Utah State University
DigitalCommons@USU

The Bark Beetles, Fuels, and Fire Bibliography

Quinney Natural Resources Research Library, S.J. and Jessie E.

1-1-1985

Integrating Management Strategies for the Mountain Pine Beetle with Multiple-Resource Management of Lodgepole Pine Forests

Mark D. McGregor

Dennis M. Cole

Recommended Citation

McGregor, M. and Cole, D. (1985). Integrating management strategies for the mountain pine beetle with multiple-resource management of lodgepole pine forests. USDA Forest Service, Intermountain Forest and Range Experiment Station, General Technical Report INT-174, 67 pp.

This Full Issue is brought to you for free and open access by the Quinney Natural Resources Research Library, S.J. and Jessie E. at DigitalCommons@USU. It has been accepted for inclusion in The Bark Beetles, Fuels, and Fire Bibliography by an authorized administrator of DigitalCommons@USU. For more information, please contact becky.thoms@usu.edu.

Integrating Management Strategies for the Mountain Pine Beetle with Multiple-Resource Management of Lodgepole Pine Forests

DEC 21 1995
LIBRARY

EDITORS:
MARK D. McGREGOR, Entomologist, Cooperative Forestry and Pest Management, State and Private Forestry, Northern Region, Forest Service, U.S. Department of Agriculture, Missoula, MT.
DENNIS M. COLE, Research Silviculturist, Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Bozeman, MT.

RESEARCH SUMMARY

Guidelines are presented to assist forest managers in integrating pest management techniques for the mountain pine beetle (*Dendroctonus ponderosae* Hopk.) with other resource considerations in the process of planning and executing balanced resource management of lodgepole pine (*Pinus contorta* var. *latifolia*) forests. The guidelines summarize published and unpublished technical information and recent research on the ecological interaction of pest and host and present visual and classification criteria and methods for recognizing and summarizing occurrence and susceptibility status of lodgepole pine stands according to habitat types and successional roles and important resource considerations associated with them. Information is summarized for appropriate silvicultural systems and for practices that address significant resource concerns of commercial and noncommercial forest land designations and wilderness and other special administrative areas. A data acquisition, data analysis, and decision framework is presented for integrating management of mountain pine beetle populations with multiple resource management of lodgepole pine forests.

CONTENTS

Page

Introduction 1
The Beetle (Gene D. Amman and Mark D. McGregor) 2
Behavior, Biology, and Life Cycle 2
Beetle Survival 5
Climatic Factors 5
Habitat Types 5
Tree Size and Age 6
Stand Structure and Density 6
The Host (Robert D. Pfister and Dennis M. Cole) .. 7
Successional Roles of Lodgepole Pine 9
Descriptive Summary of Successional Roles and Habitat Types of Lodgepole Pine in Montana and Northern Idaho 11
Assessing Stand Hazard and Risk 29
Hazard Rating and Predicting Tree Loss in Unmanaged Stands (Gene D. Amman and Mark D. McGregor) 29
Stand Hazard Rating 29
Concepts for Evaluating Susceptibility of Managed Stands (Mark D. McGregor) 30
Effects of Outbreaks in Relation to Host Occurrence and Resource Concerns 31
Occurrence of Lodgepole Pine Stands According to Habitat Type and Successional Role (Dennis M Cole) 31
Minor Seral Successional Role 36
Major Seral Successional Role 36
Effects of Outbreaks and Management Responses on Big Game and Other Wildlife (Jerome T. Light and William B. Burbridge) 37
Rocky Mountain Elk and Mule Deer 37
Moose and Whitetailed Deer 42
Grizzly Bear 42
Other Wildlife 43
Soil and Water Quality (Mark D. McGregor) 44
Landscape and Visual Management Concerns (Mark D. McGregor) 44
Coordinating Management Objectives with Silvicultural Systems and Practices 45
Acceptable Silvicultural Systems in Relation to Desired Stand Character and Successional Roles of Lodgepole Pine (Dennis M. Cole) 45
Silvicultural Practices for Lodgepole Pine Stands in Commercial Forests (Dennis M. Cole and Mark D. McGregor) 47
Practices for Pure Lodgepole Pine Stands 47
Practices for Mixed Species Lodgepole Pine Stands 51
Other Practices for Commercial Forests 55
Practices and Considerations for Noncommercial Forests (Mark D. McGregor and Dennis M. Cole) 56
Fragile Higher Elevation Ecosystems 56
Considerations for Parks, Wilderness, and Other Reserved Areas 57
Practices for Recreational, Home, and Administrative Sites 58
Integrating Pest Management for the Mountain Pine Beetle with Management for Multiple Resource Goals (Mark D. McGregor and Dennis M. Cole) 60
Evaluating the Present and Future Problem 60
Evaluating Management Goals and Options 62
Selection and Integration of Management Options 62
Implementation 62
References 63

INTRODUCTION

The mountain pine beetle (*Dendroctonus ponderosae* Hopk.) is a native bark beetle whose depredations affect management of the lodgepole pine (*Pinus contorta* var. *latifolia* Dougl.) ecosystem. Extensive forest areas have been decimated by this insect (Amman and others 1977; Safranyik and others 1974). Historically, millions of trees are killed yearly, and, during epidemics, more than a million trees can be killed in a single year on one National Forest. The beetle has killed an estimated 2 billion board feet per year since 1975 (Safranyik 1978). The beetle, like fire, has been active and has coexisted in lodgepole pine ecosystems almost as long as there has been lodgepole pine (Roe and Amman 1970). The large increase in ground fuel and associated increase in the probability of large, high-intensity fires following beetle epidemics suggests that the interaction between beetle infestations, fires, and lodgepole pine tends to perpetuate lodgepole pine, and hence, mountain pine beetle epidemics. Scattered individual trees may be victims, but more often entire groups of trees are killed (fig. 1). Unchecked, these groups expand with succeeding beetle generations, and eventually entire stands suffer heavy mortality over large contiguous areas (fig. 2).

Depending on landowner objectives, these losses can have a catastrophic impact. For example, the value of a mountain home may be severely reduced by mortality of high-value shade and ornamental trees. From the timber producer's standpoint, infestations seriously affect even flow and sustained yield and make the task of converting unmanaged to managed forest very difficult. Epidemics disrupt management plans and affect local, regional, and national economies. Downfall following infestations hampers access and use by big game, livestock, and humans. Infestations affect recreation and esthetics, increase fire hazards, affect water and watershed management, and may increase the proportion of trees infected by dwarf mistletoe (*Arceuthobium americanum* Nutt. ex. Engelm.) (Wellner 1978). On the other hand, some managers favor grassland over timberland, and a beetle epidemic causes them much less concern. They may, however, establish this preference without fully considering other resource values—among them soil, water, and vegetation stability.

Mountain pine beetle epidemics also have major impacts on roadless and wilderness areas and national parks. Because the beetle is such a profound change agent in lodgepole pine ecosystems, the resource values and management objectives of these lands are usually modified to some degree by an epidemic. For example, although the effect on water quality and quantity of these lands may be minimal (Wellner 1978), wildlife and visual resources can be impaired.

Most epidemics develop because there are large areas of unmanaged lodgepole pine forests. Periodically in these forests, endemic mountain pine beetle populations develop to epidemic levels. In an outbreak, the beetle thins from above, first killing the older, large-diameter, more open-grown trees. As populations build, beetles eventually kill smaller and younger lodgepole pine less desirable for brood production. In general, the beetle attacks and kills proportionately more large-diameter than small-diameter trees (Cole and Amman 1969) and kills trees of largest diameter each year of the infestation. Infestations die out when all or most of the large-diameter trees are killed (Amman 1977). The effect on productivity in stands containing an appreciable proportion of lodgepole pine (for example, >40 percent) is a residual stand composed of inferior trees that are unable to adequately exploit the extra growing space provided them. Productivity is also affected by additional mortality caused by sun-scald, snow, windthrow, or other causes (Wellner 1978).

Mortality and losses in timber yields can be reduced to acceptable levels if forest managers integrate pest

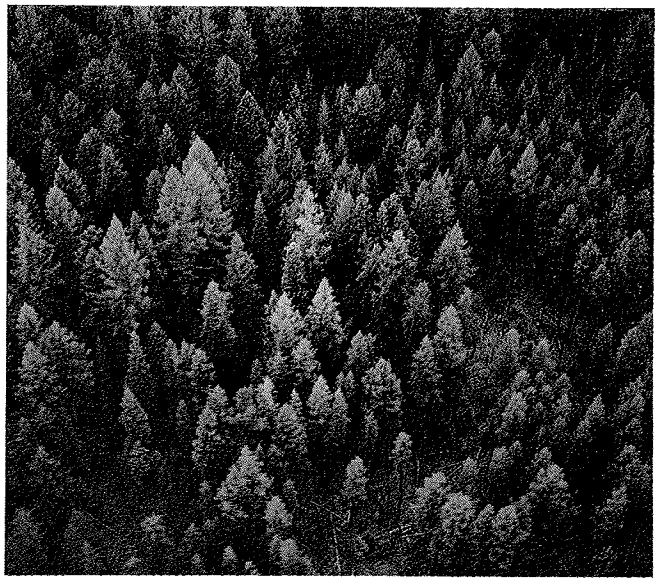

Figure 1.—Red-topped group of lodgepole pine trees killed by mountain pine beetle.

Figure 2.—High densities of red-topped lodgepole pine over large areas signify epidemic infestations.

management techniques developed for the mountain pine beetle into the timber management planning process and use appropriate methods wisely.

This management guide summarizes earlier published and unpublished technical information and recent findings of research and pest management specialists concerning the beetle and its host. It is intended to complement and supplement information contained in earlier guides (Safranyik and others 1974; Amman and others 1977; Berryman 1978; Cole and Amman 1980; Amman and Cole 1983). The objective of this guide is to synthesize information on the beetle and its host, methods for evaluating stand susceptibility, effects on various resources, coordination of silvicultural systems and practices, and integration of management for various resources with preventative management of mountain pine beetle populations.

These guidelines are a contribution to the Canada/U.S. Mountain Pine Beetle Action Plan and should be useful to forest planners, silviculturists, pest management specialists, and foresters charged with preventing or reducing losses to the mountain pine beetle in lodgepole pine forests.

THE BEETLE

Gene D. Amman
Intermountain Forest and Range
Experiment Station
Ogden, UT

Mark D. McGregor
Cooperative Forestry and Pest Management
Northern Region
Missoula, MT

BEHAVIOR, BIOLOGY, AND LIFE CYCLE

The first evidence of infestation usually consists of pitch tubes, where beetles entered the tree, and boring dust in bark cracks and at the base of trees (fig. 3). Infested trees remain green until spring, when they can be detected from a distance as foliage dries and changes to pale green, then to light orange, and finally to bright orange-red by July (fig. 4). Emergence holes made from mid-July through early August signify the brood has emerged from the tree to attack green trees (fig. 5).

The mountain pine beetle usually completes a single generation per year (fig. 6); however, up to 2 years may be required to complete the life cycle if cool temperatures at high elevations and in more northern latitudes delay development and emergence of beetles (Amman 1973; McCambridge 1974; Safranyik and others 1975).

Emergence and flight of new adults begin early in July and may continue through September. Although emergence may continue for a month or more, usually 80 percent of the beetles emerge within about 1 week (Rasmussen 1974). Initial attacks on pines usually occur on the lower 15 ft (4.4 m) of the bole. Unmated females make the initial attacks and release odors, called aggregating pheromones, that attract males and other females until a mass attack occurs on that tree and surrounding trees.

Figure 3.—Whitish to brownish pitch tubes on boles and similar-colored boring dust at base of tree indicate successful attack.

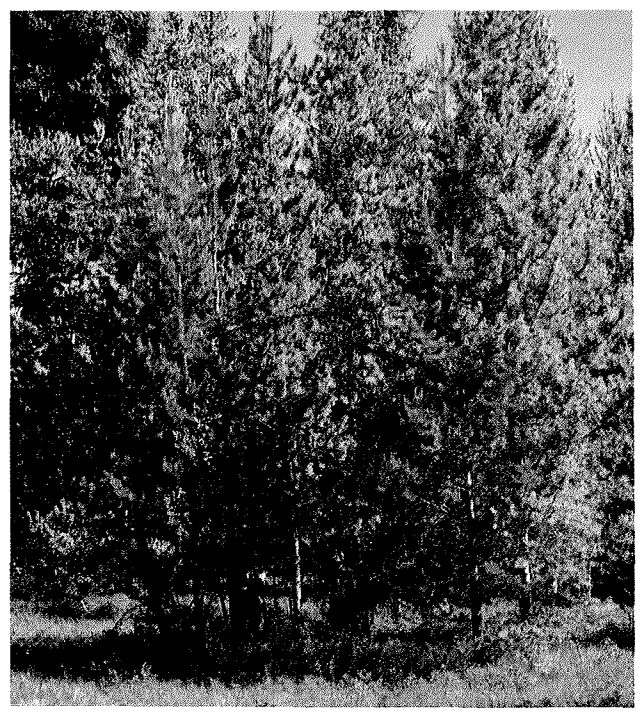

Figure 4.—Progressive fading of killed lodgepole pine trees in early summer. Greenish-yellow to tan-colored trees on left will look like tree at right within several weeks.

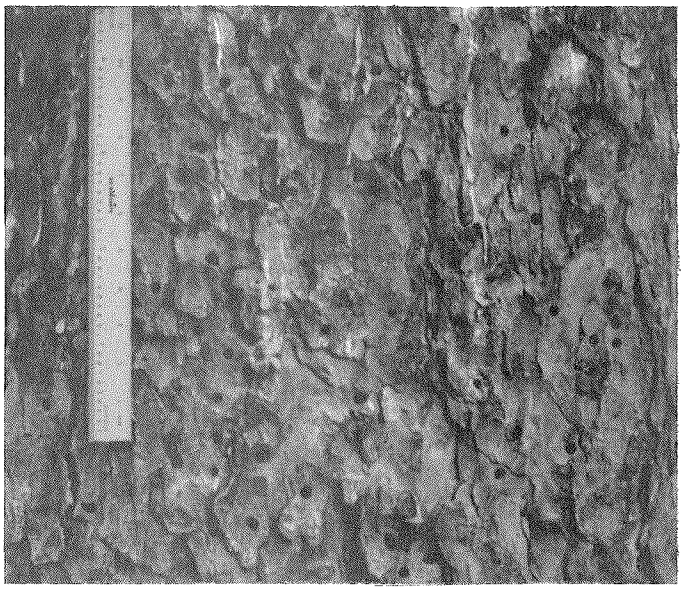

Figure 5.—Exit holes in lodgepole pine bark signify broods have emerged from the tree to attack others.

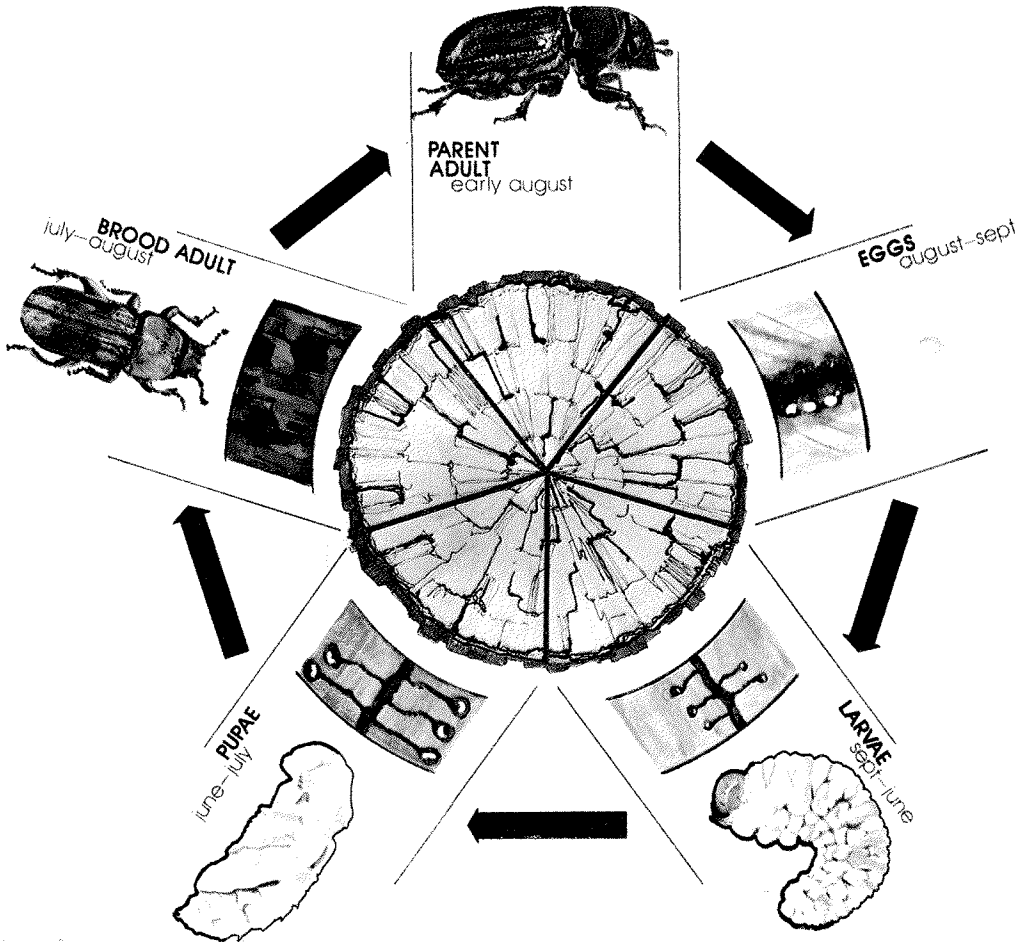

Figure 6.—General life cycle of mountain pine beetle in lodgepole pine. Color cycle of trees refers to the color change of foliage of successfully attacked trees, which is associated with the season and stage of the beetle's annual life cycle.

When populations are too light to mass-attack trees, or the tree is successful in repelling attacking beetles, the tree remains alive and is termed an unsuccessful attack or pitchout (fig. 7). Sometimes a portion of a tree is successfully infested and brood is produced without killing the tree. This is called a strip attack. Successful attacks are usually accomplished by a single generation of beetles. As populations increase from year to year, the mass-attack phenomena is heightened and larger groups of trees are infested and killed. The unmated female initiates the egg gallery and, following mating, lays eggs in alternating groups along the sides of the gallery. Egg galleries average about 12 inches long (31 cm) and are usually completed by late October when temperatures are too cold for the beetles to continue boring and ovipositing. Most eggs hatch in about 2 weeks; however, more time is required as temperatures begin to cool in the fall.

Newly hatched larvae feed on the phloem, constructing galleries that extend approximately at right angles to egg galleries (fig. 8). Larvae cease feeding in the fall, overwinter, and begin feeding again in April, completing development in June. Larvae change to pupae within cells excavated in the bark and sapwood. Pupae then transform to adults, usually from late June to mid-July.

In addition to the action of larvae feeding in the phloem, fungi and possibly other microorganisms aid in killing the infested trees (Safranyik and others 1975).

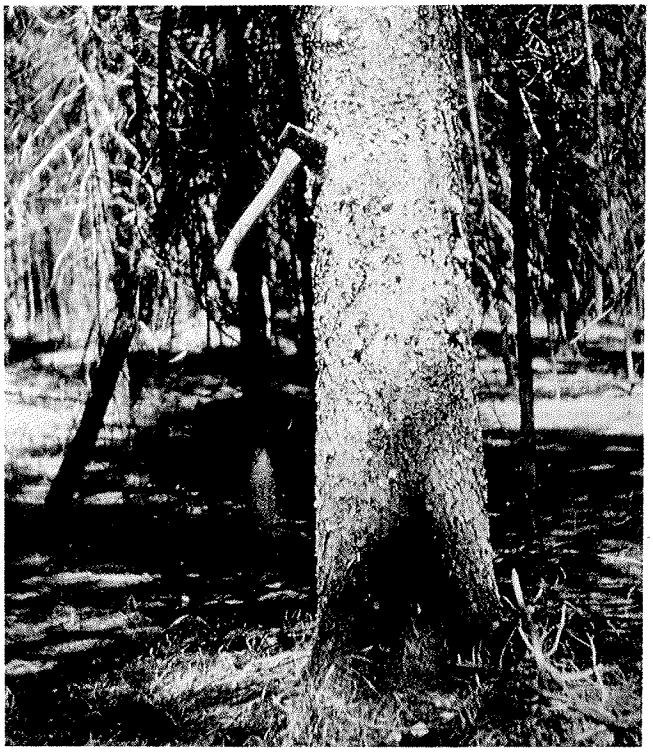

Figure 7.—Unsuccessful attack, called a pitchout. The tree was able to overcome the attacking beetles with a copious resin (pitch) response. Notice the absence of boring dust at base of tree.

New adults pick up blue stain fungi and probably other microorganisms in special structures located in their mouths while feeding in the bark before emerging. Blue stain fungal spores and yeast and bacterial spores are carried to newly attacked trees, where they develop, eventually spreading throughout the sapwood (fig. 9). The microorganisms commence growth in living phloem and xylem tissues soon after the beetle starts gallery construction. This hinders translocation in the xylem and makes moisture conditions under the bark more favorable for beetle development.

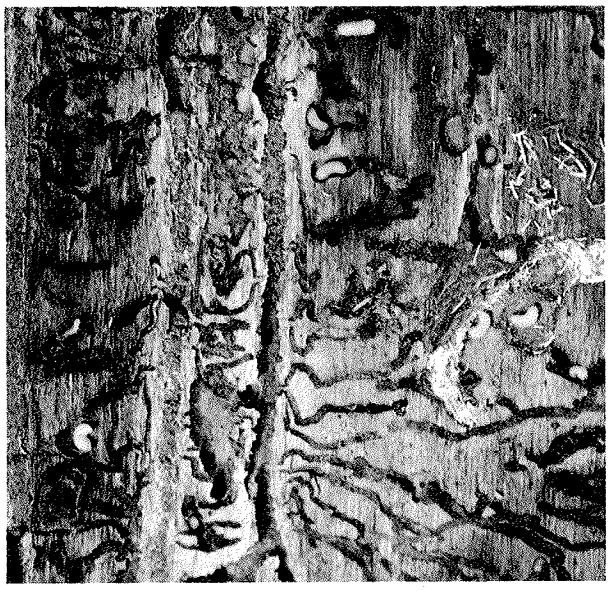

Figure 8.—Stripping the bark from trees in the progressive fading stage reveals egg and larval galleries, with the white larvae in various sizes of development. Brown granular material in galleries is feeding frass of the larvae.

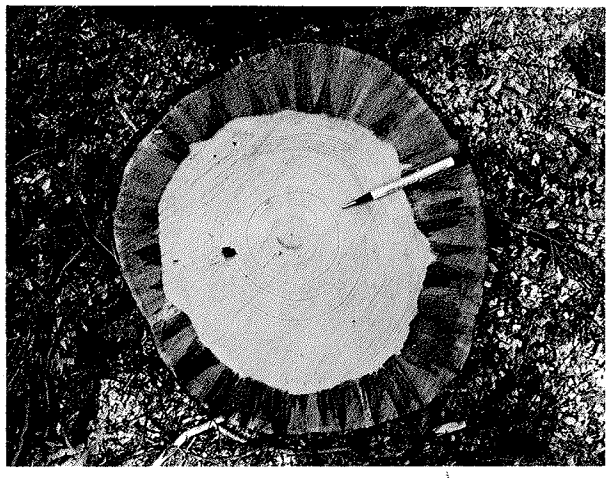

Figure 9.—Blue-stain fungi introduced into the cambial layer by the attacking beetles ramify throughout the sapwood. The bluish-colored band affected by the fungi indicates the extent of sapwood.

BEETLE SURVIVAL

The most important factors affecting survival of the beetle brood and the expansion of beetle populations to epidemic levels are climate, habitat type, size and age of trees, phloem thickness, moisture content of phloem, stand structure, and stand density.

Climatic Factors

Climate can significantly influence the dynamics of beetle populations at extreme northern latitudes and at high elevations in more southerly latitudes (Amman 1976). At the lower elevational zone (below 4,920 ft [1 500 m] at lat. 49° N. to 8,528 ft [3 000 m] at lat. 39° N.), temperatures generally favor survival and multiplication (Amman and others 1977; Safranyik 1978), and the beetle poses a continuous threat to lodgepole pine of susceptible age and size. Above this zone, climate becomes progressively adverse to brood development and survival. Broods tend to undergo a 2-year cycle and become poorly synchronized with climate (Amman 1973) because the least cold-hardy life stages (egg, pupa) coincide with winter. Because of reduced brood survival, infestations become less frequent and intense with increasing elevation, although ample food supply exists (Amman and Baker 1972; Amman and others 1973). Therefore, stands of lodgepole pine at high elevations often contain a higher proportion of large-diameter trees than stands at low elevations.

Habitat Types

Habitat types are reflections of differences in environments. The beetle/lodgepole pine interaction varies in different habitat types. For example, in southeastern Idaho and northwestern Wyoming, 44 percent of the lodgepole pine stands were infested in the *Abies lasiocarpa/Vaccinium scoparium* habitat type (h.t.) between 6,500 and 8,500 ft (1 980 and 2 600 m) elevation; 92 percent were infested in the *Abies lasiocarpa/Paschistima myrsinities* h.t. between 6,500 and 7,800 ft (1 980 and 2 377 m) elevation; and 64 percent were actively infested in the *Pseudotsuga menziesii/Calamagrostis rubescens* h.t. between 6,000 and 7,800 ft (1 828 and 2 377 m) elevation (Roe and Amman 1970).

When habitat types were grouped into four classes on the Gallatin National Forest, MT, tree mortality from the beetles was shown to vary among habitat types and decreased in the following order: Douglas-fir, Engelmann spruce, subalpine fir, and lodgepole pine climax (figs. 10 and 11).

Among the dry habitat types, mortality of the lodgepole pine basal area in trees ≥8 inches (20 cm) d.b.h. ranged from 42 percent at 6,000 ft (1 828 m) elevation on *Pseudotsuga menziesii/Calamagrostis-Caru-Caru* phase h.t. to 25 percent at 8,000 ft (2 430 m) elevation on the *Abies lasiocarpa/Vaccinium scoparium-Vasc* phase h.t. Among moist habitat types mortality ranged from 40

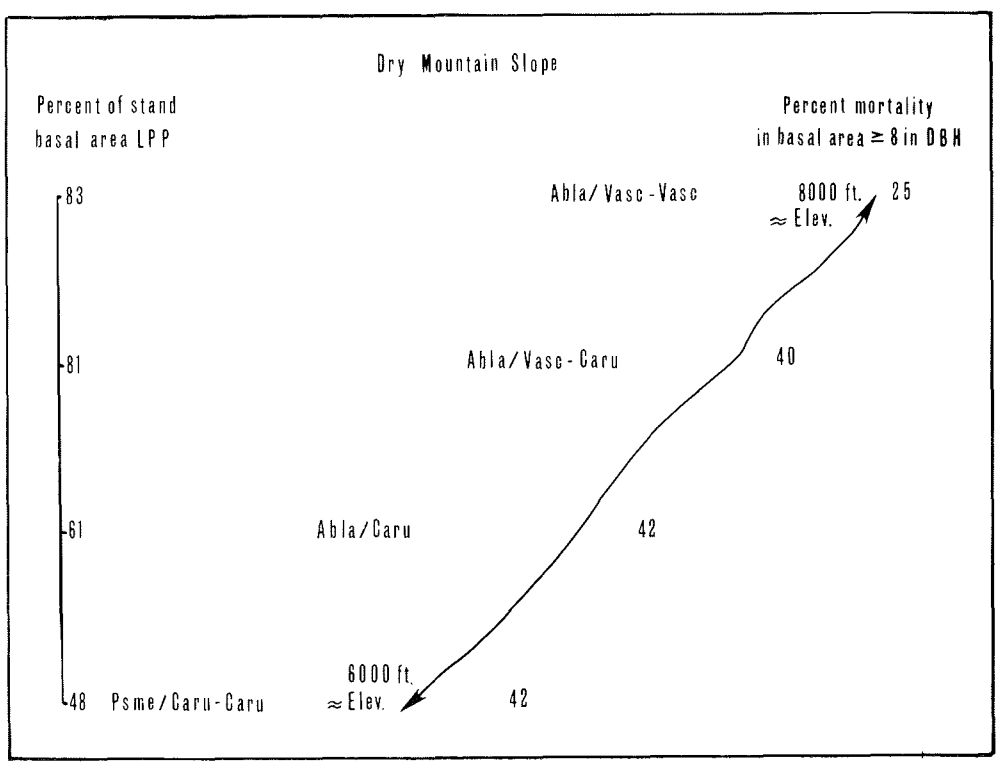

Figure 10.—Percentage of lodgepole pine basal area for trees 8 inches (20 cm) d.b.h. and larger killed by mountain pine beetle in relation to elevation, habitat type, and percentage lodgepole pine basal area in stands on dry aspects (McGregor 1978).

