation—only solar radiation and, perhaps, vertical air movement or turbulence, would play an important role in mountain pine beetle selection of particular stands.

All of these factors are integrated into the beetle's behavior when responding to traps baited with aggregative pheromones. Bartos (1988) and Bartos and Amman (1989) reported on beetle capture from three Lindgren funnel traps (Lindgren 1983) baited with *trans*-verbenol, *exo*-brevicomin, and myrcene and placed in a thinned (basal area 67 square feet) and an unthinned (basal area 137 square feet) lodgepole pine stand. The stands had similar diameter distributions and contained no mountain pine beetle infestation. The traps caught a 26 and 478 beetles in the thinned and unthinned stands, respectively. Schmitz et al. (1989) caught fewer beetles in passive barrier traps in heavily thinned stands than in lightly thinned and control stands in Montana, even though large numbers of beetles were flying through the thinned stands.

Conclusions

In spite of the large knowledge base regarding silvicultural control of mountain pine beetle, there is still much to do. Although a compelling body of evidence indicates that thinning treatments act as effective deterrents to mountain pine beetle infestation, the mechanistic pathways by which these effects are expressed remain obscure. We have reviewed research that has documented the effects of thinning on stand microhabitat and the possible ways these changes could impact mountain pine beetle ecology. Additional research is needed to more fully explain, quantify, and predict the effects of specific silvicultural activ-

ities on mountain pine beetle ecology and subsequent outbreak potential. In particular, more research is needed on the mechanism of pheromone/kairomone interactions that lead to switching from a focus to adjacent trees and how the physical environment impacts switching behavior. Models are needed that relate stand structure, attributes of the physical environment, and response to pheromone and kairomone plumes. Additional information also is needed on how beetles respond to these plumes. Finally, additional information is needed on the long-term effects of forest management activities, including silvicultural prescriptions, on stand structure and integrity. In other words, what type and intensity of management activities can the ecosystem sustain and remain intact? Such an understanding will provide information necessary to design more effective silvicultural prescriptions for bark beetle disturbance management.

Research designed to improve silvicultural prescriptions for mountain pine beetle management undoubtedly will contribute to a deeper understanding of the basic ecology of this insect and how this important agent of natural disturbance impacts western forests. The interior West currently is undergoing the greatest societal changes since European colonization. Accompanying the shift from a local resource-based economy to a more globally based economy is a growing concern for widespread decline in forest health. Silvicultural management is one potential tool that resource managers can use to help reverse declining forest health and improve ecosystem sustainability. However, to be effective, we need to be able to predict the landscape-level impacts of silvicultural treatments over long-term time scales. Such prediction requires a deep understanding of the ecological principles involved. Simply measuring the impact of a silvicultural treatment on stand susceptibility and risk to mountain pine beetle depredation is acceptable no longer. It has become evident over the almost 60 years of attempts at silvicultural control of mountain pine beetle that we are not going to eliminate the beetle from western forests, nor should we. An emerging realization is that we need to develop the understanding required to incorporate natural disturbance events within attainable and sustainable forest management objectives.

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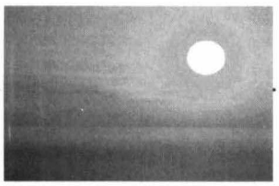

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