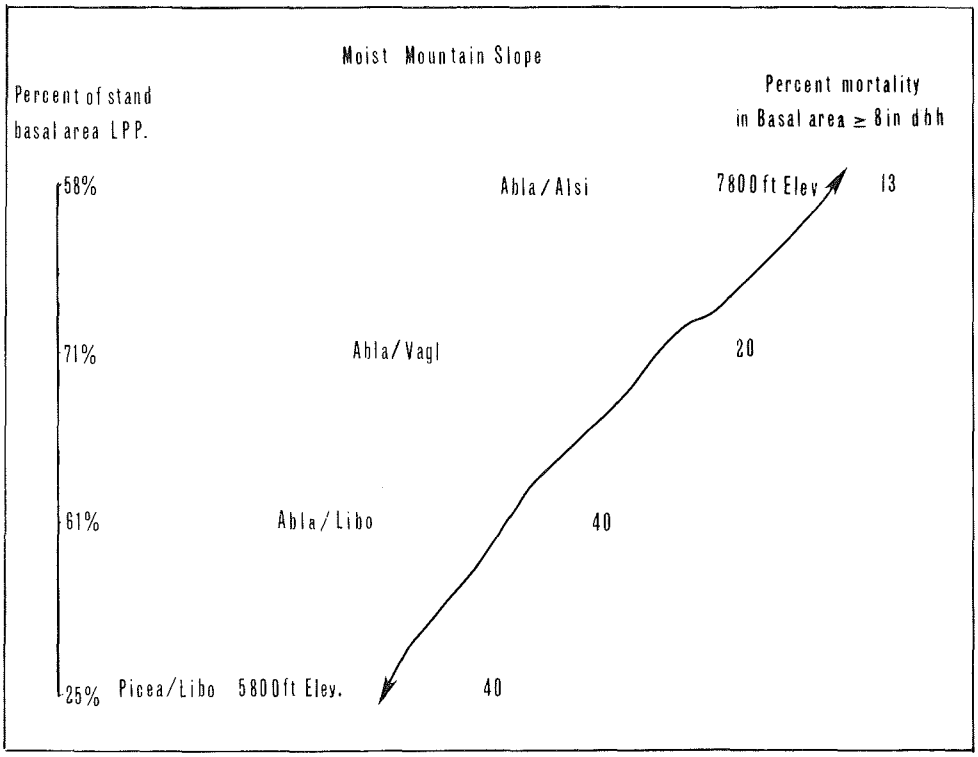

Figure 11.—Percentage of lodgepole pine basal area for trees 8 inches (20 cm) d.b.h. and larger killed by mountain pine beetle in relation to elevation, habitat type, and percentage lodgepole pine basal area in stands on wet aspects (McGregor 1978).

percent at 5,800 ft (1 727 m) elevation on the *Picea/Linnaea borealis* h.t. to 13 percent at 7,800 ft (2 377 m) elevation on *Abies lasiocarpa/Alnus sinuata* h.t. (McGregor 1978). Good sites generally have trees with thicker phloem than poorer sites. Since phloem thickness is the most important factor determining brood production where climate is not limiting, good sites can be expected to suffer more frequent and intense beetle infestations if unmanaged.

Tree Size and Age

Because the beetle selects and kills proportionately more large-diameter than small-diameter trees, large infestations require at least some lodgepole pine larger than 8 inches (20 cm) in diameter. The beetle selects the largest trees in a stand first, as well as over the life of the outbreak. Large trees usually have thicker phloem, the food of developing larvae, and maintain higher moisture levels throughout beetle development than small trees. These are the principal factors responsible for greater beetle production in large than small trees (Amman 1969, 1972; Cole and others 1976). The beetle's behavior in selecting trees of larger diameter is probably adaptive and related to the higher probability of encountering the thick phloem that results in higher progeny survival (Amman 1975).

When older stands of trees are infested, young trees in nearby stands are often attacked and killed. Because brood production and survival are low in young trees, however, young trees alone are not capable of sustaining an outbreak. The average age of trees in which outbreaks occur is about 80 years (Safranyik and others 1974; Amman and others 1977). Outbreaks in stands younger than 60 years have not been reported, a phenomenon that corresponds to general resistance of younger trees to blue stain fungi artificially inoculated under the bark. Resistance drops rapidly after age 60 and continues to decline with increased tree age (Shrimpton 1973). Outbreaks rarely begin in stands 60 to 80 years old. Phloem in trees under 80 years old is usually more spongy and resinous than that of older trees (Amman 1978). This may be because of larger cells and less phloem compression in phloem of young trees (Cabrera 1978).

Stand Structure and Density

Stand structure is important in beetle dynamics because of the beetle's preference for large-diameter lodgepole pines (Cole and Amman 1969). Losses of lodgepole increase as the proportion of lodgepole 9 inches (23 cm) or larger d.b.h. increases in stands (Amman and others 1973). As large-diameter trees are depleted from the stand, beetles turn to small trees; however, few beetles survive in small trees because of thin phloem and excessive drying. The number of beetles and infested trees subsequently declines (Cole and others 1976).

Under epidemic conditions, beetles depend upon the best trees in stands for a population buildup. Epidemics

usually start in full-crowned trees, but not necessarily the oldest or biggest, located along the outer edge of the timber bordering open rangeland or on lake and stream shores (Washburn and Knopf 1959). Trees at edges or in more open stands are usually growing faster than those within stands and, consequently, have thicker phloem. In more open stands, the proportional losses of lodgepole pine are therefore much greater (Amman 1978).

Stands with the greatest amount of dwarf mistletoe infection have proportionately fewer trees killed than do stands with little or no infection (McGregor 1978). This is because trees with medium-to-heavy dwarf mistletoe infection in the crown have significantly thinner phloem than do uninfected trees (Roe and Amman 1970).

The killing of the largest trees as they become mature, or slightly before they reach maturity in persistent and climax stands, suggests an adaptation by the beetle that results in a more continuous food supply for future generations (Amman 1977).

THE HOST

Robert D. Pfister
University of Montana
Missoula, MT

Dennis M. Cole
Intermountain Forest and Range
Experiment Station
Forestry Sciences Laboratory
Bozeman, MT

Lodgepole pine is one of the most widespread and important tree species in the coniferous forests of the western United States. It ranks fourth among timber types, covering about 13.3 million acres (5.38 million hectares), or 11 percent of the total area of commercial forest lands in this region (U.S. Department of Agriculture, Forest Service 1972). The three forms of lodgepole pine are found in distinct geographic regions:

- *P. contorta* var. *contorta*—Pacific Coast form (also known as shore pine)
- *P. contorta* var. *murryana*—Sierra-Cascade form
- *P. contorta* var. *latifolia*—Rocky Mountain and Intermountain forms

P. contorta var. *latifolia* is the preponderant form of commercial value and the one occurring where mountain pine beetle is an important part of the ecosystem. It is the form referred to throughout the rest of this paper.

Lodgepole pine forests in the Rocky Mountain and Intermountain areas provide many resources: cover for watersheds, forage for livestock, habitat for wildlife, wood products, and scenic and other recreational values. Because of the large proportion of area covered by lodgepole pine forests near and east of the Continental Divide, they are often the major provider of many of the above forest resources in this vast area.

Lodgepole pine has several notable silvical characteristics that strongly influence its management (Tackle 1955; Smithers 1957; D. M. Cole 1975). It is a seral, shade-intolerant species able to grow on most forest sites. It dominates large areas, mostly because of stand-replacing wildfires. In areas where closed cones prevail, stand-replacing fires have often resulted in overstocked lodgepole pine regeneration; however, successful fire control in the past several decades has resulted in fewer acres burned and a decreasing proportion of young, heavily overstocked stands.

Although lodgepole pine is a fast early grower, an overstocked stand soon suffers growth stagnation. Without stocking reduction, seriously stagnated stands can persist beyond normal rotation without ever producing merchantable material other than posts and poles. Growth rates of individual trees in stagnated stands can be improved by thinning, but for a given level of response, the time required for response is negatively correlated with degree of live crown ratio of leave trees and positively correlated with stocking and age (D. M. Cole 1975). Thus, the greater the degree of overstocking, the earlier the stand must receive stocking control if growth stagnation is to be minimized.

The major descriptors of stands—species composition, condition, and the age distribution of trees—greatly influence the practices chosen to prevent or reduce mortality from the beetle and their compatibility with other silviculture and management objectives. Composition (pure versus mixed species) and condition (healthy versus unhealthy) of stands are reasonably obvious, but age distribution is less so. Stands are often assumed to be even-aged when they are not. Such errors in identifying the age distribution can lead to an improper prescription from both silvicultural and entomological standpoints (D. M. Cole 1978). Tackle (1955) developed a preliminary classification for describing both pure and mixed lodgepole pine stands by age distribution and the developmental stage of the overstory versus the understory. A revised form of this classification is presented in figure 12. The revision redefines developmental stages to make them more consistent with contemporary economic rotations and ecological relationships with the mountain pine beetle. Specifically, the immature stage was redefined from 40 to 120 years to 40 to 80 years, and the mature stage from 120 to 140 years to 80 to 120 years. Although not all age classes are discussed as they might relate to mountain pine beetle infestation, most of the stand situations discussed in the following sections are identifiable in Tackle's classification.

Ecologically, the widespread occurrence of lodgepole pine is due to its capacity to grow in many different environments and the past prevalence of unchecked wildfires. The capacity to grow in a wide range of environments with a large number of other tree species illustrates its broad ecologic amplitude (Pfister and Daubenmire 1975). A comparison of this capacity in lodgepole pine and in other common associates is shown in figure 13, where the length of the occurrence bars indicates amplitude along a generalized environmental gradient.

The occurrence of lodgepole pine with and without association of other species is best explained in terms of the several successional roles that lodgepole pine can assume. These are described in the following section—

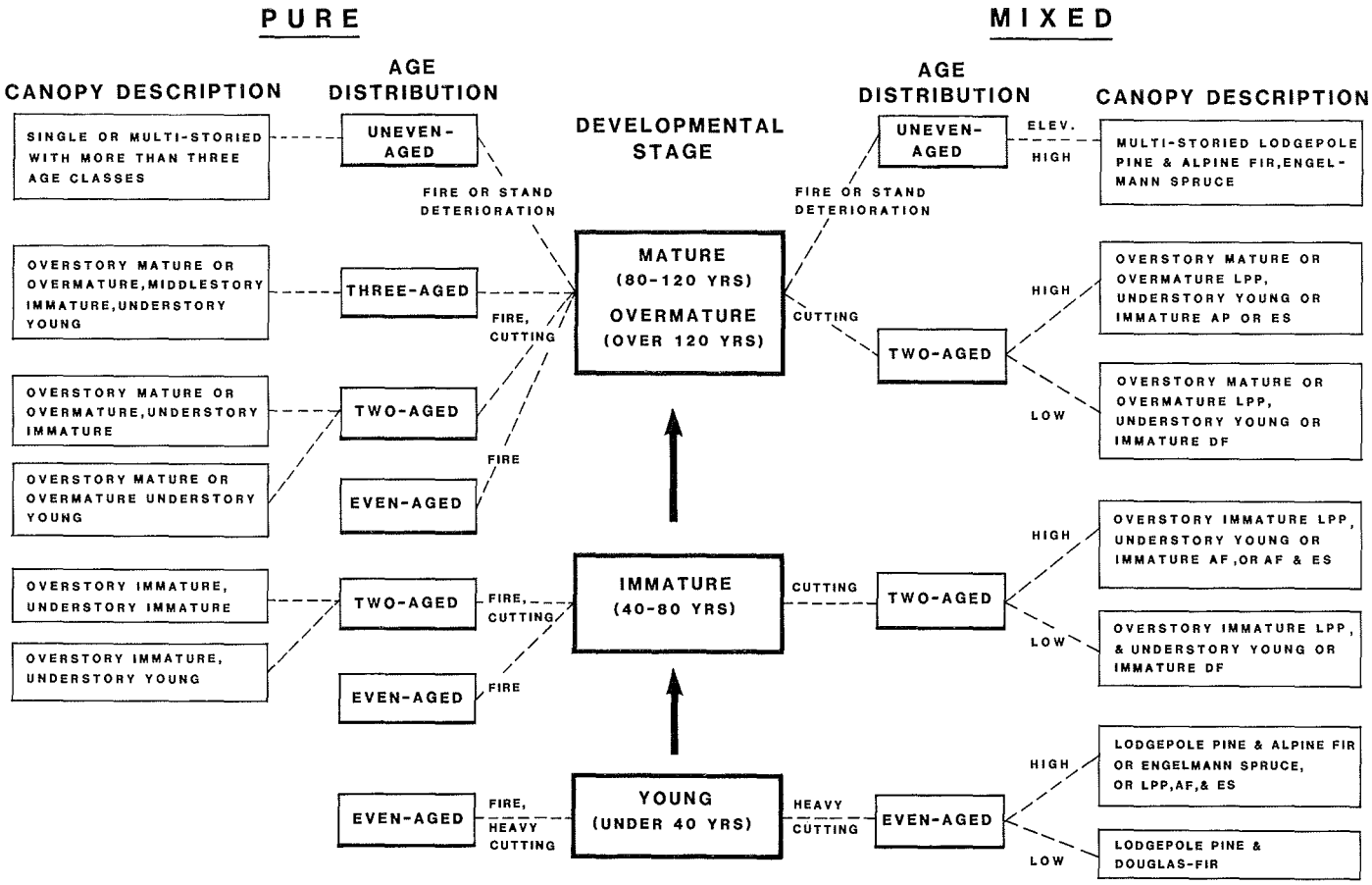

Figure 12.—Lodgepole pine stand classification (after Tackle 1955).

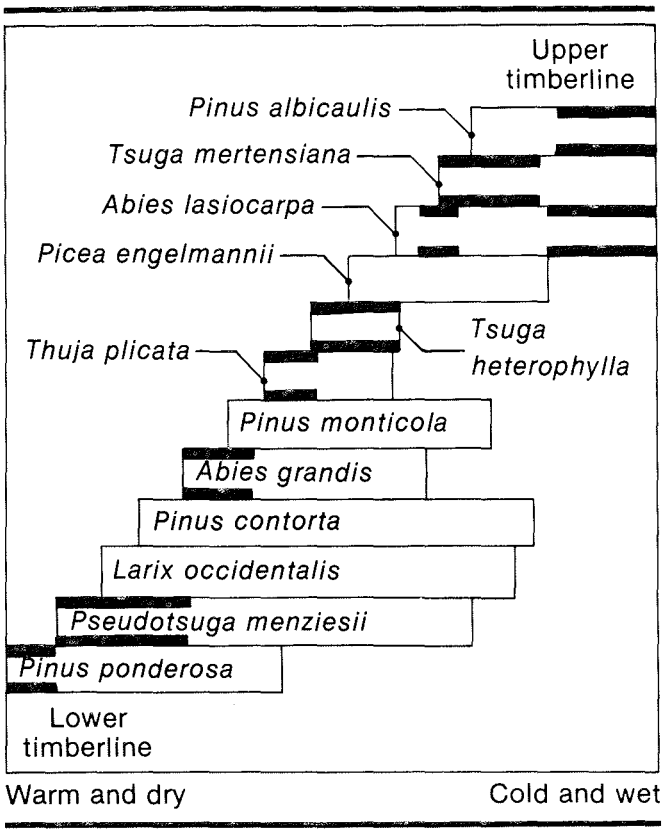

Figure 13.—Coniferous trees in the area centered on eastern Washington and northern Idaho; arranged vertically to show the usual order in which the species are encountered with increasing altitude. The horizontal bars designate relative upper and lower limits of the species' altitudinal range in which it can maintain a self-reproducing population. The heavy lines indicate range in which self-reproducing population can be maintained even in the face of intense competition (from Daubenmire 1966).

suffice it to say here that each of the successional roles manifests itself differently in one or more aspects of stand description, that is, composition, structure, condition, and form (age distribution). Understanding how these stand elements vary with successional role is important in interpreting mountain pine beetle/stand relationships and in determining likely consequences of silvicultural response to the mountain pine beetle—both discussed in later sections of this paper.

SUCCESSIONAL ROLES OF LODGEPOLE PINE

There are four basic successional roles for lodgepole pine (Pfister and Daubenmire 1975):

1. **Minor seral.**—Lodgepole pine is a minor component of young, even-aged, mixed species stands (fig. 14). It is replaced by shade-tolerant associates in 50 to 200 years; the more mesic the site, the sooner replacement occurs.

2. **Dominant seral.**—Lodgepole pine is often the dominant cover type of even-aged stands of habitat types where it exhibits a dominant seral role. In these cases, it often occurs with a vigorous understory of shade-tolerant species that will replace the lodgepole in 100 to 200 years (fig. 15). Succession occurs most rapidly where lodgepole pine and shade-tolerant associates become established simultaneously. Lodgepole pine gains dominance through rapid early growth, but shade-tolerant species persist and assume dominance as lodgepole pines die.

Figure 14.—Lodgepole pine in a minor seral successional role being replaced by Douglas-fir and Engelmann spruce. The pale green saplings are predominantly Douglas-fir.

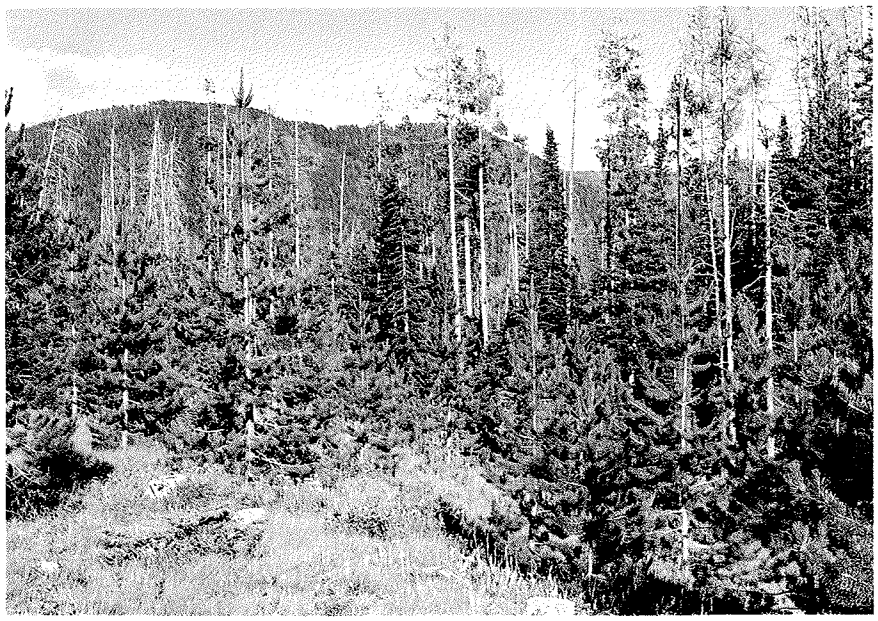

Figure 15.—Pale and dying lodgepole pine contrast with healthy dark green crowns of subalpine fir and spruce in the background remnant of this stand clearcut and regenerated with lodgepole pine. This succession and regeneration pattern is typical where lodgepole pine occupies a major seral role and fire has interrupted succession of shade-tolerant species.

3. **Persistent.**—Lodgepole pine forms the dominant cover type of even-aged stands with little evidence of replacement by shade-tolerant species (fig. 16), which occur only as scattered individuals and apparently are too few and lack sufficient vigor to replace lodgepole pine. Lodgepole pine maintains dominance either because of inadequate seed sources for potential competitors or because the sites are poorly suited for other species. Although the cause-effect relationships are not known at this time, ecologists suggest that these sites be managed as if lodgepole pine were the climax species (Pfister and others 1977).

4. **Climax.**—Lodgepole pine is the only species capable of growing on particular sites and is self-perpetuating. In central Oregon, lodgepole pine forms an edaphic climax in frost pockets (Franklin and Dyrness 1973). In Wyoming, it forms an edaphic climax on granitic soils in portions of the Bighorn Mountains (Despain 1973) and on shallow, infertile soils of schist origin in portions of the Wind River Mountains. It also forms an edaphic climax on obsidian sands in the West Yellowstone Basin of the Gallatin National Forest and in Yellowstone National Park (fig. 17).

Figure 16.—Where lodgepole pine exhibits a persistent successional role, it dominates the site and affords little opportunity for establishment of other species.

Figure 17.—Climax lodgepole pine stand on obsidian sand at West Yellowstone, MT. Such pure stands are often uneven-aged and typically multistoried as shown here.

DESCRIPTIVE SUMMARY OF SUCCESSIONAL ROLES AND HABITAT TYPES OF LODGEPOLE PINE IN MONTANA AND NORTHERN IDAHO

Using the commonly accepted habitat-type classifications for Montana and northern Idaho (Daubenmire and Daubenmire 1968; Pfister and others 1977), we have summarized the habitat types where lodgepole pine occurs—according to geographic/climatic expression and successional role (tables 1 to 4). Following each table, habitat types represented are pictured with descriptive captions (figs. 18 to 59). These successional and pictorial summaries should be helpful to readers not having formal training in habitat-type identification; by providing an ecological framework for discussion, the summaries should facilitate the managerial process of developing integrated resource approaches for dealing with the mountain pine beetle problem. They will also help readers relate to the section "Occurrence of Lodgepole Pine Stands According to Habitat Type and Successional Role," where methods and results are presented of summaries of lodgepole pine acreage by successional role, habitat type, and size class for two National Forests containing large acreages of lodgepole pine. When habitat typing is completed throughout the lodgepole pine range, tables 1 to 4 can be expanded to include the additional information.

Table 1.—Habitat types where lodgepole pine is usually minor seral

Montana	Northern Idaho – Northwestern Montana	
Warm – dry	**Pacific cool – moist**	**Cold – moist**
PSME/SYAL	ABGR/CLUN	ABLA/LUHI
PSME/PHMA	ABGR/LIBO	TSME/MEFE
ABLA/CLPS	TSHE/CLUN	TSME/LUHI
	THPL/CLUN	

PSME/SYAL	*Pseudotsuga menziesii/Symphoricarpos albus* Douglas-fir/snowberry
PSME/PHMA	*Pseudotsuga menziesii/Physocarpus malvaceus* Douglas-fir/ninebark
ABGR/CLUN	*Abies grandis/Clintonia uniflora* Grand fir/queencup beadlily
ABGR/LIBO	*Abies grandis/Linnaea borealis* Grand fir/twinflower
TSHE/CLUN	*Tsuga heterophylla/Clintonia uniflora* Western hemlock/queencup beadlily
THPL/CLUN	*Thuja plicata/Clintonia uniflora* Western redcedar/queencup beadlily
ABLA/CLPS	*Abies lasiocarpa/Clematis pseudoalpina* Subalpine fir/virgin's bower
ABLA/LUHI	*Abies lasiocarpa/Luzula hitchcockii* Subalpine fir/smooth wood-rush
TSME/MEFE	*Tsuga mertensiana/Menziesia ferruginea* Mountain hemlock/menziesia
TSME/LUHI	*Tsuga mertensiana/Luzula hitchcockii* Mountain hemlock/smooth wood-rush

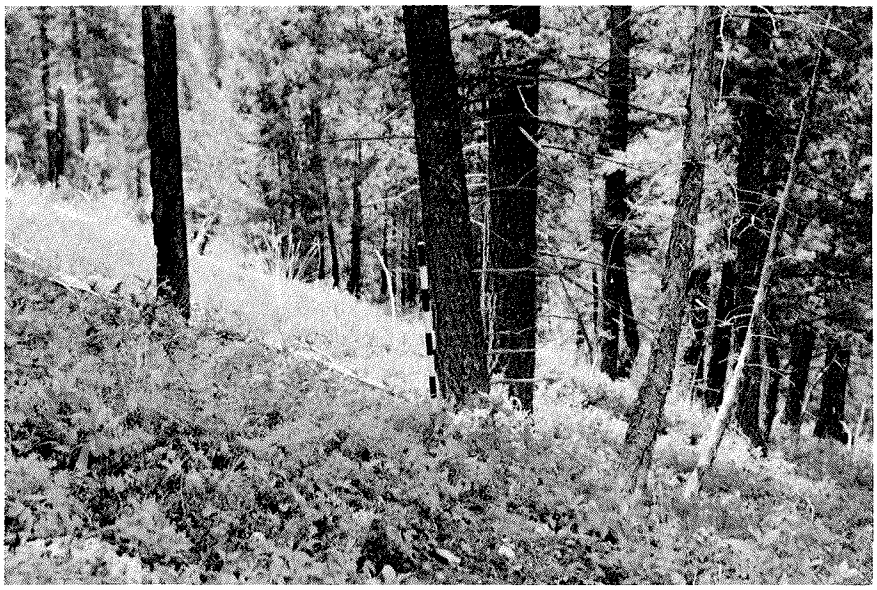

Figure 18.—The Pseudotsuga menziesii/Symphoricarpos albus *(PSME/SYAL) h.t. is found throughout Montana on moderately warm slopes and benches between 2,700 and 5,500 ft (823 and 1 676 m) elevation in northwestern and west-central Montana and 5,300 and 7,000 ft (1 615 and 2 134 m) elevation in eastern Montana.*

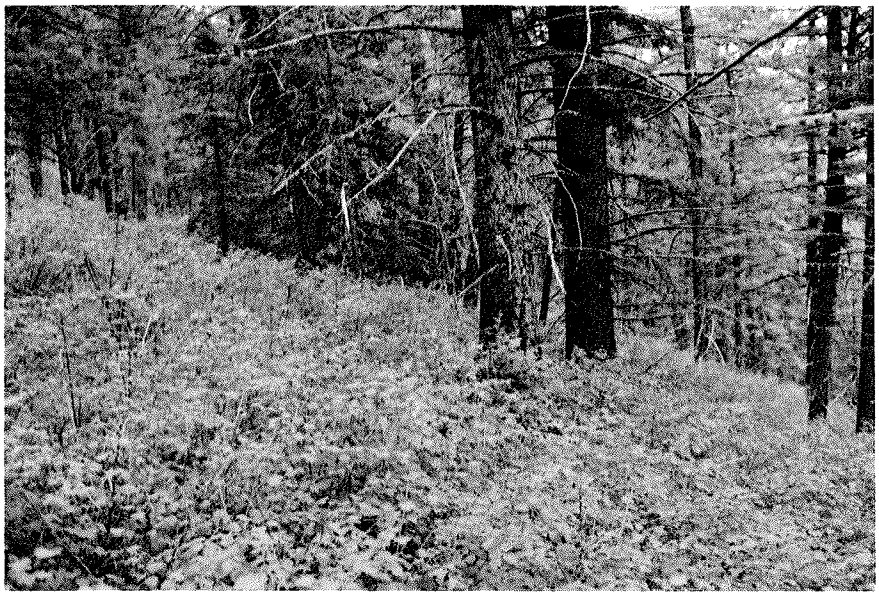

Figure 19.—The Pseudotsuga menziesii/Physocarpus malvaceus *(PSME/PHMA) h.t. occurs predominantly on cool and moist north- or east-facing slopes; between 2,000 and 5,700 ft (610 and 1 737 m) elevation in west-central Montana, 4,800 and 5,800 ft (1 463 and 1 768 m) in central Montana, and 5,100 and 6,700 ft (1 554 and 2 042 m) in south-central Montana.*

Figure 20.—The Abies grandis/Clintonia uniflora *(ABGR/CLUN) h.t. is found in relatively moist sites from 2,400 to 5,000 ft (732 to 1 524 m) elevation in northwestern and west-central Montana. It occurs on valley bottoms, benches, and on all aspects.*

Figure 21.—The Abies grandis/Linnaea borealis *(ABGR/LIBO) h.t. is a minor habitat in Montana occurring between 3,700 and 5,500 ft (1 128 and 1 676 m) elevation on northerly to southeasterly aspects.*

Figure 22.—The Tsuga heterophylla/Clintonia uniflora *(TSHE/CLUN) h.t. is a restricted h.t. in the extreme northwestern portion of Montana, with minor extensions east to Glacier National Park. It occurs mostly on valley bottoms, on benches, or on cool exposures at elevations from 1,800 to 4,000 ft (549 to 1 219 m).*

Figure 23.—The Thuja plicata/Clintonia uniflora *(THPL/CLUN) h.t. is common in northwestern Montana extending east to Glacier National Park, Swan River Valley, and south to the Bitterroot Range. It is typically associated with bottomlands, benches, and northerly exposures from 2,000 to 5,000 ft (610 to 1 524 m) elevation.*

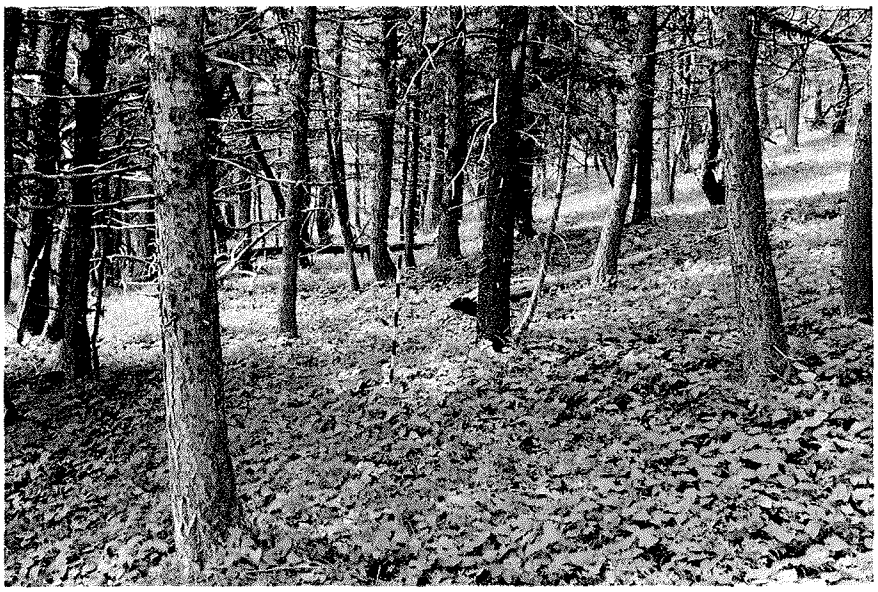

Figure 24.—The Abies lasiocarpa/Clematis pseudoalpina *(ABLA/CLPS) h.t. is a warm dry habitat of the* Abies *series. It occurs on south- and west-facing slopes having limestone or calcium-rich substrates east of the Continental Divide in Montana at elevations between 6,000 and 8,000 ft (1 829 and 2 438 m).*

Figure 25.—The Abies lasiocarpa/Luzula hitchcockii *(ABLA/LUHI) h.t. is the major upper subalpine forest habitat type from the Continental Divide westward in Montana. It forms a zone extending over 700 ft (213 m) in elevation between the ABLA/XETE or ABLA/MEFE h.t.'s below and the PIAL/ABLA or LALY/ABLA h.t.'s.*

Figure 26.—The Tsuga mertensiana/Menziesia ferruginea *(TSME/MEFE) h.t. is associated with a mountain climate having strong oceanic influence; restricted to the border region of northwestern Montana, between 5,400 and 6,400 ft (1 646 and 1 951 m) elevation.*

Figure 27.—The Tsuga mertensiana/Luzula hitchcockii *(TSME/LUHI) h.t. is found along and adjacent to the Montana/Idaho divide between 6,000 and 6,500 ft (1 829 and 1 981 m) elevation.*

Table 2.—Habitat types where lodgepole pine is often dominant seral

Montana			Northern Idaho – Northwestern Montana
Warm – dry	**Cool – moist**	**Cold – dry**	**Warm-moist**
PSME/LIBO PSME/CARU	PICEA/PHMA	ABLA/CAGE ABLA/PIAL/VASC	ABLA/CLUN
PSME/LIBO	*Pseudotsuga menziesii/Linnaea borealis* Douglas – fir/twinflower		
PSME/CARU	*Pseudotsuga menziesii/Calamagrostis rubescens* Douglas – fir/pinegrass		
PICEA/PHMA	*Picea/Physocarpus malvaceus* Spruce/ninebark		
ABLA/CAGE	*Abies lasiocarpa/Carex geyeri* Subalpine fir/elk sedge		
ABLA/CLUN	*Abies lasiocarpa/Clintonia uniflora* Subalpine fir/queencup beadlily		
ABLA – PIAL/VASC	*Abies lasiocarpa – Pinus albicaulis/Vaccinium scoparium* Subalpine fir – whitebark pine/grouse whortleberry		

Figure 28.—The Pseudotsuga menziesii/Linnaea borealis *(PSME/LIBO) h.t. is a major habitat type in northwestern, west-central, and central Montana. It occurs on all but the wettest or driest sites, on moderate slopes, at elevations ranging from 2,600 to 4,000 ft (792 to 1 219 m) in northwestern Montana; 4,000 to 6,000 ft (1 219 to 1 829 m) in west-central Montana; and 5,000 to 6,500 ft (1 524 to 1 981 m) in central Montana.*

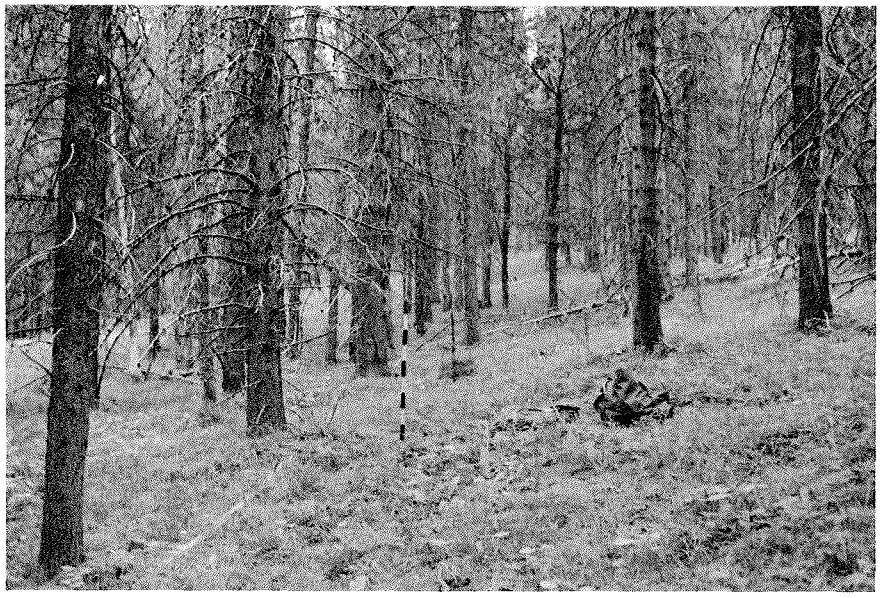

Figure 29.—The Psuedotsuga menziesii/Calamagrostis rubescens *(PSME/CARU) h.t. occurs at elevations from 2,700 ft (823 m) in northwestern Montana to 7,800 ft (2 377 m) in southwestern and south-central Montana. At lower elevations, it occurs on benches and north-facing upper slopes and mountainsides. At higher elevations, it is found in similar positions on south-facing slopes.*

Figure 30.—The Picea/Physocarpus malvaceous *(PICEA/PHMA) h.t. covers sizable areas on moist, north-facing slopes in south-central Montana on the Gallatin National Forest between 5,900 and 7,000 ft (1 798 and 2 134 m) elevation.*

Figure 31.—The Abies lasiocarpa/Carex geyeri *(ABLA/CAGE) h.t. encompasses some of the driest sites in Montana. On southerly aspects between 6,600 and 7,700 ft (2 012 and 2 347 m) elevation on the Gallatin National Forest and from 6,700 to 7,100 ft (2 042 to 2 164 m) elevation in Little Belt and Big Belt Mountains of central Montana.*

Figure 32.—The Abies lasiocarpa/Clintonia uniflora *(ABLA/CLUN) h.t. occurs on moist and warm sites in northwestern Montana in the Flathead River drainage at 3,200 to 5,500 ft (975 to 1 676 m) elevation.*

Figure 33.—The Abies lasiocarpa-Pinus albicaulis/Vaccinium scoparium *(ABLA-PIAL/VASC) h.t. is an extensive high-elevation habitat type east of the Continental Divide in all but driest mountain ranges. It is found on all exposures from 7,200 to 8,100 ft (2 195 to 2 469 m) elevation in central Montana, 8,000 to 8,800 ft (2 438 to 2 682 m) elevation in southwestern Montana, and 8,100 to 9,000 ft (2 469 to 2 743 m) elevation in south-central Montana.*

Table 3.—Habitat types where lodgepole pine is usually dominant seral

Montana			Northern Idaho – Northwestern Montana	
Dry	**Moist**	**Cold – moist**	**Cold – dry**	**Cold – moist**
PSME/JUCO	PSME/VACA	ABLA/CACA	ABGR/XETE	ABLA/MEFE
ABLA/CARU	PICEA/CLUN	ABLA/LIBO	PSME/VAGL	TSME/XETE
	PICEA/GATR	ABLA/VASC	ABLA/XETE	
	PICEA/LIBO			
	PICEA/SMST			
	PICEA/VACA			
	ABLA/VAGL			
	ABLA/ALSI			
	ABLA/ARCO			
	ABLA/GATR			

PSME/VAGL	*Pseudotsuga menziesii/Vaccinium globulare* Douglas – fir/blue huckleberry
PSME/JUCO	*Pseudotsuga menziesii/Juniperus communis* Douglas – fir/common juniper
PSME/VACA	*Pseudotsuga menziesii/Vaccinium caespitosum* Douglas – fir/dwarf huckleberry
PICEA/CLUN	*Picea/Clintonia uniflora* Spruce/queencup beadlily
PICEA/GATR	*Picea/Galium triflorum* Spruce/sweetscented bedstraw
PICEA/LIBO	*Picea/Linnaea borealis* Spruce/twinflower
PICEA/SMST	*Picea/Smilacina stellata* Spruce/starry Solomon's seal
PICEA/VACA	*Picea/Vaccinium caespitosum* Spruce/dwarf huckleberry
ABGA/XETE	*Abies grandis/Xerophyllum tenax* Grand fir/beargrass
ABLA/GATR	*Abies lasiocarpa/Galium triflorum* Subalpine fir/sweetscented bedstraw
ABLA/CACA	*Abies lasiocarpa/Calamagrostis canadensis* Subalpine fir/bluejoint
ABLA/LIBO	*Abies lasiocarpa/Linnaea borealis* Subalpine fir/twinflower
ABLA/MEFE	*Abies lasiocarpa/Menziesia ferruginea* Subalpine fir/menziesia
ABLA/XETE	*Abies lasiocarpa/Xerophyllum tenax* Subalpine fir/beargrass
TSME/MEFE	*Tsuga mertensiana/Menziesia ferruginea* Mountain hemlock/menziesia
ABLA/VAGL	*Abies lasiocarpa/Vaccinium globulare* Subalpine fir/blue huckleberry
ABLA/VASC	*Abies lasiocarpa/Vaccinium scoparium* Subalpine fir/grouse whortleberry
ABLA/ALSI	*Abies lasiocarpa/Alnus sinuata* Subalpine fir/Sitka alder
ABLA/CARU	*Abies lasiocarpa/Calamagrostis rubescens* Subalpine fir/pinegrass
ABLA/ARCO	*Abies lasiocarpa/Arnica cordifolia* Subalpine fir/heartleaf arnica

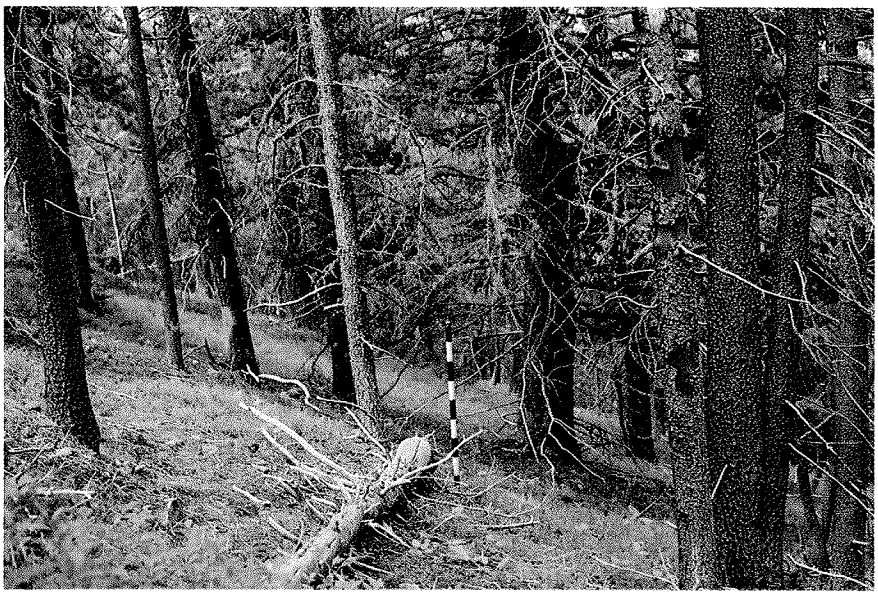

Figure 34.—The Pseudotsuga menziesii/Vaccinium globulare *(PSME/VAGL) h.t. occurs on cold, well drained slopes at elevations between 4,300 and 6,800 ft (1 311 and 2 073 m) on the Lolo and Bitterroot National Forests.*

Figure 35.—The Pseudotsuga menziesii/Juniperus communis *(PSME/JUCO) h.t. is a common habitat type in cool-dry environments of central and northwestern Montana, occurring on the Lewis and Clark, Deerlodge, and Beaverhead National Forests. It is one of the driest h.t.'s supporting lodgepole pine in the Douglas-fir series. Juniper is typically sparse because of stand density.*

Figure 36.—The Pseudotsuga menziesii/Vaccinium caespitosum *(PSME/VACA) h.t. is a widely occurring h.t. in Montana. It is found on warm and moist benches and gentle slopes from 2,500 to 3,800 ft (762 to 1 158 m) in northwestern Montana, 2,900 to 4,500 ft (884 to 1 372 m) in west-central Montana, and 5,200 to 6,400 ft (1 585 to 1 951 m) east of the Continental Divide.*

Figure 37.—The Picea/Clintonia uniflora *(PICEA/CLUN) h.t. occurs in moist environments on benches and gentle north slopes in northwestern Montana from 3,000 to 4,100 ft (914 to 1 250 m) elevation in the Flathead Valley and occasionally on the Kootenai National Forest.*

Figure 38.—The Picea/Galium triflorum *(PICEA/GATR) h.t. is found on cool, moist sites, bordering streams, or on moist toe-slopes in south-central Montana between 6,000 and 7,000 ft (1 829 and 2 134 m) elevation.*

Figure 39.—The Picea/Linnaea borealis *(PICEA/LIBO) h.t. is found on cool, well drained benches and gentle northeast slopes east of the Continental Divide in Montana between 4,200 and 7,200 ft (1 280 and 2 195 m) elevation.*

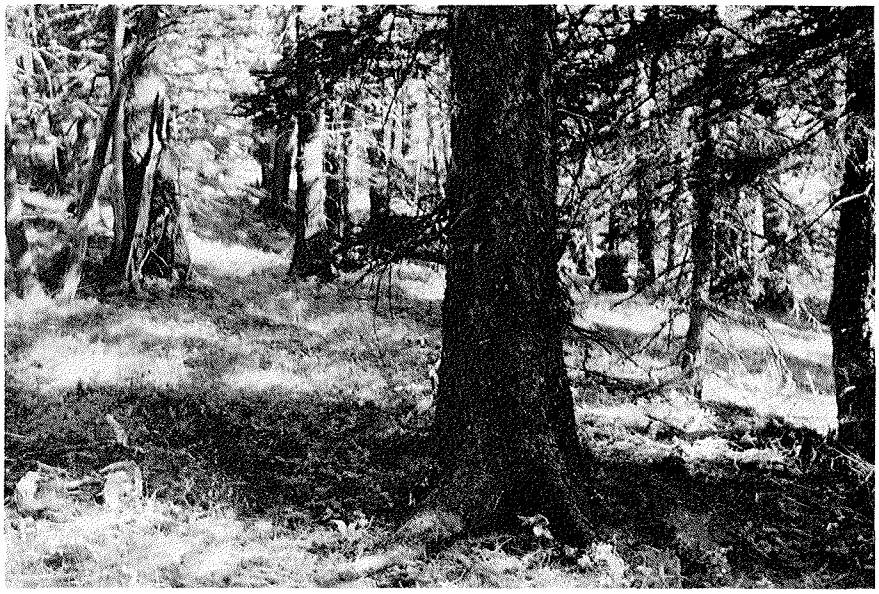

Figure 40.—The Picea/Smilacina stellata *(PICEA/SMST) h.t. occurs east of the Continental Divide from the Lewis and Clark National Forest to Yellowstone Park. It is found on warm, moist benches and lower slopes mostly between 5,000 and 7,000 ft (1 524 and 2 134 m) elevation.*

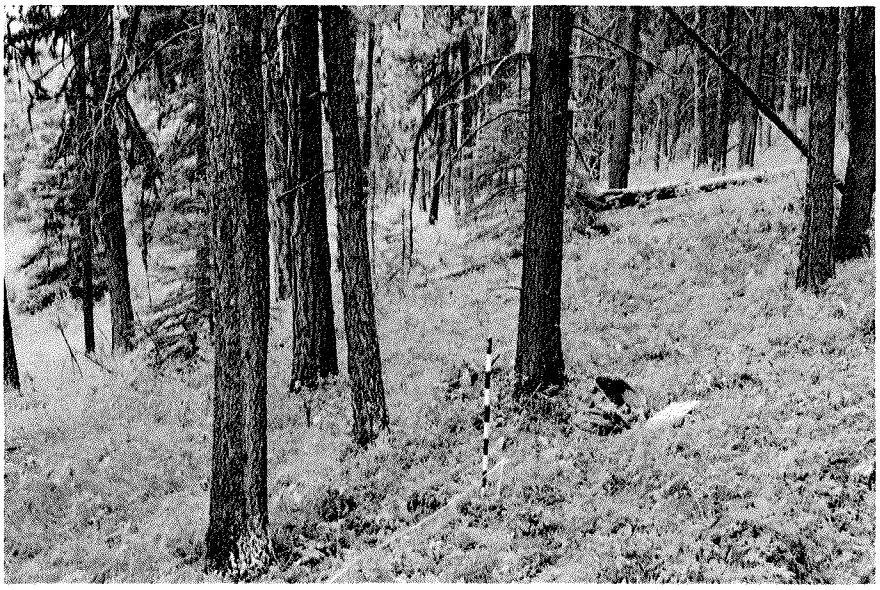

Figure 41.—The Picea/Vaccinium caespitosum *(PICEA/VACA) h.t. is common in northwestern Montana between 3,100 and 4,200 ft (945 and 1 280 m) elevation. It is restricted to benchlands at higher elevations eastward in Montana.*

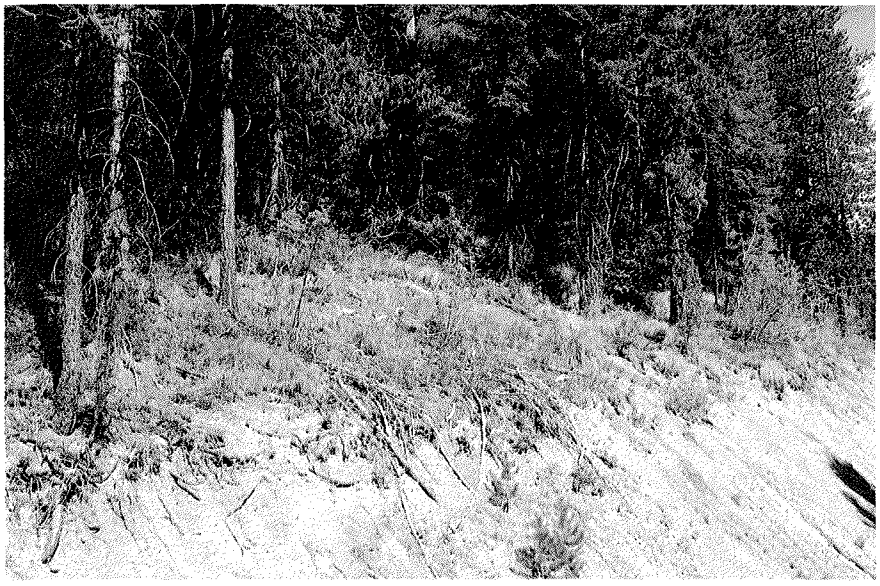

Figure 42.—The Abies grandis/Xerophyllum tenax *(ABGR/XETE) h.t. is common on well-drained slopes between 4,700 and 5,300 ft (1 433 and 1 615 m) elevation in western portions of the Lolo and Bitterroot National Forests.*

Figure 43.—The Abies lasiocarpa/Galium triflorum *(ABLA/GATR) h.t. occurs throughout the Montana Rockies on moist bottomlands, benches, northern exposures, and occasionally seepage areas on southern exposures between 5,000 and 6,800 ft (1 524 and 2 073 m) elevation except on the Gallatin National Forest, where it occurs from 6,300 to 7,700 ft (1 920 to 2 345 m).*

Figure 44.—The Abies lasiocarpa/Calamagrostis canadensis *(ABLA/CACA) h.t. is the major type on wet sites at high elevations, except in northwestern Montana. It occurs at elevations from 6,000 to 7,500 ft (1 829 to 2 286 m) in west-central Montana and from 7,000 to 8,500 ft (2 134 to 2 591 m) east of the Continental Divide.*

Figure 45.—The Abies lasiocarpa/Linnaea borealis *(ABLA/LIBO) h.t. is associated with relatively moist sites on north-facing slopes and benches throughout the Montana Rockies. It occurs mostly at elevations of 5,000 to 7,000 ft (1 524 to 2 134 m).*

Figure 46.—The Abies lasiocarpa/Menziesia ferruginea *(ABLA/MEFE) h.t. is abundant in the moist, higher elevations of western Montana and extends slightly eastward of the Continental Divide near Hebgen Lake and the Madison Range in southwestern Montana.*

Figure 47.—The Abies lasiocarpa/Xerophyllum tenax *(ABLA/XETE) h.t. occurs west of the Continental Divide on steep, dry exposures between 5,200 and 7,000 ft (1 585 and 2 134 m) elevation.*

Figure 48.—The Tsuga mertensiana/Xerophyllum tenax *(TSME/XETE) h.t. is usually found at 5,500 to 6,500 ft (1 676 to 1 981 m) elevation on upper slopes and ridges only in the extreme northwestern part of Montana.*

Figure 49.—The Abies lasiocarpa/Vaccinium globulare *(ABLA/VAGL) h.t. occurs on moist north- or east-facing slopes on cool benches, between 6,000 and 7,800 ft (1 829 and 2 377 m) elevation. It is largely restricted to areas near or east of the Continental Divide.*

Figure 50.—The Abies lasiocarpa/Vaccinium scoparium *(ABLA/VASC) h.t. is one of the most abundant types near and east of the Continental Divide. It occurs mostly on gentle, well-drained slopes, broad ridges, and benches between 7,000 and 8,000 ft (2 134 and 2 438 m) elevation. It is also locally common at 5,000 to 5,700 ft (1 524 to 1 737 m) in dry mountains south and west of Eureka, MT.*

Figure 51.—The Abies lasiocarpa/Alnus sinuata *(ABLA/ALSI) h.t. occurs throughout the mountains of Montana as a scattered h.t. on cool and moist north-facing slopes between 6,500 and 7,500 ft (1 981 and 2 286 m) elevation, except in northwestern Montana, where it occurs between 5,000 and 5,800 ft (1 524 and 1 768 m).*

Figure 52.—The Abies lasiocarpa/Calamagrostis rubescens *(ABLA/CARU) h.t. occurs east of the Continental Divide on warm, dry slopes. It is found at elevations between 6,500 and 7,700 ft (1 981 and 2 347 m) in the Centennial Mountains of southwestern Montana and in the Gallatin National Forest and is common at elevations between 5,000 and 6,300 ft (1 524 and 1 920 m) in the Front Range west of Great Falls, MT.*

Figure 53.—The Abies lasiocarpa/Arnica cordifolia *(ABLA/ARCO) h.t. is a moist, relatively cool h.t. occurring on bench-like uplands and north-facing slopes of semiarid mountains east of the Continental Divide. It occurs on the Beaverhead National Forest at elevations from 7,600 to 8,400 ft (2 316 to 2 560 m) and in the Little Belt Mountains, where it usually occurs on limestone substrates at elevations from 6,900 to 7,600 ft (2 103 to 2 316 m).*

Figure 54.—The Abies lasiocarpa/Vaccinium caespitosum *(ABLA/VACA) h.t. is confined largely to well-drained sites on benchlands and in frosty basins where cold air accumulates at 6,000 to 7,200 ft (1 829 to 2 195 m) elevation near the Continental Divide and in the Little Belt Mountains. Lodgepole pine dominates the overstory, whereas regeneration is lodgepole pine, alpine fir, and Douglas-fir.*

Table 4.—Habitat types where lodgepole pine is persistent/climax

	Central and Eastern Montana
	Cold – dry community types
	ABLA/VACA PICO/VACA PICO/LIBO PICO/CARU PICO/VASC PICO/PUTR
ABLA/VACA	*Abies lasiocarpa/Vaccinum caespitosum* Subalpine fir/dwarf huckleberry
PICO/VACA	*Pinus contorta/Vaccinium caespitosum* Lodgepole pine/dwarf huckleberry
PICO/LIBO	*Pinus contorta/Linnaea borealis* Lodgepole pine/twinflower
PICO/CARU	*Pinus contorta/Calamagrostis rubescens* Lodgepole pine/pinegrass
PICO/VASC	*Pinus contorta/Vaccinium scoparium* Lodgepole pine/grouse whortleberry
PICO/PUTR	*Pinus contorta/Purshia tridentata* Lodgepole pine/bitterbrush

Figure 55.—The Pinus contorta/Vaccinium caespitosum *(PICO/VACA) h.t. occurs east of the Continental Divide on benches and gentle slopes between 6,200 and 7,200 ft (1 890 and 2 195 m) elevation. Some stands occur at 4,800 to 6,500 ft (1 463 to 1 981 m) west of the Divide.*

Figure 56.—The Pinus contorta/Linnaea borealis *(PICO/LIBO) h.t. is common east of the Continental Divide between elevations of 6,500 and 7,200 ft (1 981 and 2 195 m) on benchlands and north-facing midslopes.*

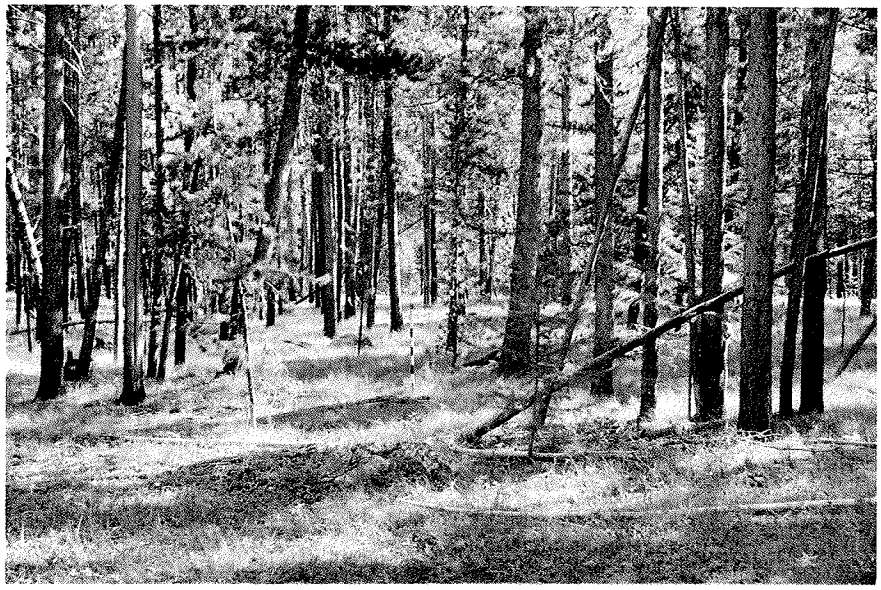

Figure 57.—The Pinus contorta/Calamagrostis rubescens *(PICO/CARU) h.t. is found near and east of the Continental Divide at 5,900 to 6,800 ft (1 798 to 2 073 m) elevation on cool exposures and benches and between 6,600 and 7,500 ft (2 012 and 2 286 m) on south-facing slopes.*

Figure 58.—The Pinus contorta/Vaccinium scoparium *(PICO/VASC) h.t. occurs at elevations of 6,000 to 7,000 ft (1 828 to 2 134 m) near and east of the Continental Divide. It is usually found in relatively cool, dry environments on gentle middle and upper slopes and broad ridgetops.*

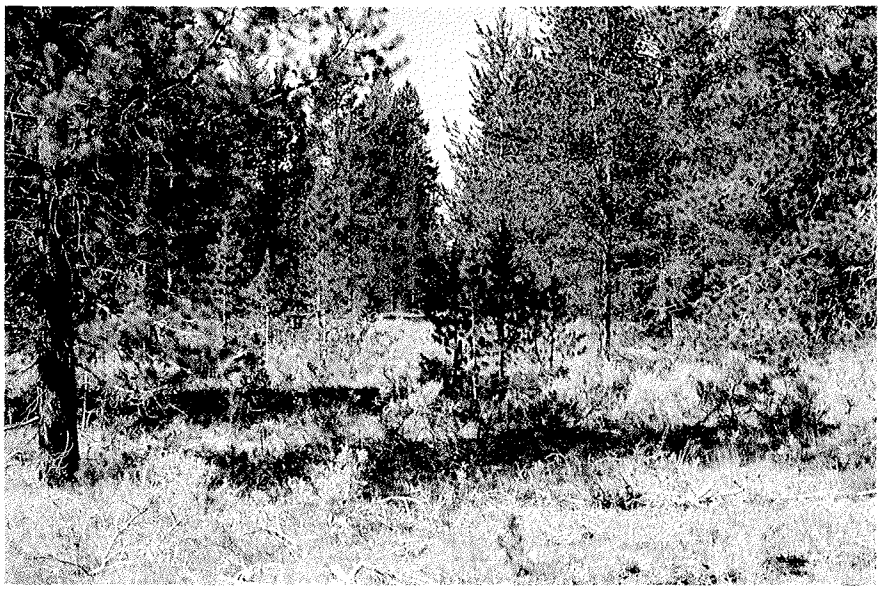

Figure 59.—The Pinus contorta/Purshia tridentata *(PICO/PUTR) h.t. occurs on obsidian-sand benchland near West Yellowstone, MT, at 6,600 ft (2 012 m) elevation. This environment is subject to summer frosts.*

ASSESSING STAND HAZARD AND RISK

HAZARD RATING AND PREDICTING TREE LOSS IN UNMANAGED STANDS

Gene D. Amman
Intermountain Forest and Range
Experiment Station
Ogden, UT

Mark D. McGregor
Cooperative Forestry and Pest Management
Northern Region
Missoula, MT

Effective systems for assessing susceptibility to the mountain pine beetle of managed and unmanaged stands are essential in designing and accomplishing sound multiple resource forest management where lodgepole pine is an important part of the forest cover.

Which of the lodgepole pine stands are most susceptible to beetle outbreak and how many trees will be lost depend upon risk (Safranyik 1982). Reliable methods are not available to predict when an outbreak will develop (Shrimpton and Thomson 1981), but the stand susceptibility and extent of losses can be predicted.

Stand Hazard Rating

As foresters implement strategies to prevent, minimize, or reduce losses to the mountain pine beetle, they will be faced with new challenges in managing the new forest to rotation. Not only will they be faced with implementing a variety of strategies to minimize damage from pests infesting immature lodgepole pine stands, they will also need to consider various hazard and risk rating procedures for assessing susceptibility of managed stands.

Several methods of rating lodgepole pine stands for susceptibility to outbreaks have been developed (Amman and others 1977; Berryman 1978; Mahoney 1978; Safranyik and others 1974; Schenk and others 1980; Waring and Pitman 1980). The methods are designed to help land managers identify high-hazard stands so that losses can be minimized and particular objectives can be met, whether they pertain to timber harvest, wildlife, hydrology, esthetics, or other aspects. Several of these methods utilize data normally obtained from standard inventory surveys, a highly desirable attribute (Lorio 1978; Hedden 1981).

All of the hazard rating systems for mountain pine beetle were developed in unmanaged stands, and none has been tested exclusively in managed stands. Except for Amman and others (1977) and Safranyik and others (1974), these hazard rating methods are based on measurement of tree vigor. Mitchell and others (1983) applied the Waring and Pitman (1980) method to small thinnings made several years before a mountain pine beetle outbreak. The results suggest that growth efficiency may be used as an indicator of susceptibility to mountain pine beetle infestation. Amman (in press), however, found no preference by mountain pine beetle for trees of low growth efficiency and, in many cases, trees killed by mountain pine beetle exceeded the threshold considered resistant to mountain pine beetle attack. None of the vigor-related hazard rating systems improved predictions over that of the Amman and others (1977) system (Amman, in press).

The Amman and others (1977) and Safranyik and others (1974) hazard rating systems are based on three major factors that affect mountain pine beetle survival—climate, tree age, and tree size.

Climatic suitability of stands for mountain pine beetle in the United States is based on observed lodgepole pine mortality for many different elevations and latitudes from Colorado to the Canadian border (fig. 60). Beetle populations do well at low elevations where temperatures are optimum for their development. Brood development slows as elevations increase until, at high elevations, 2 years may be required to complete a generation (Amman 1973). Delay in development frequently results in beetles entering winter in stages more prone to winter kill. In addition, beetles in a 2-year cycle are subjected to mortality factors for a much longer time than during a 1-year cycle. Adverse effects on the beetle populations associated with increasing elevation are reflected in reduced tree mortality.

Average stand age is more an indicator of phloem suitability than a measure of tree vigor, as far as the beetle is concerned. Lodgepole pine >80 years of age have considerably firmer phloem that contains fewer and smaller cortical resin ducts. Such trees dry more slowly than younger trees, thus providing adequate moisture throughout beetle development (McGregor and others 1981).

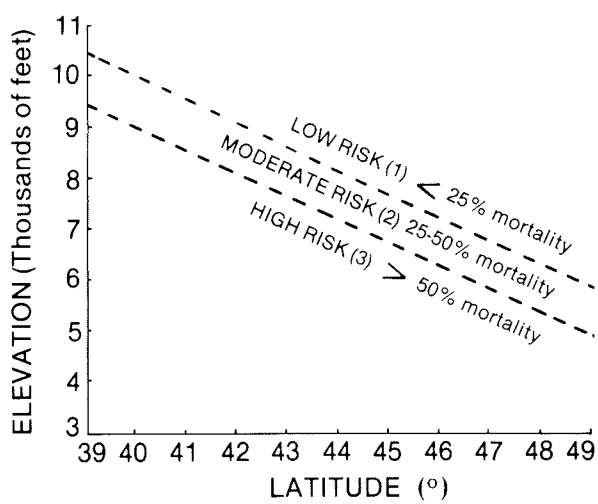

Figure 60.—Risk of mountain pine beetle infestation in unmanaged lodgepole pine can be defined by zones of elevation and latitude. Percentage of mortality is for trees 8.5 inches d.b.h. (21.6 cm) and larger (Amman and others 1977).

Average d.b.h. of lodgepole pine is used because of the beetle's strong preference for larger trees, which generally have thicker phloem and dry more slowly than small-diameter trees. Brood production is strongly influenced by phloem thickness and tree moisture (Cole and others 1976). Unmanaged lodgepole pine stands with an average d.b.h. ≥8 inches (20 cm) can be expected to have a sufficient number of larger diameter trees for the beetle population to build up and be sustained.

Average elevation, stand age, and d.b.h. are obtained during a standard stand examination. For stands <20 acres (8.0 ha), a systematic random or grid sample of 10 variable plots is recommended. For larger stands, 20 variable plots are suggested. A basal area factor giving 10 count trees per variable plot is usually sufficient. Age is obtained from increment cores taken at breast height from three trees nearest to plot center that are 5 inches (13 cm) d.b.h. or larger. Average stand diameter is determined from measurement of all lodgepole pine trees ≥5 inches (13 cm) d.b.h. within each plot. Risk values are assigned to each of three factors—climatic suitability, average tree age, and d.b.h. (fig. 60). Greater than 50 percent mortality can occur in high-risk stands, 25 to 50 percent in moderate-risk stands, and <25 percent in low-risk stands.

Only the Amman and others (1977) hazard rating system has been tested extensively in the United States. Its use on the Kootenai National Forest in western Montana gave very good results (McGregor and others 1981). Therefore, until the other hazard rating systems have been tested on a large scale, we recommend the Amman and others (1977) system.

Extensive tests of all the hazard rating systems are planned as part of the Canada/United States mountain pine beetle agreement (USDA Forest Service 1983). From these tests, the geographic area of applicability for each hazard rating system will be determined, and new combinations of factors that may be better predictors of mountain pine beetle outbreak and tree loss will be explored. Therefore, until the various susceptibility and damage concepts receive additional field evaluation and testing, we do not recommend applying them to managed situations.

After stands have been rated for beetle hazard, the next step is to determine the expected rate and amount of tree loss if a stand becomes infested. The probability of a tree becoming infested depends on the susceptibility of the tree, the length of the flight period, the size of the attacking beetle population, and environmental conditions of the stand (Cole and McGregor 1983). A rate of loss model incorporating these factors has recently been developed (Cole and McGregor 1983). It is based on the Reed and Frost model (Abbey 1952).

The rate of loss model assumes optimum conditions for the beetle throughout the life of the epidemic; however, detrimental conditions can impede beetle populations and cause actual tree losses to be less than predicted. Although actual and predicted tree losses are usually similar for the larger diameter classes where epidemics begin, the model tends to overestimate losses in the smaller diameter classes when conditions are less than optimum for the beetle. This bias is not considered detrimental, but rather helpful, since it allows examination of "worst case" scenarios. Such examinations are made possible by looking at other measures of loss in addition to number of trees killed.

The rate of loss model has been integrated with the INDIDS model (Bousfield 1981) to estimate mortality trends for already infested stands and to obtain loss estimates in cubic and board foot volume for green stands if they become infested. The INDIDS model is used to analyze forest insect and disease survey data collected from variable or fixed plots. It summarizes, by tree species, size class, and damage class, the loss to be expected in number of trees, basal area, and volume killed per acre.

The Amman and others model is useful for classifying unmanaged stands according to high, moderate, and low classes of susceptibility. The rate of loss model provides a method for predicting which of the high-hazard stands will sustain the greatest amount of loss over time.

CONCEPTS FOR EVALUATING SUSCEPTIBILITY OF MANAGED STANDS

Mark D. McGregor
Cooperative Forestry and Pest Management
Northern Region
Missoula, MT

Various methods previously discussed are available for hazard rating unmanaged lodgepole pine stands. As foresters implement strategies to prevent, minimize, or reduce losses to the mountain pine beetle, they will be faced with new challenges in managing the new forest to rotation. Not only will they be faced with implementing a variety of strategies to minimize damage from pests of immature lodgepole pine stands, they will also need to consider various hazard and risk rating procedures for assessing susceptibility of managed stands.

Sufficiently reliable data are available to verify present hazard and risk rating systems for unmanaged lodgepole pine stands; however, in managed forests, additional parameters may become evident and will thus be useful for developing susceptiblity ratings for managed stands. Some of the same parameters used to define susceptibility (hazard) may also be applicable for predicting the amount of loss (risk); however, finer resolution of susceptibility and damage concepts appears necessary for classifying managed stands into hazard and risk categories.

Descriptors that might improve prediction of susceptibility in managed stands are site, habitat type, growth rate, crown ratio, phloem quality and physiological maturity, stand density, slope, aspect, and disease. These factors do not diminish the importance of average d.b.h. and age of lodgepole pine, elevation, and climate.

Various hazard and risk concepts that reflect measures of vigor, stress, resistance, and susceptibility have been and are being tested throughout the Western United States and Canada. Although some of the methods for determining susceptibility have been extensively tested

and work well for wide geographic areas, others have been tested only on a limited basis and are still under scrutiny. Information obtained from evaluations over an extensive geographic area might provide additional data on why some systems work best in some geographic areas and not in others.

We know from basal area and diameter limit cuts that mortality from mountain pine beetle is prevented or significantly reduced for 5 to 10 years following cutting (Cole and Cahill 1976; Cole and others 1983; Cole and McGregor, in press; McGregor and others, in press). Initial results appear favorable, but further evaluations are needed to determine if low levels of loss will persist.

Why various cutting prescriptions (other than clearcut) reduce infestation levels is still under evaluation. Established demonstration areas and establishment of some additional areas should provide data that will further explain cause and effect relationships. Until the various susceptibility and damage concepts receive additional field evaluation and testing, we do not recommend applying them to managed situations. Time will permit testing them for their efficacy under epidemic beetle pressure. Until this is done, we caution against their use for managed stands.

EFFECTS OF OUTBREAKS IN RELATION TO HOST OCCURRENCE AND RESOURCE CONCERNS

OCCURRENCE OF LODGEPOLE PINE STANDS ACCORDING TO HABITAT TYPE AND SUCCESSIONAL ROLE

Dennis M. Cole
Intermountain Forest and Range
Experiment Station
Forestry Sciences Laboratory
Bozeman, MT

The previously described successional roles of lodgepole pine in the habitat types in which they are expressed provide a basic ecological criterion for summarizing and analyzing the quantitative and qualitative effects of the lodgepole pine/mountain pine beetle interaction on various resources (Pfister 1975). They also provide a basis for evaluating appropriate silvicultural management responses to the mountain pine beetle problem in regard to immature stand management, regeneration silviculture, wildlife values, fuels management, watershed values, and other resource considerations.

Forest inventories of the Gallatin and Flathead National Forests provide examples of how the habitat type-successional role criterion allows us to summarize and describe potential mountain pine beetle problems. The inventories were summarized according to habitat type acreage of lodgepole pine in basal area and size classes historically associated with significant mountain pine beetle damage levels (tables 5 and 6). The Gallatin and Flathead National Forests were chosen to allow contrast of the successional roles and habitat type acreage of lodgepole pine in a forest east of the Continental Divide (Gallatin), where lodgepole pine is a more predominant and persistent cover type, with a forest west of the Divide (Flathead), where mixed-species stands more commonly occur. From tables 5 and 6, data were further grouped to show overall occurrence of lodgepole pine by successional role (table 7) and to show percentage of forested land by successional role in stocking classes and size classes susceptible to the beetle (tables 8 and 9). Such summaries provide valuable information for assessing potential for future losses to the mountain pine beetle and for designing programs to prevent or limit them.

The type of information found in tables 5 and 6 can be used in conjunction with the unmanaged stand hazard rating system previously discussed and mountain pine beetle damage surveys to develop probabilities on time and severity of future attacks within individual habitat types. To be used in this way, damage surveys must have sampling designs and habitat classifications that are compatible with the sampling design and habitat classifications of the forest inventory.

Tables 5 and 6 can likewise be used to supplement the rudimentary guidelines developed by Forest planning teams for identifying preferred silvicultural systems for managing major damaging pests (table 10). This was done by computing the proportion of the Gallatin and Flathead National Forests in successional roles and susceptibility classes and summarizing the silvicultural alternatives applicable to each (table 11).

Tables 5 to 9 and 11 provide specific information for answering several of the questions posed by Rost (1978) concerning critical information needs of managers responsible for managing lodgepole pine forests in the face of the mountain pine beetle threat: (1) What is the abundance of the host species? (2) Is it widespread or isolated? (3) Is the total host population susceptible to attack? If not, what proportion is? (4) Are other species present or possible?

The tables provide a basis for assessing opportunities on the Gallatin and Flathead Forests for creating species and age-class diversity by varying species composition and size and rotation objectives of management—according to the location and area of the various habitat types where lodgepole pine occurs in different diameter and basal area classes.

To illustrate, we will use tables 5 to 9 and 11 to examine some similarities and differences in the extent of the mountain pine beetle problem and silvicultural alternatives for addressing them—in relation to the occurrence by successional role of lodgepole pine in the Gallatin and Flathead National Forests.

Table 5.—Successional role of lodgepole pine by habitat type (h.t.)—Gallatin National Forest

Successional role	H.t. abbreviation	H.t. area on NF		Stands where ≥20% of BA is in LPP exceeding following sizes: LPP >5″ d.b.h.			LPP ≥7″ d.b.h.			LPP ≥8″ d.b.h.		
				Acres	Mean BA[1]	Mean LPP BA[1]	Acres	Mean BA[1]	Mean LPP BA[1]	Acres	Mean BA[1]	Mean LPP BA[1]
		Acres	*Percent*		*Ft²*			*Ft²*			*Ft²*	
Minor seral												
	PSME/PHMA – CARU	15,176	18.5	0	0	0	0	0	0	0	0	0
	PSME/AGSP	6,453	.4	0	0	0	0	0	0	0	0	0
	PIFL/JUCO	28,188	1.6	0	0	0	0	0	0	0	0	0
	PSME/CAGE	19,683	1.1	0	0	0	0	0	0	0	0	0
	PSME/ARCO	9,150	.5	0	0	0	0	0	0	0	0	0
	PICEA/PHMA	29,683	1.7	0	0	0	0	0	0	0	0	0
	PICEA/GATR	4,112	.2	0	0	0	0	0	0	0	0	0
	PIAL/ABLA	114,689	6.6	0	0	0	0	0	0	0	0	0
	PIAL/FEID	5,471	.3	4,460	44	29	4,460	44	11	4,460	44	11
	PSME/FEID	54,204	3.1	8,871	49	25	8,871	49	21	8,871	49	21
	PSME/PHMA	82,491	4.8	5,542	139	40	5,542	139	40	0	0	0
	PSME/PHMA – PHMA	66,528	3.8	14,487	123	61	7,682	126	61	7,682	126	41
	PSME/SYAL	55,560	3.2	25,735	82	44	25,735	82	28	9,665	127	40
	PSME/SYAL – SYAL	30,573	1.8	2,320	40	13	2,320	40	13	2,320	40	13
	PSME/SYAL – CARU	17,736	1.0	7,253	114	41	7,253	114	34	7,253	114	34
	PSME/SPBE	4,253	.2	2,578	160	133	2,578	160	120	2,578	160	93
	ABLA/CLPS	61,326	3.5	2,399	149	80	2,399	149	80	2,399	149	80
	ABLA/CAGE – PSME	87,440	5.0	44,027	111	59	36,737	103	59	31,662	112	69
	ABLA – PIAL/VASC	219,776	18.5	139,550	149	65	139,550	149	61	133,402	146	58
Major seral												
	PSME/CARU-CARU	23,645	1.4	17,084	100	53	17,084	100	57	17,084	100	57
	ABLA/ALSI	6,355	.4	6,355	147	52	6,355	147	46	6,355	147	43
	ABLA/ARCO	57,151	3.3	16,180	146	69	16,180	46	69	15,770	156	78
	ABLA/CAGE	25,831	1.5	5,021	50	50	5,021	50	50	5,021	50	50
	ABLA/VAGL-VAGL	18,539	1.1	0	0	0	0	0	0	0	0	0
	ABLA/CACA-CACA	15,011	.9	9,310	143	45	9,310	143	45	7,950	137	42
	ABLA/CACA-GATR	4,407	.2	2,262	183	114	2,252	183	114	2,252	183	114
	ABLA/LIBO-LIBO	7,293	.4	4,663	174	109	2,784	168	87	1,665	147	90
	ABLA/VAGL	177,842	10.3	109,829	149	81	109,829	149	71	96,188	148	70
	ABLA/VASC-CARU	19,814	1.1	16,387	161	84	16,287	161	73	16,287	161	70
	ABLA/VASC-VASC	95,405	5.5	79,251	160	101	77,715	169	87	76,592	165	84
	ABLA/CLPS	8,393	.5	8,393	121	120	8,393	121	112	8,393	121	104
	ABLA/ARCO	44,473	2.6	38,554	99	30	38,554	99	29	38,554	99	26
	ABLA/GATR	6,004	.3	6,004	139	80	6,004	139	80	6,004	139	77
	ABLA/GATR-GATR	8,986	.5	7,325	167	84	7,325	167	80	7,325	167	72
	ABLA/LIBO	11,757	.7	0	0	0	0	0	0	0	0	0
	ABLA/VASC-THOC	8,300	.5	0	0	0	0	0	0	0	0	0
Persistent or climax												
	PICO/PUTR	28,871	1.7	28,871	82	59	26,086	83	48	26,086	83	41
	PICO/VACA	22,236	1.3	20,263	171	131	20,263	171	119	20,263	171	115
	PICO/VASC	21,193	1.2	21,193	152	94	1,196	126	88	1,996	126	64
	PICO/CARU	5,599	.3	5,599	60	40	5,599	60	40	5,599	60	40
Other												
	Scree	17,685	1.0	0	0	0	0	0	0	0	0	0
	Nonforested	51,541	3.0	25,993	28	10	25,993	28	10	19,597	6	5

[1]Basal area.

Table 6.—Successional role of lodgepole pine by habitat type (h.t.)—Flathead National Forest

Successional role	H.t. abbreviation	H.t. area on NF		Stands where ≥20% of BA is in LPP exceeding following sizes: LPP >5″ d.b.h.			LPP ≥7″ d.b.h.			LPP ≥8″ d.b.h.		
				Acres	Mean BA[1]	Mean LPP BA[1]	Acres	Mean BA[1]	Mean LPP BA[1]	Acres	Mean BA[1]	Mean LPP BA[1]
		Acres	*Percent*		*Ft²*			*Ft²*			*Ft²*	
Minor seral												
	PSME/VAGL – ARUV	4,199	0.28	0	0	0	0	0	0	0	0	0
	PSME/AGSP	1,549	.10	0	0	0	0	0	0	0	0	0
	PSME/CAGE	500	.03	0	0	0	0	0	0	0	0	0
	TSHE/CLUN – CLUN	1,861	.12	0	0	0	0	0	0	0	0	0
	ABLA/CLUN – ARNU	39,011	2.60	0	0	0	0	0	0	0	0	0
	PSME/ARUV	521	.03	521	160	80	521	160	80	521	160	80
	ABGR/ARNU	34,993	2.33	0	0	0	0	0	0	0	0	0
	THPL/CLUN – CLUN	57,895	3.86	30,854	77	27	6,854	56	33	283	40	40
	THPL/CLUN – ARNU	3,880	.26	1,170	147	40	0	0	0	0	0	0
	ABLA/OPHO	21,463	1.43	3,282	33	11	3,282	33	11	3,282	33	11
	ABLA/LUHI – MEFE	48,140	3.21	4,812	99	32	4,812	99	26	899	83	20
	PSME/PHMA	3,961	.26	2,641	38	11	0	0	0	0	0	0
	PSME/LIBO – SYAL	10,404	.69	4,851	42	13	0	0	0	0	0	0
	PSME/CARU	34,205	2.28	10,520	112	34	3,621	62	23	3,261	63	23
	PSME/SYAL	943	.06	943	40	40	943	40	40	0	0	0
	PSME/ARNU	5,661	.38	1,862	148	33	0	0	0	0	0	0
	ABGR/XETE	87,287	5.82	1,770	51	50	544	80	80	544	80	80
	ABLA/CLUN – MEFE	147,571	9.83	16,101	162	86	12,479	164	61	7,835	157	62
Major seral												
	PSME/VACA	22,309	1.49	14,242	93	57	11,637	96	53	9,466	99	55
	PSME/CARU	17,534	1.17	2,518	107	63	2,258	103	49	2,258	103	43
	PSME/CARU-PIPO	10,275	.68	0	0	0	0	0	0	0	0	0
	PICEA/LIBO	32,913	2.19	3,954	75	22	741	149	60	741	149	40
	ALBA/CLUN-CLUN	84,312	5.62	28,599	133	72	20,052	132	71	20,052	132	62
	ABLA/CLUN-VACA	7,139	.48	2,632	106	62	2,253	138	79	2,253	138	77
	ABLA/CLUN-XETE	71,171	4.74	12,853	137	80	12,853	137	65	12,853	137	52
	ABLA/LIBO-LIBO	6,526	.43	3,780	110	48	0	0	0	0	0	0
	ABLA/LIBO-VASC	36,208	2.41	11,546	113	58	10,520	127	65	10,520	127	58
	ABLA/MEFE	71,711	4.78	24,813	152	100	24,813	152	91	13,502	152	97
	ABLA/VAGL	53,907	3.59	28,895	128	67	20,615	131	62	19,415	132	57
	ABLA/XETE-VASC	47,551	3.17	26,608	122	65	22,261	158	70	17,158	168	69
	ABLA/VASC-VASC	525	.03	0	0	0	0	0	0	0	0	0
	PSME/VAGL-XETE	15,211	1.01	11,188	118	66	8,606	97	37	3,317	49	17
	PICEA/CLUN-VACA	227	.02	227	69	40	0	0	0	0	0	0
	PICEA/CLUN-CLUN	6,951	.46	4,845	126	44	0	0	0	0	0	0
	ABLA/GATR	1,261	.08	1,261	125	90	1,261	125	70	1,261	125	60
	ABLA/CACA-CACA	6,547	.44	6,006	140	52	1,982	100	33	961	80	26
	ABLA/LIBO-XETE	16,930	1.13	14,324	117	57	5,154	79	34	2,274	109	40
Persistent or climax												
	ABLA/VACA	34,595	2.31	7,591	146	92	7,591	146	84	7,591	146	72
Other												
	Noncommercial forest	310,027	20.66	69,766	69	42	64,331	66	28	40,902	72	30
	Water	4,344	.29	0	0	0	0	0	0	0	0	0
	Nonforested	138,435	9.22	11,360	83	61	11,360	83	21	11,360	83	21

[1]Basal area.

Table 7.—Number of habitat types, and area represented by successional role of habitat types, where lodgepole pine can occur—Gallatin N.F. and Flathead N.F., 1975

Lodgepole pine successional roles	Gallatin N.F.			Flathead N.F.		
	H.t.'s	Area		H.t.'s	Area	
	No.	*Acres*	*Percent*	*No.*	*Acres*	*Percent*
Minor seral						
A. Accidental or sparse	8	227,134	13	10	156,117	10
B. Major component	10	465,582	27	8	290,032	19
Major seral						
A. Sometimes a major component	7	151,560	9	13	462,081	31
B. Usually a major component	11	421,078	24	5	47,127	3
Persistent or climax						
A. Persistent	0	0	0	1	34,595	2
B. Climax	4	78,899	4	0	0	0

Table 8.—Percentage of forest land by successional role and basal area stocking in lodgepole pine 5 to 8 inches d.b.h. in 1975

Successional role	Gallatin N.F. LPP stocking, 5 – 8″ d.b.h.			Flathead N.F. LPP stocking, 5 – 8″ d.b.h.		
	21 – 40% BA	41 – 60% BA	>60% BA	21 – 40% BA	41 – 60% BA	>60% BA
Minor seral	1.4	0	1.7	1.7	0	1.2
Major seral	.5	0	6.6	2.1	2.0	7.1
Persistent or climax	1.7	0	0	0	0	0

Table 9.—Percentage of forested land by successional role and basal area stocking in lodgepole pine >8 inches d.b.h. in 1975

Successional role	Gallatin N.F. LPP stocking, >8″ d.b.h.			Flathead N.F. LPP stocking, >8″ d.b.h.		
	21 – 40% BA	41 – 60% BA	>60% BA	21 – 40% BA	41 – 60% BA	>60% BA
Minor seral	9.5	2.6	0	1.0	0	0.1
Major seral	3.2	15.0	0.9	1.3	6.2	1.0
Persistent or climax	0	[1]1.6	[1]1.5	0	.5	0

[1]Occurs on single district where it comprises about 15 percent of forested area.

Table 10.—Preferred silvicultural systems for managing major damaging organisms

Damage agent	Applicable cover types[1]	Highly susceptible stand characteristics	Preferred silvicultural systems[2]
Western spruce budworm	Douglas-fir Spruce Subalpine fir	Pure stands of tolerant tree species, overstocked, mature multistoried stands.	CC, ST, SHEL
Mountain pine beetle	Lodgepole pine (especially at lower elevations)	LPP trees greater than 8 inches d.b.h. and older than 80 years in pure stands.	CC, ST, SHEL
	Ponderosa pine	Pure even-aged PP, 50-100 years, 8-12 inches d.b.h. Greater than 150 ft^2/acre, slow growing, live crown ratios less than one-third.	CC, ST, SHEL, SEL
Other bark beetles	All	Pure or mixed host tree species in old-growth and stressed stands.	CC, ST, SHEL, SEL
Dwarf mistletoes	Lodgepole pine	Host tree species, multistoried or pure stands, poor vigor.	CC
Root diseases	Douglas-fir	Pure host tree species.	CC
White pine blister rust	Whitebark pine Limber pine	Pure or mixed host tree species. *Ribes* undergrowth.	CC, ST, SHEL
Comandra rust	Lodgepole pine	Pure host types near natural openings.	CC

[1]Forest survey cover types.
[2]CC = clearcut; ST = seed tree; SHEL = shelterwood; SEL = selection.

Table 11.—Acreage and percentage of National Forest in 1975 having susceptible-size lodgepole pine stands, by successional role, with general silvicultural alternatives for reducing future losses

Successional role	D.b.h. size class	Gallatin National Forest		Flathead National Forest		General silvicultural options
	Inches	*Acres*	*Percent*	*Acres*	*Percent*	
Minor seral	5–8	53,700	3.1	43,520	2.9	Intermediate thinning, species discrimination; sanitation cuts; clearcut predominantly LPP stands, regenerate other species; partial cutting of larger LPP, where adequate stocking of other species occurs; develop species, age, and stand-size mosaic.
	>8	209,600	12.1	16,510	1.1	
Major seral	5–8	122,990	7.1	168,100	11.2	Stocking control thinning, intermediate thinnings; species discrimination where possible; clearcut or shelterwood cut mature stands; regenerate mixed species; manage future stand for short rotation (≅80 years); develop age-class and stand-size mosaic.
	>8	330,860	19.1	127,560	8.5	
Persistent or climax	5–8	29,450	1.7	0	0	Stocking control thinning, intermediate thinnings; clearcut mature stands, manage future stand for short rotation (≅80 years); develop age-class and stand size mosaics.
	>8	53,700	3.1	7,500	0.5	

Minor Seral Successional Role

Accidental or minor stand component.—Habitat types where lodgepole pine plays only a minor seral role in succession and generally only occurs as an accidental or minor part of the stand are obviously not a significant mountain pine beetle management problem. The eight such habitat types on the Gallatin National Forest comprise 227,134 acres (91 919 ha) or 13 percent of the Forest (table 7). On the Flathead National Forest there are 10 such habitat types, comprising 156,117 acres (63 179 ha) or 10 percent of the nonwilderness areas of that Forest (only nonwilderness areas were sampled in the Flathead forest inventory).

Major stand component.—There are also habitat types where lodgepole pine plays a minor seral role in succession but can be a major component of stands less than 100 to 120 years of age. Ten of these habitat types comprise 465,582 acres (188 418 ha) or 27 percent of the Gallatin Forest compared to eight on the Flathead National Forest, where 290,032 acres (117 374 ha) or 19 percent of that Forest is involved (table 7). The mountain pine beetle can cause serious damage to stands in these habitat types where the stocking of susceptible-sized lodgepole pine trees is greater than 20 percent of stand basal area. Susceptible acreage on the Gallatin Forest in this successional role is about 263,300 acres (106 554 ha), or a little more than half the area in the 10 habitat types involved. The Flathead Forest has only about 60,000 acres (24 280 ha) of susceptible stands in this successional role, about one-fifth the area of the eight habitat types involved. Fortunately, the species alternatives in this successional role provide three effective silvicultural options for reducing losses to the beetle, depending on the age, form, and species composition of specific stands: (1) clearcut harvesting with regeneration to species other than lodgepole pine; (2) early thinning with discrimination against lodgepole pine; and (3) partial cutting of larger lodgepole pine from overstories where other species in the overstory and understory constitute a manageable stand.

Major Seral Successional Role

When stands are dominated by lodgepole pine where it can play a major seral role, they will eventually become vulnerable to mountain pine beetle depredation if left to develop naturally. If or when they contain appreciable proportions of trees more than 8 inches (20 cm) d.b.h., they will be highly susceptible to infestation at any time that the other conditions for epidemics occur. In these stands, outbreak prevention is largely a matter of removing the stands, or the larger lodgepole pine component, before they become highly susceptible. To accomplish such prevention while maintaining other resource values, a comprehensive long-term plan for scheduling harvests and regeneration is necessary. In regenerating these stands, usually by clearcutting, other species can be featured. In some of these habitat types, Douglas-fir is the major species alternative to lodgepole pine but is itself highly susceptible to spruce budworm (*Choristoneura occidentalis* Freeman) epidemics. In this situation, it is worth considering regenerating the stand with lodgepole pine and managing it for a shorter rotation if another species alternative is not acceptable.

Lodgepole pine sometimes plays a major seral role.—Depending on the circumstances of stand establishment (for example, timing and intensity of wildfires, method of regeneration), there are habitat types where lodgepole pine sometimes is the predominant species of the stands and where succession to climax species will take several hundred years, even in the absence of wildfires.

In the Gallatin Forest, there are seven habitat types where lodgepole pine sometimes plays a major seral role comprising 151,560 acres (61 335 ha) or 9 percent of the Forest. Of this area, only about one-third (3 percent of the Forest) had over 20 percent of stand basal areas in vulnerable-sized lodgepole pine. On the Flathead Forest, there are 13 habitat types where lodgepole pine sometimes plays a major successional role. These habitat types occupy 462,081 acres (187 001 ha) or 31 percent of the nonwilderness area of the Forest; however, of the total 462,081 acres (187 001 ha), only about one-third (10 percent of the Forest) had over 20 percent of the basal area in lodgepole pine of vulnerable size.

Lodgepole pine usually plays a major seral role.—There are considerable acreages where lodgepole pine usually plays a major seral species role because it is usually a dominant component of the stand. On the Gallatin National Forest, there are 11 habitat types where this situation prevails. They comprise about 421,078 acres (170 407 ha) or 24 percent of the Forest, with about 70 percent of this area (286,115 acres [115 789 ha]) occupied by stands having from 30 to 60 percent of their basal areas in lodgepole pine trees of 8 inches (20 cm) d.b.h. and larger. On the Flathead National Forest, there are only five habitat types and 47,127 acres (19 072 ha) or 3 percent of the Forest where lodgepole pine is usually a major seral species involving 30 to 60 percent of stand basal area in lodgepole pine trees more than 8 inches (20 cm) d.b.h.

Stands in the habitat types where lodgepole pine usually plays a major seral role and that have over 20 percent of their basal areas in larger lodgepole pine trees are very vulnerable to the mountain pine beetle—especially if they are older than 80 years. In these habitats, if stands are less than 200 years old, the overstory is usually dominated by lodgepole pine or the stand is pure lodgepole pine. If the stands are younger than 80 years, they should (in consideration with all other lodgepole pine stands) be scheduled for harvest at somewhere around 80 years of age, or perhaps the rotation extended by thinning on a schedule to maintain stand growth. In practical terms, most 80- to 100-year-old natural stands in this successional situation do not have a large component of high-hazard trees because most were established by wildfires that resulted in serious overstocking. When this is the case, significant basal areas of vulnerable tree size do not usually occur until stands reach ages of 140+ years.

Persistent seral or climax successional role.—There appear to be no habitat types where lodgepole pine is a persistent seral species on the Gallatin Forest; however, there are considerable acreages of habitat types where lodgepole pine is a virtual climax species and expresses

itself in essentially pure stands. Four habitat types of the *Pinus contorta* series occur on the Gallatin and involve 78,899 acres (31 925 ha) or 4 percent of the Forest. The typical basal area of these stands, in trees 8 inches (20 cm) d.b.h. and more, ranged from 48 to 67 percent of the total stand basal areas. Younger stands, of course, have lower basal areas of susceptible-sized trees, but the oldest natural stands in these habitat types do not greatly exceed these basal area proportions of susceptible-sized trees because the mountain pine beetle periodically reduces the stocking of larger trees. The result is two- or three-story stands of trees of different age and size classes. The overall effect is likely to be more chronic infestations by the beetle because of a more constant food source. Beetle infestations in each stand may result in fewer trees being killed during each infestation than would occur in even-aged stands developed after fires and in those stands where lodgepole pine is seral. Managers should take these factors into consideration when reviewing and prescribing silvicultural alternatives for this situation.

On the Flathead National Forest, no habitat types exist where lodgepole pine has a climax role in succession; however, there is one habitat type (*Abies lasiocarpa/Vaccinium caespitosum*) where lodgepole pine is a persistent seral species dominating stands. It occupies only about 2 percent of the Forest (34,595 acres [14,000 ha]), and of this only about one-fifth (7,000 acres [2 833 ha]) has greater than 20 percent of its basal area in susceptible-sized trees. Thus, the persistent or climax role is less of a concern on the Flathead than on the Gallatin.

EFFECTS OF OUTBREAKS AND MANAGEMENT RESPONSES ON BIG GAME AND OTHER WILDLIFE

Jerome T. Light
Gallatin National Forest
Bozeman, MT

William B. Burbridge
Wildlife and Fisheries
Intermountain Region
Ogden, UT

Lodgepole pine forests provide habitat for big game wildlife such as the Rocky Mountain elk (*Cervus canadensis*), mule deer (*Odocoileus hemionus*), grizzly bear (*Ursus arctos horribilis*), and numerous small game and nongame species. An approach for integrating wildlife habitat requirements with stand management of lodgepole pine forests has been addressed in general terms (Thomas 1979). But the management of big game, especially during hunting seasons, has assumed increasing importance as forest cover is reduced and human access increases. Such management is a growing concern of many State fish and game agencies (Lonner and Cada 1982). As a result, timber management in lodgepole pine, particularly harvesting and associated roading, often creates considerable controversy regarding effects on big game. The occurrence of and potential for mountain pine beetle outbreaks add greater complexity to these controversies. This section describes the effects on stands, and thus on big game and other wildlife, of epidemics left to occur and recur naturally and discusses alternative silvicultural responses for preventing or reducing beetle outbreaks in terms of how these practices affect habitat and other management concerns for big game and other wildlife.

Silvicultural practices to meet wildlife management objectives should encompass (1) scheduling of treatments, (2) distribution of stand age classes in time and space, (3) stand condition desired, (4) size of treatment area, and (5) the habitat characteristics (cover/forage) of the land type to be affected by the treatment. It is interesting to note that meeting wildlife management objectives will often make the forest less susceptible to damage from the mountain pine beetle.

The stand/beetle/silviculture interactions are discussed in relation to wildlife effects for species groups of major wildlife management interest:

- Elk and mule deer
- Whitetailed deer and moose
- Grizzly bear
- Other wildlife

Rocky Mountain Elk and Mule Deer

Beetle epidemics can affect elk and mule deer by altering the arrangement and abundance of food, cover, and other key components of habitat, thus altering wildlife use patterns. Management activities to prevent or reduce beetle effects also influence these factors, as well as increase human disturbance through management activities and roading.

In some habitat types where other species are well represented, recurring bark beetle epidemics have helped maintain wildlife habitat diversity of unmanaged stands. However, with this increased diversity is an associated increase of dead wood accumulation on the forest floor which can inhibit elk and deer use (Lyon and Jensen 1980) and eventually dispose the area to a stand replacement fire.

Biological effects of beetle epidemics and timber management on elk and deer depend largely upon the relationship between the abundance and arrangement of forage and cover. Optimum summer habitat for elk consists of a ratio of 40 percent cover and 60 percent openings, properly sized and arranged in space (Black and others 1976) (fig. 61). These authors further recommended that cover areas consist of approximately 20 percent hiding, 10 percent thermal, and 10 percent either hiding or thermal cover on big game summer range (figs. 62 and 63). If big game are to make maximum use of forage areas, no point should be more than 600 ft (183 m) from the edge of cover; use beyond that distance declines steadily (Reynolds 1962, 1966; Harper 1969; Kirsh 1962; Hershey and Leege 1976).

Having determined the consequences of beetle epidemics on elk and deer habitat as well as other resource values, managers should review and select silvicultural alternatives for reducing or preventing these consequences. Clearcutting appears to be the most desirable

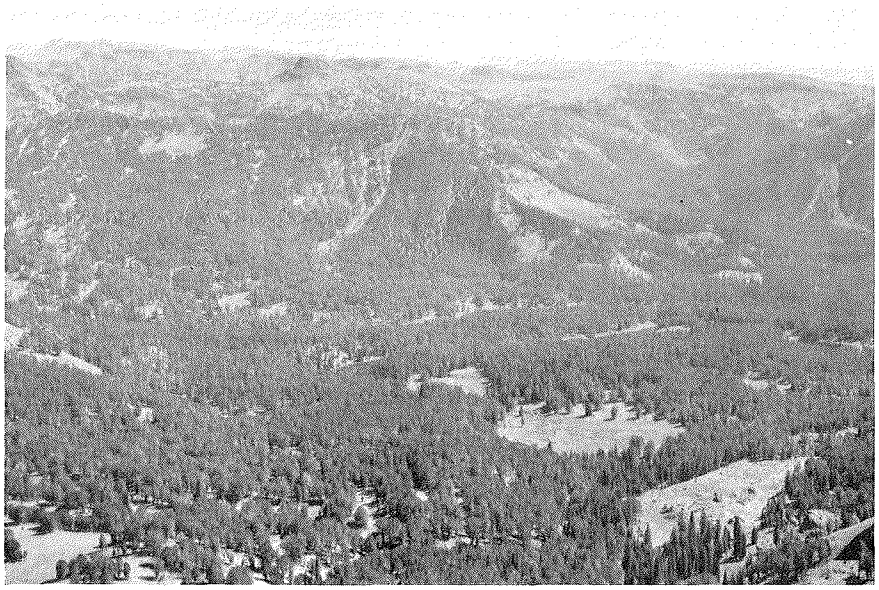

Figure 61.—Optimum summer range for elk contains approximately a 40:60 ratio of cover and forage. When these situations occur naturally, there is potential for degradation of summer range from beetle epidemics and management responses to them.

Figure 62.—Regeneration harvests should not be initiated in leave strips until adjacent cut-over areas provide hiding cover or if the leave strips are needed for thermal cover. This lodgepole pine regeneration does not appear to provide hiding cover.

Figure 63.—This lodgepole pine regeneration appears to provide suitable hiding cover.

silvicultural system for preventing or reducing losses to the beetle and for creating forage areas for big game. If the stand is already at cover/forage limits for big game, then other prescriptions should be considered.

At any time before epidemic outbreaks and where stands have been hazard-rated, group selection cuts might be made in a pattern favorable for both preventing losses to the beetle and enhancing wildlife habitat. In younger stands, initial and intermediate thinnings can be used to reduce future stand susceptibility to the beetle. Likewise, in older stands with a manageable component of other species, the larger lodgepole pine can be harvested. The farther in advance of epidemics these preventative measures are implemented, the more significant their impact on wildlife habitat.

Edgerton (1972) found that clearcutting in mixed conifers in northeastern Oregon benefited forage for elk and deer, with elk preferring clearcuts as feeding sites almost twice as much as unlogged areas. Deer displayed essentially the same order of preference as elk, but to a smaller degree (fig. 64).

Clearcutting in lodgepole pine was shown to stimulate the production of understory vegetation for an estimated 20 or more years, providing a grazing resource for big game and livestock in Montana with peak productivity at 11 years (Basile and Jensen 1971). Similarly, Wallmo (1969) found that mule deer use in Colorado doubled 10 years after logging in clearcut lodgepole pine and spruce/fir types, as compared to previous use.

Silvicultural practices that clear or open lodgepole pine stands increase forage for elk and deer, depending upon stand structure and composition, but the availability to elk and deer depends on slash treatment. Lemos and Hines (1974) found that slash accumulations inhibited forage production and restricted its availability to elk and deer. Lyon (1976) also found that elk use of clearcuts was influenced by slash accumulation inside and adjacent to the affected openings. Slash depths greater than 1.5 ft (45.7 cm) significantly reduced elk utilization of foraging areas. Slash disposal can cause additional problems, however. Broadcast burning of slash rather than machine piling and burning is the preferred method of disposal because, as Pengelly (1972) observed, the mechanical disturbance of soil by heavy equipment combined with the burning of piles tended to eliminate some desirable forage species. Harper (1971) and Lemos and Hines (1974) also found that broadcast burning of slash is more advantageous for big game. Broadcast burning removes physical barriers, promotes sprouting of desirable shrubs, encourages the establishment of a greater diversity of forbs and grasses, releases nutrients, and often retards succession, providing forage over an extended period of time.

Forage in clearcut openings during the winter is usually unavailable to big game due to deep-crusted snow. On elk and deer winter range where winds do not influence snow depth, clearcutting in response to beetle epidemics generally results in loss of cover and no gains in available forage. Uneven-aged stands with small openings favor both elk and deer winter forage and cover requirements (Wallmo and Schoen 1981). To avoid wholesale loss to the mountain pine beetle of winter cover in historical winter range, lodgepole pine stands should come under long-term management from the regeneration process onward so that needed cover is maintained.

The alteration of key habitat components of elk and deer requires special consideration by forest managers,

Figure 64.—Clearcutting is usually the most desirable silvicultural system for creating forage areas for both deer and elk in mixed conifer forests.

as these key areas contribute significantly to the carrying capacity of a given area. The Montana Cooperative Elk-Logging Study (1978) reported that moist sites (wet sedge meadows, bogs, seeps), especially those located at the heads of drainages (fig. 65), are important components of elk summer range. These sites provide lush, nutritious forage for elk late into the summer (fig. 66), enabling them to move to winter range in better condition. These sites also are important breeding areas for elk (fig. 67) and are used for wallowing.

Moist sites receive disproportionately higher use given their relative size. Other key areas include winter range with nearby thermal cover (fig. 68) and calving and rearing areas (fig. 69).

Silvicultural prescriptions, including those designed to prevent beetle effects on wildlife habitat, should be designed to maintain the integrity and value of all key areas. Areas adjacent to moist sites, breeding areas, and reproduction areas should remain in cover to provide cover linkages with the uncut forest. Whenever practical, disturbance of these sites should be avoided during the rut through the use of timber sale contract clauses and road closure.

Perry and Overly (1977) conducted research to determine the biological effects of roads on elk and deer. Wildlife biologists and forest managers recognize road management as one of the most important aspects of elk management. Allen (1977) concluded that roads or other human disturbances could be more significant in evaluating the effectiveness of elk habitat than vegetative manipulation. Ward (1976) and Perry and Overly (1977) reported decreased elk use adjacent to open roads for distances ranging from one-fourth to one-half mile (0.4 to 0.8 km). Rost and Bailey (1979) found that deer and elk in Colorado avoided areas within 10 chains (201 m) of roads and avoided roads in shrub zones more than in the

Figure 65.—Moist sites, particularly those at the heads of drainages, are used by elk for wallows and are important components of elk summer range.

Figure 66.—Optimum elk summer habitat should consist of approximately 60 percent foraging areas which are properly arranged in time and space.

Figure 67.—Wet areas such as this have been identified as important components of elk summer range and should be protected.

Figure 68.—Protection of winter range and nearby thermal cover are important considerations in silviculture prescriptions and road layout.

Figure 69.—Key habitat components such as elk calving areas should be maintained through proper silvicultural prescriptions. Human activity should be restricted in calving areas during the spring and early summer.

ponderosa pine zone. These data are comparable to those of Lyon (1979), who concluded that the impacts from open roads were greatest where cover was low. Cover modification and roading can affect hunting opportunities and the variety of hunting experiences, thus affecting levels of game harvest (Lonner and Cada 1982). Hunting conditions are affected most significantly by the density of open roads. Cover availability and the density of open roads can also influence season lengths and the number of hunting recreation visitor days.

Moose and Whitetailed Deer

Moose (*Alces alces*) and whitetailed deer (*Odicoileus virginianus*) are primarily browsers of deciduous shrubs; however, moose browse evergreen (spruce and fir) saplings in addition to deciduous shrubs and herbaceous plants. Their cover requirements seem to be more restrictive than those of elk and mule deer (Peek and others 1983). Vertical structure of stands and snow structure are critical factors to consider for moose and deer on winter range. In southwestern Montana, Schladweiler (1973) found that the Shira's moose responded positively to clearcuts the first year in lodgepole pine stands, with use peaking 10 years after harvesting. This is most noticeable where clearcut stands develop an understory of shrubs providing both forage and cover. Whitetailed deer respond similarly. Schladweiler (1973) and, in southeastern Idaho, Ritchie (1978) found that moose use was greatest in habitat types providing high densities of understory shrubs in both mature and postlogged forest conditions. Both moose and whitetailed deer were found to favor stand characteristics that provide small openings with both thermal and hiding cover. Engelmann spruce/alpine fir and alpine shrub understories are preferred by moose (Schladweiler 1973; Ritchie 1978). In uneven-aged stands with small openings, evergreen saplings and deciduous shrubs are usually most available as browse.

Grizzly Bear

The grizzly bear is a federally classified threatened species. Grizzlies once ranged throughout most of the Western United States; however, fewer than 1,000 are now estimated to exist in the lower 48 States. This population is distributed among three major ecosystems: the Yellowstone, the Northern Continental Divide, and the Cabinet-Yaak. Lodgepole pine provides the dominant cover for the grizzly within all of these ecosystems. Mountain pine beetle infestations and timber management practices to reduce the risk and spread of infestation can, therefore, affect grizzlies by changing their habitat use patterns, food availability and abundance, and security.

Grizzly habitat use patterns may be modified by vegetational changes affecting cover and food availability. A major food source—whitebark pine nuts—was all but eliminated by epidemic infestations in whitebark pine stands in portions of the Beaverhead, Flathead, and Gallatin National Forests. On the Flathead National Forest, such a loss of the whitebark pine resulted in the breakdown of a historical grizzly bear use pattern (Servheen 1981). Food production (for example, berry and herbaceous foods) may be increased through timber management (Ruediger and Mealey 1978) causing bears to immigrate.

Ruediger and Mealey (1978) recommend that at least 30 percent of grizzly habitat be managed as cover. Decreasing the amount of cover can have either positive or negative effects on bear habitat suitability. If cover is determined to be limiting, either in relative amount or distribution, beetle epidemics or timber harvesting will probably have a negative impact on the grizzly bear. Where cover is abundant, however, epidemics or timber harvest can improve the abundance and/or distribution of forage; hence, the consequences will probably be positive for the grizzly.

In view of the grizzlies' need for forest cover, it would be better in some areas to reduce the potential for epidemics in critical grizzly habitat where stand management options are still allowed, especially where stand management or diversity of an even-age class will not adversely affect the grizzly.

Grizzlies derive most of their energy from whitebark pine nuts and succulent herbaceous plants from mesic microsites in forest stands and mountain grasslands (Mealey and others 1977) (fig. 70). Grizzlies west of the Continental Divide derive most of their energy from huckleberries and whitebark pine nuts. When berry production trends are up west of the Divide, grizzlies derive most of their energy from the sugars the berries provide. East of the Divide, energy is derived mainly from succulent plants, carrion, insects from downed logs and anthills, and parts of specific plants such as spring beauty, elk thistle, biscuitroot, and clover (Ruediger and Mealey 1978). Since the grizzly spends all of its time eating in or close to the cover of forest stands (Blanchard 1980), timber management in roaded areas should be oriented to maintaining cover corridors for day bedding and travel security.

The grizzly bear's precarious situation can primarily be attributed to human encroachment and the loss of the large roadless areas which were once prime grizzly habitat. Development of these areas has adversely impacted the bear by increasing encounters with humans, which often have resulted in death for the grizzly. In the Yellowstone ecosystem, there is concern that mortality may still exceed recruitment; therefore, reducing bear mortality is probably the single most important task for recovering the grizzly bear population. This can be helped by developing management systems which minimize human encounters with grizzlies. Rigorously enforced road and trail regulations are important for accomplishing this objective.

Timber management without road and trail management has usually provided the initial inroad for humans into otherwise secure grizzly habitat. We suggest, then, that roads constructed to prevent or mimimize future epidemics or for other necessary management activities in grizzly-occupied habitat should be managed (closed if necessary) as soon as administrative use allows.

Figure 70.—The grizzly is an aggressive opportunist and will capitalize on all available forage items in its home range.

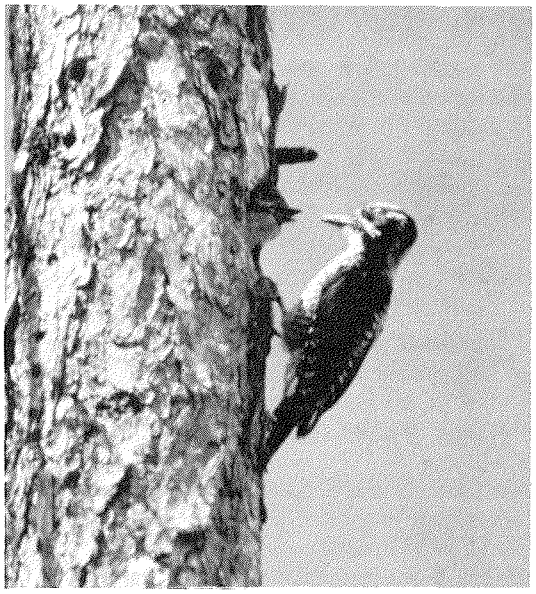

Figure 71.—The northern three-toed woodpecker is a common primary cavity user in lodgepole pine forests and is one of the natural control agents for keeping mountain pine beetle populations at endemic levels.

Other Wildlife

Mountain pine beetle epidemics and management activities to prevent or reduce them can affect many other species of wildlife. Although it is not possible to give direct attention to each species, forest managers should provide habitat conditions that will maintain viable populations of all wildlife. This can be achieved by modifying silvicultural practices to provide a broad spectrum of habitat conditions (Thomas 1979). This includes maintaining special habitats such as riparian zones, edges, snags, and dead and downed woody material.

Timber management may produce successional conditions that mimic wildlife habitat conditions produced by natural events such as wildfire. Maintenance of viable populations of wildlife is most heavily influenced by the maintenance of areas of early (grass/forb and shrub/seedling) and late (mature and old growth) forest successional stages (Thomas 1979). Management to minimize or prevent beetle outbreaks, therefore, should be designed to provide the amount and variety of habitat for viable populations of desired wildlife species.

Snag management for cavity nesting birds (fig. 71) is an important facet of managing lodgepole pine forests because of the many snag-dependent species which prey on harmful insects.

Hein (1980) suggests leaving an average of two snags per acre (five snags/ha) in managing lodgepole pine forests. Thomas and others (1978) recommend leaving an average of 0.6 snags per acre (1.5/ha) as a minimum to ensure viable populations of cavity-dependent species. Snags more than 10 inches (25.4 cm) d.b.h. with broken tops should be given priority when selecting snags to leave (fig. 72).

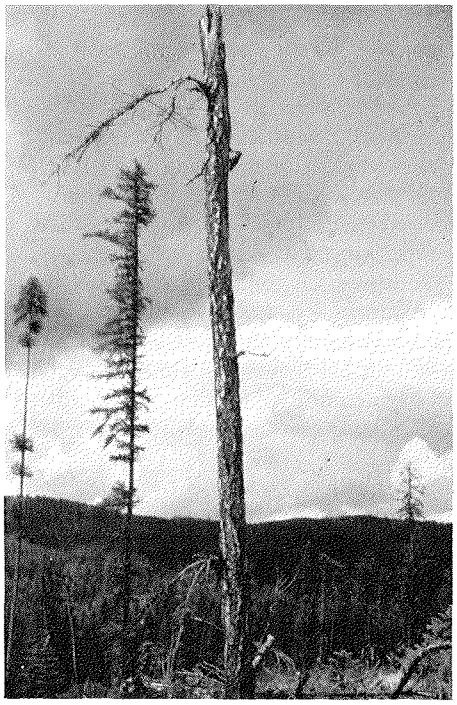

Figure 72.—Snags with broken tops receive higher use from cavity-dependent species and should be emphasized for retention.

Because most birds in the lodgepole pine communities glean insects from bark and foliage, bird management should be an important consideration as a possible means of maintaining beetle populations at endemic levels.

SOIL AND WATER QUALITY

Mark D. McGregor
Cooperative Forestry and Pest Management
Northern Region
Missoula, MT

The effect of mountain pine beetle epidemics on water quality and quantity and the overall effect on watersheds are not well known. Effects might be minimal in some drainages but of more concern in others. The degree of increased water yield depends largely on the amount of lodgepole pine in the stand, soil type and depth, the amount of snow intercepted by the original stand, and how rapidly understory vegetation uses the increased soil water.

Removal of infested trees, and thus creation of openings, can increase melt rates and peak runoff. An extensive number of large clearcuts could create the potential of floods—increasing channel changes and erosion. In this case, up to 50 years may be required before watershed recovery following vegetation reestablishment.

Stands of dead trees would increase soil moisture and subsequent yields from the watershed. These trees also provide some reduced shading cover, intercept rain and snow, and protect soil through holding soils in place with roots.

The primary watershed concerns with epidemics thus appear to be the potential for lowering water quality through sedimentation from roads constructed to salvage timber and the loss of shade, which can elevate water temperatures to levels detrimental to fish. Nutrient losses can also occur with erosion, to the detriment of biological processes.

In harvested stands, proper slash disposal and site preparation can provide organic matter and dead shade and maintain soil protection.

Soil disturbances on sites with soils subject to frost heaves could further degrade the sites and add to stream siltation. These soils are generally shallow and thus have low moisture storage capacity. This, plus exposure, leads to overland flow and high runoff. Slash can entrap silts and retard surface flows and thus help maintain site fertility (Carter 1978).

Appropriate silviculture can be achieved by consulting available specific guidelines that address concerns about maintaining soil stability and water quantity and quality (Leaf 1975; Singer and Maloney 1977). These guidelines should be consulted in designing specific management prescriptions.

LANDSCAPE AND VISUAL MANAGEMENT CONCERNS

Mark D. McGregor
Cooperative Forestry and Pest Management
Northern Region
Missoula, MT

Mountain pine beetle epidemics leave many acres of lodgepole pine dead or dying and have a negative visual effect. This is apparent even in stands that have considerable amounts of other species. From a visual perspective, the more rapidly the dead lodgepole pine is replaced with healthy vegetation, the better (Carter 1978); however, if cutting methods selected for natural regeneration or to minimize losses are visually more undesirable than the effect of standing and fallen dead timber, the visual discontinuity of the landscape will have been aggravated or even magnified instead of lessened (Carter 1978). Such negative elements should be identified along with positive elements of visual form that can be emphasized. Both the negative and positive elements of existing or future landscapes should be considered within the perspective of "desired landscape character" to attain visual quality objectives. Visual quality objectives (VQO's), desired landscape character, and positive and negative landscape elements are concepts used to analyze and manage landscapes in the National Forest system. They are being used to address landscape concerns in many complex resource management situations. A specific example involving the mountain pine beetle was the Lane-Peet Study conducted by the Umatilla and Wallowa-Whitman National Forests in northeastern Oregon (Umatilla National Forest 1974). From this effort came six recommendations for minimizing visual impairment of landscapes from management responses to the mountain pine beetle (Carter 1978):

1. Avoid sharp-edged rectangles or other geometric patterns when laying out cutting units. Units should also vary in size, thus repeating the variety of meadow and opening sizes that occur in nature. Unit sizes could vary from 4 to 60 acres (1.6 to 24.3 ha).
2. Leave trees in shelterbelt units in groupings instead of rows to eliminate the straight line effect.
3. The location of roads should be as well planned as in green sales, with thought given to such things as minimum clearing widths.
4. Fill slopes and ditches along system roads, especially in unstable, light-colored soil areas, should be seeded immediately to appropriate grasses. Temporary spurs should be seeded as soon as salvage operations cease.
5. A "dead screen" may be useful in slowing down or stopping the eye as it travels over or through large open spaces created by the salvage activities. It is understood that the dead trees will need to be managed as they begin to fall.
6. Existing regeneration groupings should be used as screens wherever possible. Landings may be screened from a major travel route, even though most of the sale area is not.

Although some of the above recommendations are pertinent to silvicultural practices used to prevent mountain pine beetle epidemics, it is clear the emphasis of the recommendations is to ameliorate the visual effects of epidemics after the fact. It is beyond the scope of this paper to address landscape management in the preventative sense of mountain pine beetle/lodgepole pine management because of the complexities of social, economic, and biological factors involved. Readers should consult USDA Handbook No. 559, Vol. 2, Chap. 5 (Bacon and Twombly 1977), a valuable management guide for these purposes.

COORDINATING MANAGEMENT OBJECTIVES WITH SILVICULTURAL SYSTEMS AND PRACTICES

ACCEPTABLE SILVICULTURAL SYSTEMS IN RELATION TO DESIRED STAND CHARACTER AND SUCCESSIONAL ROLES OF LODGEPOLE PINE

Dennis M. Cole
Intermountain Forest and Range
Experiment Station
Forestry Sciences Laboratory
Bozeman, MT

All lodgepole pine stands in a management jurisdiction, regardless of habitat type—but especially where the successional role of lodgepole pine is dominant seral, persistent, or climax—must be considered together to develop a long-range plan for increasing age-class and species diversity of the future forest. Summaries such as tables 5 to 9 and 11 will be helpful in this effort.

Such information can also be used with recently developed criteria for identifying appropriate silvicultural systems for managing multiple resources (USDA Forest Service 1980, p. 87) and with various published guidelines for a variety of management concerns. Among these are guides for regeneration (Lotan and Perry 1983); fire ecology (Fischer and Clayton 1982); dwarf mistletoe infection (Hawksworth and others 1977; Van Sickle and Wegwitz 1978); windfall risk (Alexander 1975); watershed considerations (Leaf 1975); scenic values (Bacon and Twombly 1977); and wildlife values (Thomas 1979; Perry and Overly 1977; Lyon and O'Neil 1981; Ruediger and Mealy 1978; Hein 1980).

As an example of how information from tables 5 to 9 and 11 can contribute to better plans for achieving allocated resource management objectives, consider a recent management analysis conducted while preparing the Forest Plan for the Gallatin National Forest (Gilbert and others 1980). This analysis was guided by three principles of policy: (1) the concept of "desired character of stand" was adopted as the means of identifying appropriate silvicultural systems for achieving allocated resource management objectives; (2) uneven-aged silvicultural systems would only be considered when timber is not included in resource management objectives; and (3) five silvicultural/management criteria (USDA Forest Service 1980) were adopted as the basis for choosing acceptable silvicultural systems.

The five criteria were:

1. The (silvicultural) system must develop stand conditions required for meeting allocated resource management objectives over the longest possible time.
2. The (silvicultural) system must permit enough control of competing vegetation to allow establishment of an adequate number of trees growing at acceptable rates.
3. The (silvicultural) system must promote stand structures, compositions, and conditions that minimize damage from pest organisms, animals, wind, and fire.
4. The (silvicultural) system must be compatible with acceptable logging methods so that future stands produced can be cultured and harvested.
5. Uneven-aged silviculture will be considered only where stands presently have a homogenous uneven-aged structure or where steps and the time necessary for conversion to an identifiable uneven-aged goal can be defined.

From the above principles and criteria, the Gallatin Forest team identified important regeneration problems and keyed them to the character of competing vegetation and topographic aspect (table 12); defined classes of desired stand character and identified preferred (acceptable) silvicultural systems for achieving each in the lodgepole pine cover type (table 13); and identified preferred

Table 12.—Selection of silvicultural system based on common regeneration problems on the Gallatin National Forest

Competing vegetation	Key habitat series or type	Critical aspect	Preferred system	
			Even-aged	Uneven-aged[1]
High-elevation brush	ABLA series; ABLA/ALSI h.t.	All	Clearcut	All selection
Low-elevation brush	PICO, PICEA series; PSME/PHMA, PSME/SYAL, PSME/PUTR h.t.'s	All with slopes >30 percent	Shelterwood Clearcut with artificial regeneration	All selection
Grasses (warm sites)	PIPO, PSME, and ABLA series	All	Shelterwood	Group selection
Grasses (cool sites)	PICO, PSME, and ABLA series	All	Clearcut Seed tree Shelterwood, artificial regeneration	Group selection

[1]Only applicable for resource management objectives other than timber production.

(acceptable) silvicultural systems for handling important damage agents and cross-referenced them to applicable Forest Survey Cover Types and highly susceptible stand characteristics (table 10). Preferred (acceptable) silvicultural systems were also identified in relation to fuels management and logging methods; however, the information of table 5 does not relate well to these management interests, so they are not considered further here.

The identification of general classes of competing vegetation that are associated with regeneration problems and the determination of preferred silvicultural systems for minimizing the problems (table 12) helps the manager, on the ground, to select a proper silvicultural system for successful regeneration when harvest is planned and accomplished. Reference to summaries like table 5 and tables of plant presence, constancy, and coverage (Pfister and others 1977) provides additional information on the acreage and character of habitat types where problems can occur from each of the classes of competing vegetation.

Table 13 lists six different "desired stand characters," with preferred (acceptable) silvicultural systems for attaining each—under both even-aged and uneven-aged management. The manager needs additional information, however, to select the most appropriate "desired stand character" for meeting allocated multiple resource management objectives. This is particularly the case for the lodgepole pine type and habitat types where lodgepole pine is represented, because of the management complications wrought by the mountain pine beetle. Summaries, such as table 5, of the total habitat-type acreage and of the habitat-type acreage where appreciable basal area of the stand is in lodgepole pine in sizes susceptible to the mountain pine beetle can help the manager select the stand character that will best serve the various resource values he or she considers important. From such summaries, he or she can also determine where, and to what extent, the various "desired stand character" alternatives are attainable and maintainable. For each habitat type, other information for determining "desired stand character," which can be used in conjunction with the summaries, can be found in lists of plants, along with their constancy and average coverage values. These lists are included in published habitat type classifications (Pfister and others 1977).

Table 13.—Preferred silvicultural system to achieve desired lodgepole pine forest character

Desired character	Preferred silvicultural system	
	Even – aged	Uneven – aged[1]
Continuous site occupancy with trees	Shelterwood	Single tree selection
Mosaic of forest and opening	Clearcut, seed tree, shelterwood	None
Multistoried stand (all components less than rotation)	Clearcut, seed tree, shelterwood	Single tree and group selection
Maximum species diversity	Shelterwood	Group selection
Old growth character	Shelterwood	Single tree and group selection
Closed canopy	Clearcut, seed tree, shelterwood	None

[1]Only applicable for resource management objectives other than timber production.

SILVICULTURAL PRACTICES FOR LODGEPOLE PINE STANDS IN COMMERCIAL FORESTS

Dennis M. Cole
Intermountain Forest and Range
Experiment Station
Forestry Sciences Laboratory
Bozeman, MT

Mark D. McGregor
Cooperative Forestry and Pest Management
Northern Region
Missoula, MT

By knowing the area, composition, form, structure, age, habitat type, and successional role of each lodgepole pine stand occurring on a District or Forest, administrators can make computer simulations to preview time and scale effects of appropriate silvicultural systems and practices on these characteristics of the future forest. The different computer-generated stand and forest scenarios can then be evaluated for various resource concerns and susceptibility to the mountain pine beetle using the information of these guidelines. Evaluations of successional roles in relation to appropriate silvicultural systems for specific resource allocation objectives of a representative National Forest were presented earlier. Following is a brief review of silvicultural practices for pure and mixed species lodgepole pine stands on lands designated as commercial forest.

Practices for Pure Lodgepole Pine Stands

In pure lodgepole pine stands, valid silvicultural practices for dealing with the mountain pine beetle include (1) stocking control, (2) clearcutting mature stands under a long-term plan to create age, size, and species mosaics, (3) salvage cutting to mitigate losses in stands under attack, and (4) sanitation cutting in some situations.

Stocking control.—Stocking control is an extremely important practice in pure, even-aged lodgepole pine. It promotes good stand vigor and can be used to direct stand growth toward moderate tree size and rotation objectives (D. M. Cole 1978). Initial stocking control (fig. 73) by age 25 (preferably by age 15) to a spacing of 10 or 12 ft (3 or 3.7 m) usually results in culmination of mean annual cubic volume increment on medium-to-good sites at about age 80—with average stand diameters of about 10 inches (26 cm) d.b.h. (D. M. Cole 1975). Stands of this age and structure do not have high risk of mountain pine beetle infestation.

Control of stocking through intermediate thinnings can also reduce the susceptibility of mature and near-mature stands; however, once begun, such thinnings might need to be repeated to maintain stand vigor until harvest. Thinnings repeated to maintain stand vigor will usually be uneconomic in terms of value of volume removed, but might be justified as a loss-prevention practice. Improved vigor of trees in managed stands will prevent infestation by *Ips* spp. and *Pityogenes* sp. and other secondary bark beetles that assist mountain pine beetle populations to survive in unhealthy trees during endemic levels (Schmitz 1984). Nevertheless, managers should consider the possibility of secondary bark beetle populations building up in thinning slash and attacking and killing leave trees. Late summer, early fall, or winter thinning will prevent a population buildup and mortality of leave trees. If dwarf mistletoe is present in stands, it should be considered in leave tree selection since thinning usually intensifies dwarf mistletoe effects.

Figure 73.—Stocking control in a young lodgepole pine stand has resulted in favorable spacing for future growth.

Clearcutting.—Clearcutting in small- to moderate-sized blocks (fig. 74) creates age and size mosaics from extensive, pure lodgepole pine stands and is a highly recommended practice (Roe and Amman 1970; Amman 1976). Timely surveys and maps of stand growth and volume, site quality, dwarf mistletoe distribution—and related factors such as phloem thickness, elevation, stand structures and form, composition, and ecological habitat type—are essential for clearcutting to be effective. Size and shape of clearcuts are extremely important in dwarf mistletoe-infected stands.

Schedules for clearcutting as a preventative measure should be coordinated with other multiple-use management objectives. In areas where probability for loss is high, future damage can be reduced by directing regeneration to alternating species among blocks or to mixed species within blocks (fig. 75) (D. M. Cole 1978). Models for predicting stand growth have been developed for determining the effects of prescribed management activities (Stage 1972; Edminster 1978). Caution is needed, however, in using such models to examine the interaction of the mountain pine beetle and lodgepole pine forests over time.

Figure 74.—Organized block clearcutting can be used to create age, species, and size mosaics from extensive, pure, even-aged lodgepole pine stands.

Figure 75.—Clearcuts regenerated with mixed species and alternating species among blocks.

Salvage and sanitation cutting.—Salvage cutting is defined as the removal of dead, dying, or deteriorating trees damaged by fire, wind, insects, diseases, or other injurious agents; sanitation cutting is the removal of infested trees to prevent the spread of pests or pathogens. Sanitation and salvage cutting should be justified either directly by timber economics or indirectly through protection of other resources to qualify as loss reduction practices (D. M. Cole 1978). Salvage and sanitation cutting should be carefully planned and administered as conscious silvicultural practices to protect other resource values (fig. 76).

Time between tree killing and salvage cutting should be minimal to prevent wood deterioration. Sanitation cutting of infested trees from high-hazard stands may slow disease outbreak, but it must be done before beetle flight or it will not be effective (fig. 77). The cost of repeated entries for sanitation purposes, however, is usually prohibitive, and success depends on timely execution and accurate assessments of hazard and risk.

Figure 76.—Salvaging heavily infested stands through clearcutting and sanitation cutting, as was done in background stand, can provide protection, at least temporarily, for nearby stands where esthetic and other resource values are crucial (North Fork Flathead River drainage, Montana).

Figure 77.—Proper scale, marking, and timing of sanitation cuts are crucial to prevent beetles from seeking out and attacking large-diameter trees in adjacent high-hazard stands. This stand shows spread of beetles after a poorly marked and timed sanitation cut.

Surveys to inventory stand structure and the diameter-phloem thickness distribution of stands can identify high-risk trees for preventative cutting (fig. 78) to forestall beetle infestation for several years.

Sanitation cutting must be carefully coordinated to prevent spread of beetles into other stands along haul roads or from infested logs decked at sawmills (fig. 79). Sanitation cutting must also take into account the factors of windthrow and dwarf mistletoe infection in the residual stand. These factors are dealt with in the discussion of partial cutting in the section on practices for mixed species stands.

Sanitation cutting, as previously described, is, of course, partial cutting for sanitation purposes. Partial cutting of larger lodgepole pine in pure, and particularly even-aged, lodgepole pine stands as a preventative practice should be used sparingly and with caution. Nevertheless, it has application in a couple of situations: (1) where extensive clearcutting has occurred in a drainage and further clearcutting is prohibited by nontimber concerns such as wildlife cover, riparian zones, esthetic values, or watershed values and (2) where the pest manager feels that the spread of infestations can be slowed enough that losses can be prevented or reduced in nearby stands through the use of other practices.

Partial cutting to achieve longer term benefits through species discrimination is discussed in the following section on practices for mixed species stands.

Figure 78.—Removal of high-risk trees in the foreground reduced subsequent infestation levels in this high-hazard stand, West Yellowstone, MT.

Figure 79.—Timely processing of infested logs before beetles emerge from them will prevent infestation of susceptible stands in the area.

Practices for Mixed Species Lodgepole Pine Stands

Mixed species lodgepole pine stands vary greatly in form, proportion, and structure of the lodgepole pine, relative to the other species present. Still, some common expressions of these stand characteristics occur.

A common situation in habitat types of the subalpine fir series is a mature or overmature lodgepole pine overstory with a mixture of smaller shade-tolerant species and some younger lodgepole pine in the understory (fig. 80). The size and mixture of the understory depends largely on the number and size of openings created in the overstory by insects, diseases, and climatic factors (D. M. Cole 1978). This successional situation is common near and east of the Continental Divide, where mixed overstory stands are usually well advanced in succession of Douglas-fir, Engelmann spruce, and subalpine fir, and the lodgepole pine is in a decadent condition (fig. 81).

Figure 80.—Mature overstory of lodgepole pine with mixture of shade-tolerant subalpine fir and some lodgepole pine in the understory.

Figure 81.—Overstory of lodgepole pine with climax understory of spruce and subalpine fir. Lodgepole pine is severely infected with dwarf mistletoe.

Even-aged mixed species lodgepole pine stands also occur. These are usually lodgepole pine-western larch (fig. 82) or lodgepole pine-Engelmann spruce (fig. 83) mixtures where lodgepole pine did not predominate the site in the regeneration process.

Another common situation involves one or more other species in the overstory with lodgepole pine, with an understory of one or more climax species (figs. 84 and 85). This is common west of the Continental Divide in the range of western larch and the ranges of more shade-tolerant species such as Douglas-fir, Engelmann spruce, grand fir, and western white pine.

Stocking control, clearcutting, sanitation cutting, and salvage cutting are acceptable silvicultural practices for mixed species lodgepole pine stands. As with pure lodgepole pine stands, the applicability and choice of any given practice depends on management objectives and the age, form, structure, and condition of the stand. The major distinction between acceptable silvicultural practices for mixed species stands and for pure lodgepole pine stands is the opportunity in mixed species stands for species discrimination in stocking control and partial harvest cuttings.

Stocking control, with species discrimination, is applicable in immature mixed species stands (fig. 86).

Figure 82.—Even-aged western larch, lodgepole pine stand. A common stand situation in northwest Montana.

Figure 83.—Mixed, even-aged stands of lodgepole pine and Engelmann spruce occur both east and west of the Continental Divide.

Figure 84.—Mixed overstory of lodgepole pine, spruce, and subalpine fir with a mixed understory of climax species.

Figure 85.—Overstory of lodgepole pine and western larch with understory of shade-tolerant species. The western larch is severely infected with dwarf mistletoe.

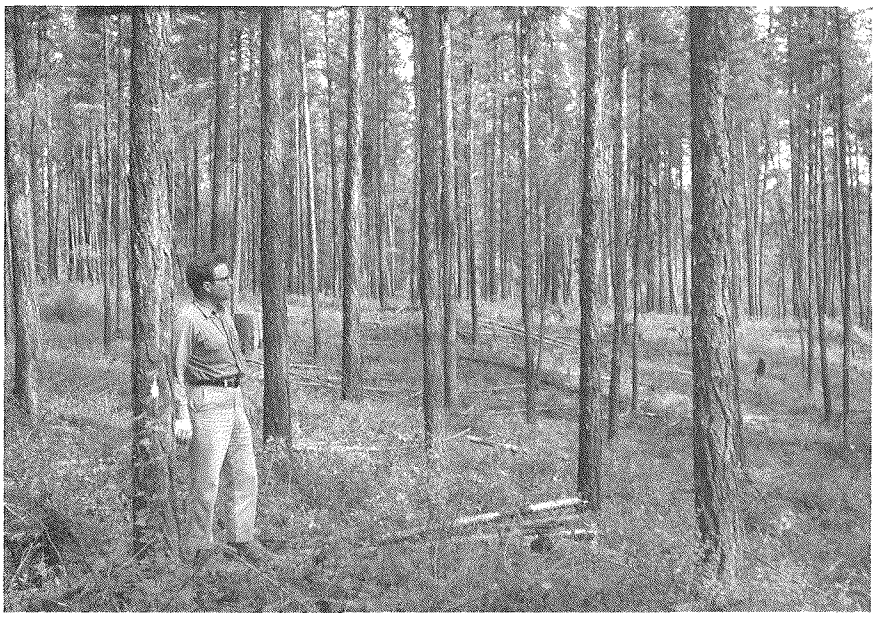

Figure 86.—Lodgepole pine was discriminated against in this thinned immature western larch-lodgepole pine stand. The vigorous, well-stocked western larch crop trees are capable of excellent yield.

In older mixed species stands, we can discriminate against lodgepole pine by cutting only the larger trees. This is a valid practice in regulated forests **only** if the residual stand is of sufficient vigor and stocking to maintain stand growth near the capability level of the site or if the objective is a shelterwood or seed tree cut (fig. 87) in preparation for stand regeneration.

Partial cutting of larger lodgepole pine from a stand is sometimes justified in the short term—in both pure and mixed species lodgepole pine stands threatened with outbreaks—in order to deny the beetle the trees needed for population buildup. It thus can help provide additional time for other measures, more appropriate for large-scale application, to be applied.

Partial cutting has been demonstrated to reduce subsequent beetle infestation levels in numerous tests of susceptible lodgepole pine stands (Cole and others 1983; Cole and McGregor, in press; Hamel 1978; Cahill 1978; Cole and Cahill 1976). However, because the intent of most of these tests was to determine if partial cutting could be used to manage beetle populations (infestation levels), its qualifications as a practice for maintaining stand productivity were not emphasized. Amman (1976) concluded that partial cutting is sometimes an option where timber values are primary but applies only where (1) a small proportion of the lodgepole pine have large diameters and thick phloem conducive to beetle buildup and (2) residual trees would be numerically adequate and vigorous enough to maintain stand productivity.

Usually only stands having a sizable and healthy basal area component of other species can provide a residual stand capable of attaining the yield capability of the site. Discriminating against the beetle-preferred lodgepole pine in such stands can be silviculturally acceptable, but the volume involved may not be economical to remove. Conversely, removal of sufficient additional volume of other species may overcut the stand (fig. 88). The volume of beetle-preferred trees may not be enough to pay for the road system. Thus, maintaining adequate growing stock must be considered important enough to subsidize development costs where only a small proportion of the lodgepole pine volume is susceptible in any one infestation cycle (D. M. Cole 1978).

When complete or partial removal of the overstory is used, future productivity is likely to be further impaired by logging damage, dwarf mistletoe (*Arceuthobium americanum* Nutt. ex Engel.) infection, and windthrow (Hatch 1967; Alexander 1972, 1975). The yield-reducing effect of dwarf mistletoe infection, in itself a serious management problem, becomes even more serious in multistoried stands where lodgepole pine understories are infected. It is extremely doubtful if yield capability of the site can be attained if such understories are featured in management through partially cutting the overstory, unless costly mistletoe control programs are carried out. Thus the dwarf mistletoe factor needs careful consideration when partial cuts are contemplated for beetle control purposes (D. M. Cole 1978). If partial cutting is otherwise defensible in dwarf mistletoe infected stands, residual infected trees should be removed before lodgepole pine regeneration is 10 years old or taller than 3 ft (0.9 m) (Hawksworth 1975).

Figure 87.—Lodgepole pine was discriminated against in harvesting this mixed species situation, leaving western larch seed trees to regenerate the stand.

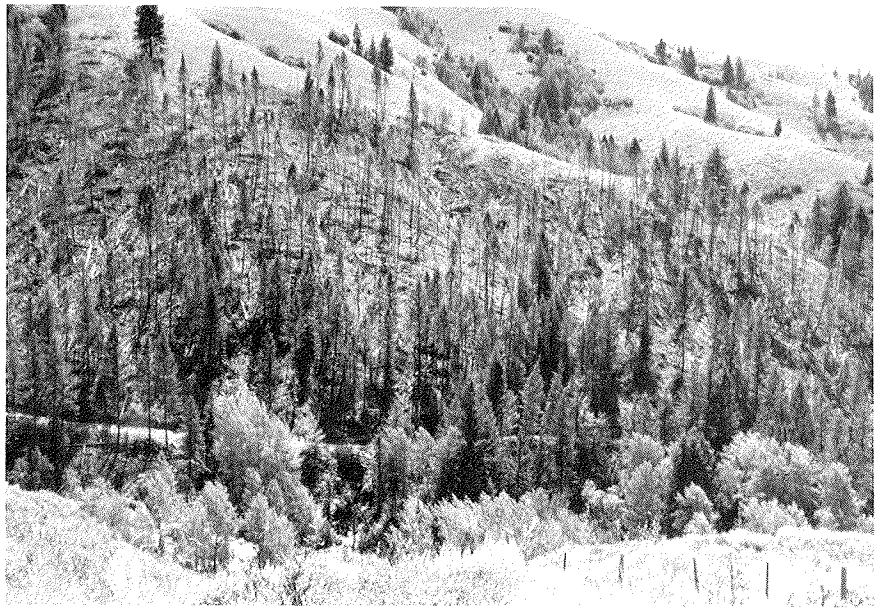

Figure 88.—In discriminating against beetle-susceptible lodgepole pine, removal of sufficient additional volume, including other species, to make the sale economically viable, may result in overcutting the stand and have adverse effects on other resource values.

The risk of windfall is increased by such factors as poor drainage, shallow soils, and defective roots and boles. Stands exposed to special topographic features, such as gaps and saddles at higher elevations, have higher windfall risk, and the risk increases in all stands regardless of exposure when the stand is opened up by intermediate cutting or partial cutting of the overstory (Alexander 1975). Susceptibility of residual trees to windthrow is generally greater in stands cut from above than in those cut from below. Root system development varies with soil and stand conditions. On deep, well-drained soils, trees have a better root system than on shallow or poorly drained soils. With the same conditions, the more dense the stand, the less windfirm are individual stems because trees that develop together in dense stands over long periods of time support each other and do not have roots and boles able to withstand exposure to wind if opened up drastically. The risk of windthrow is also greater on some exposures than others. Further detail on procedures for properly identifying and dealing with windfall risk in partial cutting of lodgepole pine can be found in the guidelines of Alexander (1964, 1967).

Other Practices for Commercial Forests

Another strategy to reduce losses to the mountain pine beetle is the use of behavior-modifying chemicals called Semiochemicals (Borden and others 1983a). These are combinations of pheromones produced by the beetle and terpenes of the host tree. Pheromones are chemical messengers used by insects for communication. They trigger behavioral responses which result in aggregation. Behavior-modifying chemicals can be used effectively to (1) contain small infestations, preventing them from spreading into adjacent green stands (Borden and others 1983b; Conn and others 1983); (2) bait and trap small developing outbreaks (Borden and others 1983a; Conn and others 1983); and (3) to manipulate or trap small populations after logging (Borden and others 1983b). Also, Semiochemicals placed in release devices (funnel traps) provide a tool for monitoring infestation levels. In forest pest management programs, pheromone trapping systems also provide foresters with data necessary for making procedural changes in logging and log storage and handling.

Trees baited with Semiochemicals can also be used in conjunction with Sevimol-4 (a pesticide) as lethal trap trees, in combination with felling and burning of infested trees in isolated developing outbreaks, or in drainages where clearcutting has exceeded the amount allowed by watershed and regenerated-area guidelines. Baiting-trapping can also be used in conjunction with large-scale harvesting to reduce beetle populations. In areas where outbreaks are just developing, the stands designated for harvest can be baited on a 55-yd (50-m) grid (Borden and others 1983c; S. Lindgren 1983), then clearcut following beetle attack of the baited-trap trees. It would be necessary to ensure removal and milling of these trees before beetle flight the following year.

Stands designated for partial cutting can be baited on a 27-yd (25-m) grid along roads, then on a 55-yd (50-m) grid surrounding the stands or infestation centers (Borden and others 1983c; S. Lindgren 1983). This strategy is recommended for small infestation centers (groups of 3 to 20 trees). For medium-size infestations of 5 to 50 acres (2 to 20 ha), where the goal is containment, it is recommended that lures be placed on one tree every 55 yd (50 m) on a grid basis, so that flying beetles will pass within 27 yd (25 m) of a baited tree (S. Lindgren 1983). A cut-tree zone should also be created around the baited infestation center. This strategy would be effective for smaller stands or small group selection cuts.

For infestations larger than 50 acres (20 ha), it is of no concern if beetles fly about within the infested area; therefore, we recommend that two bait lines, 55 yd

(50 m) apart with a tree baited every 55 yd (50 m), be placed in a band within the margin of the infestation to intercept flying beetles attempting to leave the infestation center. Baited trees should be at least 27 yd (25 m) inside any exposed margin (S. Lindgren 1983). This strategy is applicable where drainages are coming under management and the objective is to obtain a mosaic of age and size classes in even-aged lodgepole pine stands. Such trappings can contain beetle infestations, reduce damage, and buy time for other preventative measures. It is also useful where one desires to maintain hiding/thermal cover or to protect riparian and visual values from the effects of the mountain pine beetle.

PRACTICES AND CONSIDERATIONS FOR NONCOMMERCIAL FORESTS

Mark D. McGregor
Cooperative Forestry and Pest Management
Northern Region
Missoula, MT

Dennis M. Cole
Intermountain Forest and Range
Experiment Station
Forestry Sciences Laboratory
Bozeman, MT

Fragile Higher Elevation Ecosystems

Mountain pine beetle outbreaks usually begin and develop to epidemic levels in susceptible lodgepole pine stands at lower elevations and eventually progress to higher elevations after depleting the lower elevation lodgepole pine. At higher elevations, whitebark pine (*Pinus albicaulis*) is also attacked (fig. 89).

Extensive stands of whitebark pine occur above 6,000 ft (1 830 m) elevation in some forests. Habitat types are *A. lasiocarpa-P. albicaulis/V. scoparium, A. lasiocarpa/Luzula hitchcockii*, and *P. albicaulis-A. lasiocarpa*. Stands in these habitat types are often economically inaccessible. Soils are shallow, and timber production is usually low (20 ft^3/acre [1.4 m^3/ha] per year), although some large trees up to 30 inches (76 cm) d.b.h. occur (Wilson 1979). Some stands are 450 to 500 years old. Although most stands in these habitat types are dominated by whitebark pine, there are extensive areas in the lower elevations of the *A. lasiocarpa-P. albicaulis/V. scoparium* habitat type where lodgepole pine is a significant stand component. (This was previously shown in the summary of the Gallatin National Forest habitat types.) In these transition zones, mountain pine beetle effects are serious.

On the Gallatin National Forest, the *A. lasiocarpa-P. albicaulis/V. scoparium* habitat type occupies 319,776 acres (129 411 ha)—about 19 percent of the Forest. This habitat type does not occur on the Flathead National Forest. The significance of this habitat type, of course, is that whitebark pine is also vulnerable to the mountain pine beetle. According to table 5, about one-third of the area represented by this habitat type on the Gallatin National Forest has over one-third of the stand basal area in lodgepole pine more than 8 inches (20 cm) d.b.h. These stands generally are in the lower elevation part of the habitat type, adjacent to habitat types of the *A. lasiocarpa* series, where lodgepole pine plays a major seral or dominant seral role. Because there is a high potential for beetle epidemics to build in adjacent lower elevation habitat types to eventually attack the larger lodgepole pine and then the whitebark pine in the *A. lasiocarpa-P. albicaulis/V. scoparium* habitat type, tree mortality and other resource losses can be very high. Silvicultural options are limited in this habitat type because current technology does not usually provide economic harvest or natural regeneration methods that ensure resource protection and stand regeneration following cutting in high-elevation whitebark pine stands. Planning for regeneration should be given high priority when cutting is contemplated in these fragile ecosystems.

Figure 89.—Extensive stands of whitebark pine have become infested in fragile, high-elevation areas, often designated as critical wildlife habitat.

The first concern should be to hazard-rate and risk-rate stands at lower elevations and implement stand management practices there to prevent outbreaks from spreading into the whitebark pine zone. In conjunction with stand management, additional management practices are felling, piling, and burning infested trees in small-spot infestations and baiting and trapping to contain infestations (Borden and others 1983a, 1983b, 1983c; B. S. Lindgren 1983; S. Lindgren 1983).

Considerations for Parks, Wilderness, and Other Reserved Areas

In National Parks and ecological reserves or wilderness areas, high value is placed on maintaining a natural ecosystem. Mortality is generally considered in terms of visual resource impairment and increased costs to maintain convenience and safety for recreationists. Of the following management options for these areas, all except fire management are thought of as good housekeeping rather than silvicultural practices (D. M. Cole 1978).

Although seldom feasible, felling and burning infested trees in spot outbreaks can sometimes prevent or delay epidemics.

Fire has been largely responsible for maintaining lodgepole pine as a widespread forest type, so it must be considered in plans for parks, wilderness, and reserved areas.

Although wildland fires have been suppressed in parks and wildernesses for 50 to 60 years, the effects of fire exclusion in lodgepole pine ecosystems have not been as pronounced as in some other forest types—for example, ponderosa pine. The difference between how these two types respond to fire exclusion is explained largely by the fact that lodgepole pine has a natural fire cycle of 40 to 60 years while that of ponderosa pine is about 10 years. Succession and other effects of 50 to 60 years of fire suppression in lodgepole pine are therefore less than for the same period of fire exclusion in ponderosa pine (Mutch 1984). Nevertheless, mountain pine beetle epidemics, large fuel accumulations (fig. 90), and stand replacement fires (fig. 91) are a normal sequence for unmanaged lodgepole pine ecosystems. But naturally occur-

Figure 90.—Accumulations of dead wood resulting from earlier beetle epidemics in unmanaged stands.

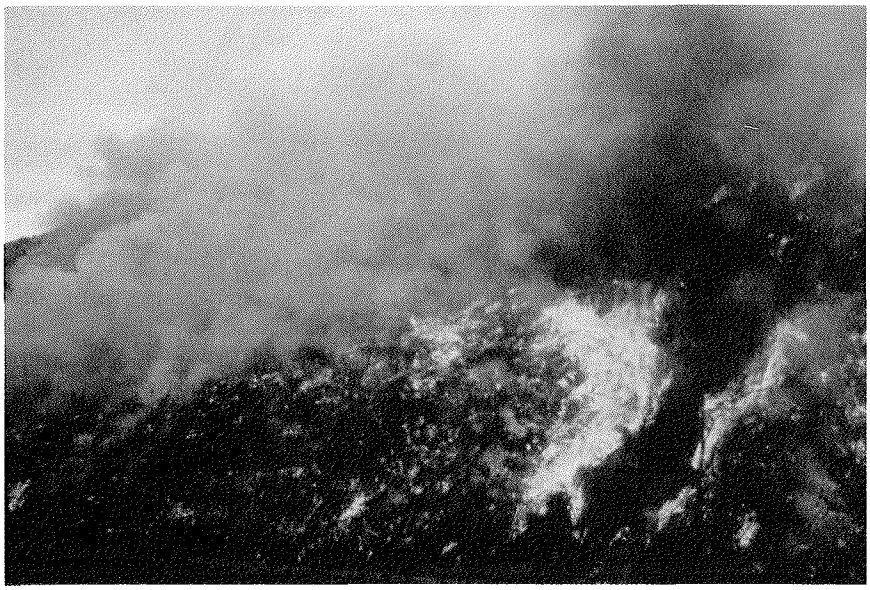

Figure 91.—Heavy fuel loadings from mountain pine beetle epidemics and high burning conditions result in high-intensity, stand replacement fires.

ring stand replacement fires can be more destructive than managed or prescribed fires, and they can perpetuate future extremes in the mountain pine beetle/lodgepole pine/fire cycle (D. M. Cole 1978). This cycle can be moderated if a deliberate program of prescribed fire management is initiated (fig. 92).

There are two types of prescribed fires—those originating from unplanned ignitions and those from planned ignitions. Both types of prescribed fires have a place in management, and objectives should help in deciding which method to employ. Prescribed burning offers real silvicultural advantages over trying to manage naturally occurring fires in such high-hazard situations as beetle-infested areas (D. M. Cole 1978).

Visual considerations regarding fire management programs in wilderness need to be tested continually against the concept of wilderness—"areas to be affected primarily by the forces of nature." Thus, fires are not judged as good or bad in wilderness but simply viewed as one of several natural forces affecting wilderness ecosystems. Fires varying in intensity and size will affect foreground, middleground, and background views in significant but different ways. High-intensity fires often burn across main travel and viewing corridors in wilderness, leaving long-lasting scenes of scorched trees and blackened snags.

Ideally, a prescribed fire in wilderness should be used to create a dynamic ecosystem change similar to random natural fire—killing some trees but leaving others, removing undergrowth in places but also leaving unburned areas, exposing mineral soil, producing open-grown forests and dense stands of lodgepole pine, converting dead organic material to ash, recycling nutrients, restricting some plants and favoring others. Not only are fire-dependent communities well adapted to such change, but the diversity of plants and animals that follows fire contributes to ecosystem stability and landscape beauty. It should be noted that a similar prescribed fire program may be appropriate for backcountry areas outside wilderness that are being managed primarily for wildlife and dispersed recreation (Habeck and Mutch 1975).

Reliable surveys and maps of stand age and size and fuels structure are necessary to develop a plan to allow some fires, once started, to burn under supervision to create a mosaic of regenerated stands within the extensive areas of large timber that have developed (fig. 93). Such mosaics are easier to accomplish with prescribed fire in wilderness areas than in the general forest zone.

In some wilderness areas, periodic crown fires play a vital role in natural development of lodgepole pine ecosystems, and their use should be considered when consistent with the need to protect human life, property, and resource values outside wilderness (Fischer and Clayton 1982).

Practices for Recreational, Home, and Administrative Sites

In recreation areas, home sites, and administrative sites, trapping and the use of protective sprays are preferred methods for protecting high-value trees. A protective spray that is effective and safe is Sevimol-4 (a pesticide) (Gibson and Bennett, in press). Sevimol-4 (1.0 percent) applied to the tree bole before beetle flight (fig. 94) will protect a tree for 2 years. Pine oil (a repellant), applied to the lower 10 to 15 ft (2.8 to 4.4 m) of the bole of green lodgepole pines has proven effective in repelling attacking mountain pine beetle (Nijholt and McMullen 1980; Nijholt and others 1981). However, additional field and pilot testing are planned before pine oil can be recommended for operational use. Baited traps hung outside campgrounds and administrative sites will attract beetles and help protect high-value sites during early developing or declining epidemics.

Managers of high-use recreation areas, such as campgrounds, should also consider planting trees of different species when planning such facilities or where lodgepole pine has been killed in existing sites. Hazard trees, both dead and those with root disease, should be removed for

Figure 92.—Prescribed fire can be beneficial to wildlife and reduce potential mountain pine beetle hazard.

safety and esthetic reasons. Trees baited in stands adjacent to campgrounds can be logged, chemically treated, or felled and burned. Pest management specialists should be consulted on locations and intervals of bait and trap placement and on proper use of pesticides, repellents, and attractants. Information on the availability of these chemicals can be obtained from Cooperative Forestry and Pest Management units at Forest Service Regional Offices.

Figure 93.—Supervised fires can create a mosaic of age classes, reducing area of susceptible high-hazard stands while benefiting other resources.

Figure 94.—Application of Sevimol-4 will protect high-value trees for up to 2 years.

INTEGRATING PEST MANAGEMENT FOR THE MOUNTAIN PINE BEETLE WITH MANAGEMENT FOR MULTIPLE RESOURCE GOALS

Mark D. McGregor
Cooperative Forestry and Pest Management
Northern Region
Missoula, MT

Dennis M. Cole
Intermountain Forest and Range
Experiment Station
Forestry Sciences Laboratory
Bozeman, MT

Beetle populations can be managed by a process in which known aspects of the mountain pine beetle/lodgepole pine system are evaluated and integrated with multiple resource management through a process called Integrated Pest Management (IPM). This provides the resource manager with information for limiting damage from mountain pine beetle to tolerable levels. To be most effective, IPM should include prevention, suppression, and postsuppression activities, developed in an ecological framework that addresses the needs of other forest resources.

An IPM system designed to reduce losses to the mountain pine beetle should emphasize prevention. Prevention is the best approach because techniques are more effective, economical, environmentally acceptable, and compatible with management for other forest resources. Nevertheless, the full array of available pest management responses must be considered in an orderly process to insure sufficient, cost-effective pest management prescriptions.

Such a process requires a systems approach to data assembly, analysis, and decisionmaking. Freeman's (1978) decisionmaking process as developed by Coster (1980) into a decision process and support system for developing integrated management strategies for the southern pine beetle (*Dendroctonus frontalis* Z.) is a good framework for developing an IPM system for the mountain pine beetle. We have adapted Coster's decision process into a suggested system for making integrated management decisions (fig. 95). Although this report is entitled "Integrating Management Strategies for the Mountain Pine Beetle with Multiple-Resource Management of Lodgepole Pine Forests," we do not presume to call the process presented here a complete IPM Program. Such a program can only be developed by forest managers, who must establish explicit management objectives and assign responsibilities for accomplishing them. Guidelines presented in this paper, however, support the suggested decisionmaking process and decision support system by providing information relative to Steps 3, 4, 5, 6, and 7 of figure 95, as discussed below.

EVALUATING THE PRESENT AND FUTURE PROBLEM

The Pest Management Team, in cooperation with the local Forester and Planner, can obtain data for Step No. 3. This will identify the problems: where, what species, current effects, relation or association with other pests, and prognosis for future damage. These data are obtained through (1) aerial and ground detection surveys, (2) biological evaluations and forest inventories, and (3) hazard rating surveys.

The detection of beetle infestations relies on observations of damage, which require observing and mapping individual trees or groups of trees with off-color foliage. It can be accomplished efficiently by the scheduled use of aircraft and trained observers at appropriate times of the year. Casual observations and reports by practicing foresters, woods workers, and other forest users provide a valuable source of information on unusual beetle activity. These reports are encouraged by continuing education and information programs by the Forest Service and other public agencies and, to some extent, by large forest landowners; however, timely and effective coverage of the extensive forest areas subject to beetle attack requires aerial surveillance on an annual basis.

The attractant pheromones provide another, more direct means of detecting significant increases in beetle numbers and potential damage (S. Lindgren 1983). Baited traps can be deployed on an annual basis to detect changes in mountain pine beetle populations.

The evaluation phase of monitoring by intensive surveys accomplishes three purposes: (1) it provides a quantitative basis for judging the need for direct suppression and for determining the type of actions that should be taken; (2) it provides the basis for evaluating the efficacy and benefits of the action(s) that are carried out; and (3) it provides a source of input data for models of stand dynamics and beetle populations, where such models are applicable. Annual biological evaluations are needed to keep the forest manager properly informed of situations warranting management action (Waters 1984).

The buildup and spread of beetle outbreaks often are evaluated solely in terms of the damage occurring. Specific information is needed by the resource manager on tree species, age and size classes affected, and on mortality rates in different stands. Forest inventory surveys supply data to the forest resource manager in terms of stand composition, stocking density, age-size structure, regeneration, and other relevant management planning data. They include data on tree mortality and defect, stand growth, changes in stand structure and composition, potential yield, and other dynamic variables of interest. Stage and Long (1976) describe the types of forest stand dynamics models that can make use of forest inventory data and the relevance of these to forest pest management. Estimates are also obtained from biological and stand surveys using the INDIDS model (Bousfield 1981) and the rate of loss model (Cole and McGregor 1983) previously described. Briefly, models are useful to the manager in determining:

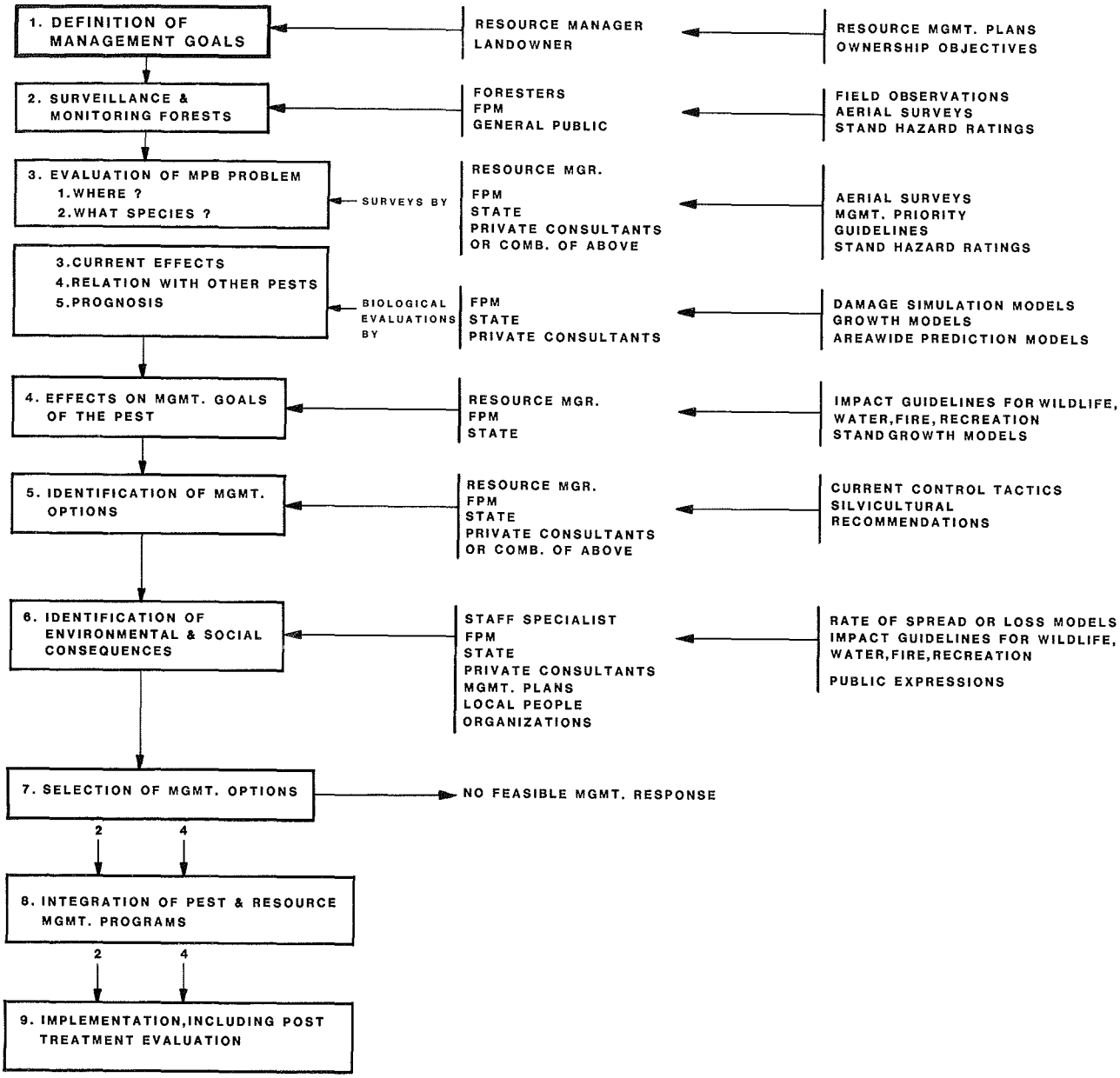

Figure 95.—Information and decision process for integrating pest management with management of multiple resources.

1. Expected losses for general information and planning purposes (Beckley 1983). Tree risk and stand/area hazard ratings serve several important functions in the management of the mountain pine beetle. Risk and hazard ratings are the sole means of forewarning the forest manager of potential beetle-caused losses and thus are essential to managers in taking preventative actions consistent with management objectives. They have a uniquely important place, therefore, in the management of pine bark beetles (Waters 1985).

2. Structure and composition of probable residual stands if outbreaks occur and are allowed to run their course. This helps managers to determine probable impacts on resource values such as big game cover and watershed and visual values.

3. Silvicultural alternatives. If characteristics of the postepidemic stand are predictable, it will be possible to narrow down the silvicultural options. For example, if the postepidemic stand is within acceptable stocking levels, the alternative of partial cutting is a viable option; but, if predicted losses are high, regeneration harvesting may be the only feasible alternative.

4. Priority for silvicultural treatments. Stands with the highest hazard and risk and potential resource inputs can be scheduled for treatment first.

EVALUATING MANAGEMENT GOALS AND OPTIONS

Both the resource management and the pest management specialist contribute information for determining the effect on management goals (Step 4, fig. 95). Available management options, their potential costs and benefits, and how they might affect outbreaks through prevention, or alteration of epidemics (Steps 5 and 6) should be evaluated by a pest/resource management team.

SELECTION AND INTEGRATION OF MANAGEMENT OPTIONS

After analyzing the management options and their cost effectiveness, a management option can be selected (Step 7, fig. 95). One might determine none of the options is cost effective or perhaps the environmental/social consequences of all actions are untenable. On the other hand, the decision might be to select one or more preventative or suppressive actions. For example, salvage logging, preventative spraying, stand thinning, and baiting-trapping may be selected to simultaneously manage existing infestations, recover some loss, and minimize future mortality. Programs developed to carry out the pest management actions should then be refined to give appropriate consideration to all important resources threatened by the mountain pine beetle or affected by management response to the pest (Step 8).

Cooperation between pest management specialists and resource managers is essential. Resource managers bear the responsibility for final decisions regarding management of multiple resources and must, therefore, spell out clearly the time, space, and economic limitations that these decisions place on silviculture and other pest management actions designed to minimize future losses to the mountain pine beetle.

IMPLEMENTATION

Prevention of resource losses is an idealized objective of forest pest management. Complete prevention of losses to the mountain pine beetle is, of course, not realistic. A realistic goal, implicit in the concept of integrated pest management, is to define a relatively long-term balance among resource values of lodgepole pine forests and to manage the forest and the mountain pine beetle to achieve and maintain the balance. The information and guidelines provided in the different sections of this report should prove valuable to forest planners and managers in proceeding with this complex integrating process.

REFERENCES

Abbey, Helen. An examination of the Reed-Frost theory of epidemics. Human Biology. 24: 201-233; 1952.

Alexander, R. R. Minimizing windfall around cuttings in spruce-fir forests. Forest Science. 10: 130-142; 1964.

Alexander, R. R. Windfall after clearcutting on Fool Creek-Fraser Experimental Forest, Colorado. Research Note RM-92. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1967. 11 p.

Alexander, R. R. Partial cutting practices in old-growth lodgepole pine. Research Paper RM-92. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1972. 16 p.

Alexander, R. R. Partial cutting in old-growth lodgepole pine. Research Paper RM-136. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1975. 17 p.

Allen, E. O. A new perspective for elk habitat management. In: Proceedings, annual conference Western Association of Fish and Wildlife Agencies; Tucson, AZ. Tucson, AZ: [publisher unknown]; 1977: 195-205.

Amman, G. D. Mountain pine beetle emergence in relation to depth of lodgepole pine bark. Research Note INT-96. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1969. 8 p.

Amman, G. D. Mountain pine beetle brood production in relation to thickness of lodgepole pine phloem. Journal of Economic Entomology. 65: 138-140; 1972.

Amman, G. D. Population changes of the mountain pine beetle in relation to elevation. Environmental Entomology. 2: 541-547; 1973.

Amman, G. D. Insects affecting lodgepole pine productivity. In: Baumgartner, David M., ed. Management of lodgepole pine ecosystems; symposium proceedings; 1973 October 9-11; Pullman, WA. Pullman, WA: Washington State University, Cooperative Extension Service; 1975: 310-341.

Amman, G. D. Integrated control of the mountain pine beetle in lodgepole pine forests. In: XVI IUFRO World Congress, Proceedings Division II ; Oslo, Norway. 1976: 439-446.

Amman, G. D. The role of the mountain pine beetle in lodgepole pine ecosystems; impact on succession. In: Mattson, W. J., ed. Arthropods in forest ecosystems: proceedings in life sciences. New York: Springer-Verlag; 1977: 3-18.

Amman, G. D. The biology, ecology and causes of outbreaks of the mountain pine beetle in lodgepole pine forests. In: Berryman, Alan A.; Amman, Gene D.; Stark, Ronald W., tech. eds. Theory and practice of mountain pine beetle management in lodgepole pine forests: symposium proceedings; 1978 April 25-27; Pullman, WA. Moscow, ID: University of Idaho, Forest, Wildlife and Range Experiment Station; 1978: 39-53.

Amman, G. D. A test of lodgepole pine hazard rating methods for mountain pine beetle infestation in southeastern Idaho. In: Safranyik, Les, ed. The role of host-pest interaction in the population dynamics of forest insects: proceedings of the IUFRO Working Parties S2-07-05, 06 symposium; 1983 September 4-7; Banff, Alberta, Canada; [in press].

Amman, G. D.; Baker, B. H. Mountain pine beetle influence on lodgepole pine stand structure. Journal of Forestry. 7: 204-209; 1972.

Amman, G. D.; Baker, B. H.; Stipe, L. E. Lodgepole pine losses to mountain pine beetle related to elevation. Research Note INT-171. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1973. 8 p.

Amman, G. D.; Cole, W. E. Mountain pine beetle dynamics in lodgepole pine forests. Part II: population dynamics. General Technical Report INT-145. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 59 p.

Amman, G. D.; McGregor, M. D.; Cahill, D. B.; Klein, W. H. Guidelines for reducing losses of lodgepole pine to the mountain pine beetle in unmanaged stands in the Rocky Mountains. General Technical Report INT-36. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1977. 19 p.

Bacon, W. R.; Twombly, A. D. National forest landscape management. In: Agriculture Handbook 559. Washington, DC: U.S. Department of Agriculture, Forest Service; 1977: vol. 2, chapter 5.

Basile, J. V.; Jensen, C. E. Grazing potential on lodgepole pine clearcuts in Montana. Research Paper INT-98. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1971. 11 p.

Beckley, P. [Personal communication]. 1983. Author located at: Tally Lake Ranger District, Flathead National Forest, Whitefish, MT.

Berryman, A. A. A synoptic model of the lodgepole pine/mountain pine beetle interaction and its potential application in forest management. In: Berryman, Alan A.; Amman, Gene D.; Stark, Ronald W., tech. eds. Theory and practice of mountain pine beetle management in lodgepole pine forests: symposium proceedings; 1978 April 25-27; Pullman, WA. Moscow, ID: University of Idaho, Forest, Wildlife and Range Experiment Station; 1978: 98-105.

Black, H.; Sherzinger, R.; Thomas, J. W. Relationships of Rocky Mountain elk and Rocky Mountain mule deer habitat to timber management in the Blue Mountains of Oregon and Washington. In: Hieb, Susan R., ed. Proceedings of the elk-logging-roads symposium; 1975 December 16-17; Moscow, ID. Moscow, ID: University of Idaho; 1976: 11-31.

Blanchard, B. M. Grizzly-habitat relationship in Yellowstone area. In: Meslow, E. Charles, ed. Bears—their biology and management: proceedings 5th international conference on bear research and management; 1980 February 10-13; Madison, WI. Madison, WI: International Association for Bear Research and Management; 1980: 119-123.

Borden, J. H.; Conn, J. E.; Friskie, L. M.; Scott, B. E.; Chong, L. J. Semiochemicals for the mountain pine beetle, *Dendroctonus ponderosae* (Coleoptera: Scolytidae), in British Columbia: baited-tree studies. Canadian Journal of Forest Research. 13: 325-333; 1983

Borden, J. H.; Chong, L. J.; Fuchs, M. C. Application of Semiochemicals in post-logging manipulation of the mountain pine beetle, *Dendroctonus ponderosae* (Coleoptera: Scolytidae). Journal of Economic Entomology. 76(6): 1428-1432; 1983

Borden, J. H.; Chong, L. J.; Pratt, K. E. G.; Gray, D. R. The application of behavior-modifying chemicals to contain infestation of the mountain pine beetle, *Dendroctonus ponderosae*. Forestry Chronicle; 1983 October: 235-239.

Bousfield, Wayne E. R-1 forest insect and disease damage survey system. Report 70-2 (rev.). Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region; 1981. 12 p.

Cabrera, Homero. Phloem structure and development in lodgepole pine. In: Berryman, Alan A.; Amman, Gene D.; Stark, Ronald W., tech. eds. Theory and practice of mountain pine beetle management in lodgepole pine forests: symposium proceedings; 1978 April 25-27; Pullman, WA. Moscow, ID: University of Idaho, Forest, Wildlife and Range Experiment Station; 1978: 54-63.

Cahill, D. B. Cutting strategies as a control measure of the mountain pine beetle in lodgepole pine in Colorado. In: Berryman, Alan A.; Amman, Gene D.; Stark, Ronald W., tech. eds. Theory and practice of mountain pine beetle management in lodgepole pine forests: symposium proceedings; 1978 April 25-27; Pullman, WA. Moscow, ID: University of Idaho, Forest, Wildlife and Range Experiment Station; 1978: 188-191.

Carter, S. William, Jr. Potential impacts of mountain pine beetle and their mitigation in lodgepole pine stands. In: Berryman, Alan A.; Amman, Gene D.; Stark, Ronald W., tech. eds. Theory and practice of mountain pine beetle management in lodgepole pine forests: symposium proceedings; 1978 April 25-27; Pullman, WA. Moscow, ID: University of Idaho, Forest, Wildlife and Range Experiment Station; 1978: 54-63.

Cole, D. M. Estimating phloem thickness in lodgepole pine. Research Paper INT-148. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1973. 10 p.

Cole, D. M. Culture of immature lodgepole pine stands for timber objectives. In: Baumgartner, David A., ed. Management of lodgepole pine ecosystems: symposium proceedings; 1973 October 9-11; Pullman, WA. Pullman, WA: Washington State University, Cooperative Extension Service; 1975: 536-555.

Cole, D. M. Feasibility of silviculture practices for reducing losses to the mountain pine beetle in lodgepole pine forests. In: Berryman, Alan A.; Amman, Gene D.; Stark, Ronald W., tech. eds. Theory and practice of mountain pine beetle management in lodgepole pine forests: symposium proceedings; 1978 April 25-27; Pullman, WA. Moscow, ID: University of Idaho, Forest, Wildlife and Range Experiment Station; 1978: 149-157.

Cole, W. E.; Amman, G. D. Mountain pine beetle infestations in relation to lodgepole pine diameters. Research Note INT-95. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1969. 7 p.

Cole, W. E.; Amman, G. D. Mountain pine beetle dynamics in lodgepole pine forests. Part I: course of an infestation. General Technical Report INT-89. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1980. 56 p.

Cole, W. E.; Amman, G. D.; Jensen, C. E. Mathematical models for the mountain pine beetle-lodgepole pine interaction. Environmental Entomology. 5: 11-19; 1976.

Cole, W. E.; Cahill, D. B. Cutting strategies can reduce probabilities of mountain pine beetle epidemics in lodgepole pine. Journal of Forestry. 74: 294-297; 1976.

Cole, W. E.; Cahill, Donn B.; Lessard, Gene. Harvesting strategies for management of mountain pine beetle infestations in lodgepole pine: preliminary evaluation, East Long Creek Demonstration area, Shoshone National Forest, Wyoming. Research Note INT-333. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 11 p.

Cole, W. E.; McGregor, M. D. Estimating the rate and amount of tree loss from mountain pine beetle infestations. Research Paper INT-318. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 22 p.

Cole, W. E.; McGregor, M. D. Reducing/preventing mountain pine beetle outbreaks in lodgepole pine stands by selection cutting. In: Safranyik, Les and Alan Berryman, ed. The role of host-pest interaction in the population dynamics of forest insects: proceedings of the IUFRO Working Parties S2-07-05,06 symposium; 1983 September 4-7; Banff, Alberta, Canada; [in press].

Conn, J. E.; Borden, J. H.; Scott, B. E.; Friskie, L. M. Semiochemicals for the mountain pine beetle *Dendroctonus ponderosae* (Coleoptera: Scolytidae) in British Columbia: field trapping studies. Canadian Journal of Forest Research. 13: 320-324; 1983.

Coster, J. E. Developing integrated management strategies. In: Thatcher, R. C.; Searcy, J. L.; Coster, J. E.; Hertel, G. D. The southern pine beetle. Technical Bulletin 1631. Washington, DC: U.S. Department of Agriculture, Forest Service, Expanded Southern Pine Beetle Research and Application Program; 1980: 195-203.

Daubenmire, R. Vegetation: identification of typal communities. Science. 151: 291-298; 1966.

Daubenmire, R.; Daubenmire, J. B. Forest vegetation of eastern Washington and northern Idaho. Technical Bulletin 60. Pullman, WA: Washington Agricultural Experiment Station; 1968. 104 p.

Despain, D. G. Vegetation of the Bighorn Mountains of Wyoming in relation to substrate and climate. Ecological Monographs. 43: 329-355; 1973.

Edgerton, P. J. Big game use and habitat changes in a recently logged mixed conifer forest in northeastern

Oregon. In: Proceedings, Western Association of State Game and Fish Commissioners. 52: 239-246; 1972.

Edminster, C. B. RMYLD: computation of yield tables for even-aged and two-storied stands. Research Paper RM-199. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1978. 26 p.

Fischer, W. C.; Clayton, B. D. Fire ecology of Montana forest habitat types east of the Continental Divide. General Technical Report INT-141. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1982. 83 p.

Franklin, J. E.; Dyrness, C. T. Natural vegetation of Oregon and Washington. General Technical Report PNW-8. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1973. 417 p.

Freeman, W. L., Jr. Control planning and decision making. In: Scharf, R. F.; Parmeter, J. R., Jr., tech. eds. Proceedings of a symposium of dwarf mistletoe control through forest management; Berkeley, CA. General Technical Report PSW-31. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1978: 31-35.

Gibson, K.; Bennett, D. Effectiveness of Carbaryl in preventing attacks on lodgepole pine by the mountain pine beetle. Journal of Forestry. [In press].

Gilbert, S.; Shite, B.; Kong, R.; Dennee, B.; Dahlgren, G.; Gay, R. Decisions (agreements/disagreements): Gallatin National Forest plan. In: Meeting report: the proposed Northern Region plan. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region; 1980: 86-94.

Habeck, J. R.; Mutch, R. W. Forests and forestry. Yearbook of Science and Technology. New York: McGraw-Hill; 1975.

Hamel, D. R. Results of harvesting strategies for management of mountain pine beetle infestation in lodgepole pine on the Gallatin National Forest, Montana. In: Berryman, Alan A.; Amman, Gene D.; Stark, Ronald W., tech. eds. Theory and practice of mountain pine beetle management in lodgepole pine forests: symposium proceedings; 1978 April 25-27; Pullman, WA. Moscow, ID: University of Idaho, Forest, Wildlife and Range Experiment Station; 1978: 192-196.

Harper, J. A. Relations of elk to reforestation in the Pacific Northwest. In: Black, Hugh, ed. Wildlife and reforestation in the Pacific Northwest. Corvallis, OR: Oregon State University; 1969: 67-71.

Harper, J. A. Ecology of Roosevelt elk. Portland, OR: Oregon State Game Commission; 1971. 44 p.

Hatch, C. R. Effect of partial cutting in over-mature lodgepole pine. Research Note INT-66. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1967. 7 p.

Hawksworth, F. G. Dwarf mistletoe and its role in lodgepole pine ecosystems. In: Baumgartner, David A., ed. Management of lodgepole pine ecosystems: symposium proceedings; 1973 October 9-11; Pullman, WA. Pullman, WA: Washington State University, Cooperative Extension Service; 1975: 342-358.

Hawksworth, Frank G.; Hinds, T. E.; Johnson, D. W.; Landis, T. D. Silvicultural control of dwarf mistletoe in young lodgepole pine stands. Technical Report 122-10. Lakewood, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Region, Forest Insect and Disease Management; 1977. 12 p.

Hedden, Roy L. Hazard-rating system development and validation: an overview. In: Hedden, Roy L.; Barras, Stanley J.; Coster, Jack E. Hazard-rating systems in forest insect pest management: symposium proceedings; 1980 July 31-August 1; Athens, GA. General Technical Report WO-27. Washington, DC: U.S. Department of Agriculture, Forest Service; 1981: 9-12.

Hein, D. Management of lodgepole pine for birds. In: DeGraff [DeGraaf], Richard M., tech. coord. Workshop proceedings: management of western forests and grasslands for nongame birds; 1980 February 11-14; Salt Lake City, UT. General Technical Report INT-86. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1980: 238-247.

Hershey, T. J.; Leege, T. A. Influences of logging on elk on summer range in north-central Idaho. In: Hieb, Susan R., ed. Proceedings of the elk-logging-roads symposium; 1975 December 16-17; Moscow, ID. Moscow, ID: University of Idaho; 1976: 73-80.

Kirsh, J. B. Little Belt elk food habits and range use investigations. Job Completion Report W-9 8-R-2. Helena, MT: Montana Department of Fish, Wildlife, and Parks, Montana Fish and Game Department; 1962. 44 p. Multilith.

Leaf, Charles F. Watershed management in the Rocky Mountain subalpine zone: the status of our knowledge. Research Paper RM-137. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1975. 31 p.

Lemos, J. C.; Hines, W. W. Ecological study of Roosevelt elk. Job Progress Report W-70-R-4. Salem, OR: Oregon Wildlife Commission; 1974. 40 p.

Lindgren, B. S. A multiple funnel trap for scolytid beetles (Coleoptera). Canadian Entomologist. 115: 299-302; 1983.

Lindgren, S. Mountain pine beetle technical bulletin. Vancouver, BC: PMG/Stratford Projects Ltd.; 1983. 4 p.

Lonner, T. N.; Cada, J. D. Some effects of forest management on elk hunting opportunity. Paper presented at: Western States Elk Workshop, Arizona Fish and Game Department, Flagstaff, AZ; 1982.

Lorio, P. L., Jr. Developing stand risk classes for the southern pine beetle. Research Paper SO-114. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station; 1978. 16 p.

Lotan, J. E.; Perry, D. A. Ecology and regeneration of lodgepole pine. Agriculture Handbook 606. Washington, DC: U.S. Department of Agriculture, Forest Service; 1983. 51 p.

Lyon, L. J. Elk use as related to characteristics of clearcuts in western Montana. In: Hieb, Susan R., ed. Proceedings of the elk-logging-roads symposium; 1975 December 16-17; Moscow, ID. Moscow, ID: University of Idaho; 1976: 69-72.

Lyon, L. J. Habitat effectiveness for elk as influenced by roads and cover. Journal of Forestry. 77: 658-659; 1979.

Lyon, L. J.; Jensen, C. E. Management implications of elk and deer use of clearcuts in Montana. Journal of Wildlife Management. 44(2): 352-362; 1980.

Lyon, L. J.; O'Neill, T. A. Tests of elk guidelines: 1980 validation. Missoula, MT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1981. 4 p.

Mahoney, R. B. Lodgepole pine/mountain pine beetle risk classification methods and their application. In: Berryman, Alan A.; Amman, Gene D.; Stark, Ronald W., tech. eds. Theory and practice of mountain pine beetle management in lodgepole pine forests: symposium proceedings; 1978 April 25-27; Pullman, WA. Moscow, ID: University of Idaho, Forest, Wildlife and Range Experiment Station; 1978: 106-113.

McCambridge, W. F. Influence of low temperatures on attack, oviposition and larval development of mountain pine beetle, *Dendroctonus ponderosae* (Coleoptera: Scolytidae). Canadian Entomologist. 106: 979-984; 1974.

McGregor, M. D. Management of mountain pine beetle in lodgepole pine stands in the Rocky Mountain area. In: Berryman, Alan A.; Amman, Gene D.; Stark, Ronald W., tech. eds. Theory and practice of mountain pine beetle management in lodgepole pine forests: symposium proceedings; 1978 April 25-27; Pullman, WA. Moscow, ID: University of Idaho, Forest, Wildlife and Range Experiment Station; 1978: 129-139.

McGregor, M. D.; Amman, G. D.; Cole, W. E. Hazard-rating lodgepole pine for susceptibility to mountain pine beetle infestation. In: Hedden, Roy L.; Barras, Stanley J.; Coster, Jack E. Hazard-rating systems in forest insect pest management: symposium proceedings; 1980 July 31-August 1; Athens, GA. General Technical Report WO-27. Washington, DC: U.S. Department of Agriculture, Forest Service; 1981: 99-104.

McGregor, M. D.; Amman, G. D.; Schmitz, R. F.; Oakes, R. D. Silvicultural practices to reduce losses of lodgepole pine to mountain pine beetles. Canadian Journal of Forest Research. [In press].

Mealey, S. P.; Jonkel, C. J.; Demarchi, R. Habitat criteria for grizzly bear management. In: Proceedings XIIIth International Congress of Game Biologists. Washington, DC: Wildlife Management Institute; 1977; 12: 276-289.

Mitchell, R. G.; Waring, R. H.; Pitman, G. B. Thinning lodgepole pine increases the vigor and resistance to mountain pine beetle. Forest Science. 29(1): 204-211; 1983.

Montana Cooperative Elk-Logging Study. Progress report for the period, January 1-December 31, 1977. Annual Progress Report R-1. Missoula, MT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; Montana Department of Fish and Game; Bureau of Land Management; University of Montana, School of Forestry; 1978. 20 p.

Mutch, R. [Personal communication]. 1984. Author located at: Northern Region, Forest Service, U.S. Department of Agriculture, Missoula, MT.

Nijholt, W. W.; McMullen, L. H. Pine oil prevents mountain pine beetle attack in living lodgepole pine trees. Canadian Bi-Monthly Report. 36(2); 1980.

Nijholt, W. W.; McMullen, L. H.; Safranyik, L. Pine oil protects living trees from attack by three bark beetle species, *Dendroctonus* spp. [Coleoptera: Scolytidae]. Canadian Entomologist. 113: 337-340; 1981.

Peek, J. M.; Scott, M. D.; Pierce, D. J.; Erwin, L. L. Role of cover in habitat management for big game in the northwestern United States. In: Transactions of the North American Wildlife and Natural Resource Conference. 47: 363-373; 1983.

Pengelly, W. L. Clearcutting: detrimental aspects for wildlife resources. Journal of Soil and Water Conservation. 27(6): 225-258; 1972.

Perry, C.; Overly, R. Impact of roads on big game distribution in portions of the Blue Mountains of Washington, 1972-1973. Bulletin 11. Olympia, WA: Washington Game Department, Applied Research Section; 1977. 39 p.

Pfister, R. D.; Daubenmire, R. Ecology of lodgepole pine (*Pinus contorta* Dougl.). In: Baumgartner, David M., ed. Management of lodgepole pine ecosystems: symposium proceedings; 1973 October 9-11; Pullman, WA. Pullman, WA: Washington State University, Cooperative Extension Service; 1975: 27-46.

Pfister, R. D.; Kovalchik, B. L.; Arno, S. F.; Presby, R. C. Forest habitat types of Montana. General Technical Report INT-34. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1977. 174 p.

Rasmussen, L. A. Flight and attack behavior of mountain pine beetles in lodgepole pine of northern Utah and southern Idaho. Research Note INT-180. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1974. 7 p.

Reynolds, H. G. Use of natural openings in a ponderosa pine forest of Arizona by deer, elk, and cattle. Research Note RM-78. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1962. 4 p.

Reynolds, H. G. Use of natural openings in spruce-fir forests of Arizona by elk, deer, and cattle. Research Note RM-66. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1966. 4 p.

Ritchie, B. W. Ecology of moose in Fremont County, Idaho. Wildlife Bulletin No. 7. Boise, ID: Idaho Department of Fish and Game; 1978. 33 p.

Roe, A. L.; Amman, G. D. The mountain pine beetle in lodgepole pine forests. Research Paper INT-71. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1970. 23 p.

Rost, G. R.; Bailey, J. A. Distribution of mule deer and elk in relation to roads. Journal of Wildlife Management. 43: 634-641; 1979.

Rost, Maynard T. Comments on the mountain pine beetle/lodgepole pine symposium. In: Berryman, Alan A.; Amman, Gene D.; Stark, Ronald W., tech. eds. Theory and practice of mountain pine beetle management in lodgepole pine forests: symposium proceedings; 1978 April 25-27; Pullman, WA. Moscow, ID: University of Idaho, Forest, Wildlife and Range Experiment Station; 1978: 205-207.

Ruediger, W.; Mealey, S. Coordination guidelines for timber harvesting in grizzly bear habitat in northwestern Montana. Unpublished paper on file at: U.S. Department of Agriculture, Forest Service, Kootenai National Forest, Libby, MT; 1978. 44 p.

Safranyik, L. Effects of climate and weather on mountain pine beetle populations. In: Berryman, Alan A.; Amman, Gene D.; Stark, Ronald W., tech. eds. Theory and practice of mountain pine beetle management in lodgepole pine forests: symposium proceedings; 1978 April 25-27; Pullman, WA. Moscow, ID: University of Idaho, Forest, Wildlife and Range Experiment Station; 1978: 77-86.

Safranyik, L. Alternative solutions—preventive management and direct control. In: Shrimpton, D. M., ed. Proceedings of the joint Canada/USA workshop on mountain pine beetle related problems in western North America; 1981 November 3-4; Fairmont Hot Springs, BC. Information Report BC-X-230. Victoria, BC: Environment Canada, Canadian Forestry Service, Pacific Research Centre; 1982: 29-32.

Safranyik, L.; Shrimpton, D. M.; Whitney, H. S. Management of lodgepole pine to reduce losses from the mountain pine beetle. Technical Report 1. Victoria, BC: Canadian Department of the Environment, Forestry Service, Pacific Forest Research Centre; 1974. 24 p.

Safranyik, L.; Shrimpton, D. M.; Whitney, H. S. An interpretation of the interaction between lodgepole pine, the mountain pine beetle and its association with bluestain fungi in western Canada. In: Baumgartner, David M., ed. Management of lodgepole pine ecosystems: symposium proceedings; 1973 October 9-11; Pullman, WA. Pullman, WA: Washington State University, Cooperative Extension Service; 1975: 406-428.

Schenk, J. S.; Mahoney, R. L.; Moore, J. A. A model for hazard rating lodgepole pine stands for mortality by mountain pine beetle. Forest Ecology and Management. 3: 57-68; 1980.

Schladweiler, P. Moose ecology in southwestern Montana. Helena, MT: Montana Department of Fish, Wildlife, and Parks; 1973; Study No. 73.01 I0b, Final Report. 100 p.

Schmitz, R. [Personal communication]. 1984. Author located at: Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Ogden, UT.

Servheen, C. Grizzly bear ecology and management in the Mission Mountains, Montana. Missoula, MT: University of Montana; 1981. 138 p. Ph.D. thesis.

Shrimpton, D. M. Age- and size-related response of lodgepole pine to inoculation with *Europhium clavigerum*. Canadian Journal of Botany. 51: 1155-1160; 1973.

Shrimpton, D. M.; Thomson, A. J. Use of physiological maturity to identify hazard of lodgepole pine stands from mountain pine beetles. In: Hedden, Roy L.; Barras, Stanley J.; Coster, Jack E. Hazard-rating systems in forest insect pest management: symposium proceedings; 1980 July 31-August 1; Athens, GA. General Technical Report WO-27. Washington, DC: U.S. Department of Agriculture, Forest Service; 1981: 149-153.

Singer, Robert J.; Maloney, Ralph C. Nonpoint source control guidance for silviculture. Washington, DC: U.S. Environmental Protection Agency, Office of Water Planning and Standards; 1977. 28 p.

Smithers, L. A. Thinning in lodgepole pine stands in Alberta. Technical Note 52. Ottawa, Canada: Canada Department of Northern Affairs and Natural Resources, Forest Research Division; 1957. 26 p.

Stage, A. R. Prognosis model for stand development. Research Paper INT-137. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1973. 32 p.

Stage, A. R.; Long, G. E. Forest stand dynamics as a basis for integrated management of forest pests. In: Kibbee, D. L., ed. The bases for integrated pest management: proceedings 16th International Union of Forestry Research Organizations, group 6; 1976 June; Oslo, Norway. Moscow, ID: University of Idaho; 1976: 19-28.

Tackle, D. A preliminary stand classification for lodgepole pine in the Intermountain Region. Journal of Forestry. 53: 566-569; 1955.

Thomas, Jack Ward, ed. Wildlife habitats in managed forests—the Blue Mountains of Oregon and Washington. Agriculture Handbook 553. Washington, DC: U.S. Department of Agriculture; 1979. 512 p.

Thomas, J. W.; Maser, C.; Rodiek, J. E. Edges—their interspersion, resulting diversity and its measurement. In: DeGraaf, R. M., tech. coord. Proceedings of the workshop on nongame bird habitat management in the coniferous forests of the Western United States; 1977 February 7-19; Portland, OR. General Technical Report PNW-64. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1978: 91-100.

Umatilla National Forest. Lane-Peet Study Area, mountain pine beetle outbreak. Pendleton, OR: U.S. Department of Agriculture, Forest Service, Umatilla National Forest; 1974; Interdisciplinary Team Report. 63 p.

U.S. Department of Agriculture, Forest Service. Forest statistics of the United States by State and region, 1970. Washington, DC; 1972. 96 p.

U.S. Department of Agriculture, Forest Service. Northern Region plan. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region; 1980.

U.S. Department of Agriculture, Forest Service. Canada/United States mountain pine beetle executive summary. Washington, DC; 1983. 16 p.

Van Sickle, G. A.; Wegwitz, E. Silvicultural control of dwarf mistletoe in young lodgepole pine stands in Alberta and British Columbia. Information Report BC-X-180. Victoria, BC: Canadian Forestry Service, Pacific Forest Research Centre; 1978. 10 p.

Wallmo, O. C. Response of deer to alternate-strip clear-cutting of lodgepole pine and spruce-fir timber in Colorado. Research Note RM-141. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1969. 3 p.

Wallmo, O. C.; Schoen, J. Forest management for deer. In: Wallmo, O. C., ed. Mule and blacktailed deer of North America. Lincoln, NE: University of Nebraska Press; 1981: 434-438.

Ward, A. L. Elk behavior in relation to timber harvest operations and traffic on the Medicine Bow Range in south central Wyoming. In: Hieb, Susan R., ed. Proceedings of the elk-logging-roads symposium; 1975 December 16-17; Moscow, ID. Moscow, ID: University of Idaho; 1976: 32-43.

Waring, R. H.; Pitman, G. B. A simple model of host resistance to bark beetles. Research Note 65. Corvallis, OR: Oregon State University; 1980. 2 p.

Washburn, R. I.; Knopf, J. A. E. Mountain pine beetle conditions in the lodgepole pine stands of Forest Service, Region Four. 1959. Unpublished paper on file at: U.S. Department of Agriculture, Forest Service, Cooperative Forestry and Pest Management, Missoula, MT. 8 p.

Waters, W. E. Monitoring bark beetle populations and beetle-caused damage. In: Waters, W.E., R.W. Stark and D.L. Wood, eds. Integrated pest management in pine-bark beetle ecosystems. Wiley Interscience. New York: John Wiley and Sons, 1985: 141-175.

Wellner, C. A. Management problems resulting from mountain pine beetles in lodgepole pine forests. In: Berryman, Alan A.; Amman, Gene D.; Stark, Ronald W., tech. eds. Theory and practice of mountain pine beetle management in lodgepole pine forests: symposium proceedings; 1978 April 25-27; Pullman, WA. Moscow, ID: University of Idaho, Forest, Wildlife and Range Experiment Station; 1978: 9-15.

Wilson, G. Timber program review. Kalispell, MT: U.S. Department of Agriculture, Forest Service, Flathead National Forest; 1979. 3 p.