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Effects of the 1980s Western Spruce Budworm Outbreak on the Malheur National Forest in Northeastern Oregon

David C. Powell

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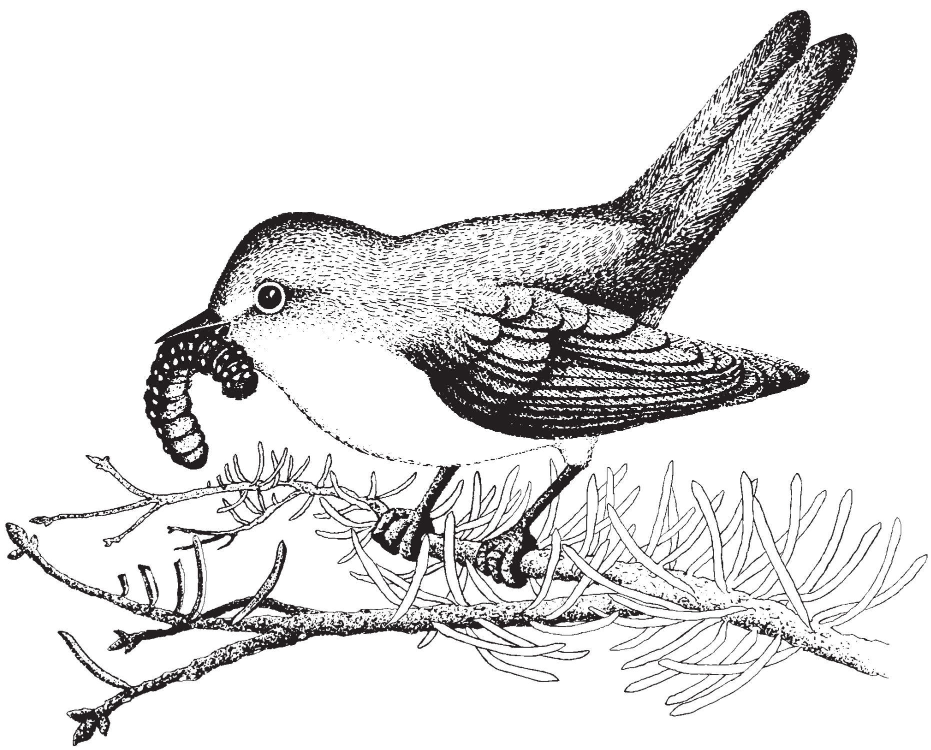

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Acknowledgments

Many people contributed to this project over the last 6 years. Tom Gregg, Bruce Hostetler, Beth Willhite, and Tim McConnell (Pacific Northwest Regional Office, Portland) provided advice, maps, and other assistance. John Teply (Pacific Northwest Regional Office, Portland) provided the original field cards and aerial photographs for each of the forest inventory plots that were remeasured to obtain budworm-impact information. Gene Paul (Forestry and Range Sciences Laboratory, La Grande) arranged for the interpretation of 942 increment cores that were used to analyze tree growth. George Taylor (Oregon State University, Corvallis) provided precipitation data and advice about its interpretation.

Wayne Long, retired Fire Management Officer for the Walla Walla Ranger District of the Umatilla National Forest, prepared the silvicultural drawings used for figures 72–81, as well as several other illustrations in this report.

Unless noted otherwise in the figure captions, all photographs were taken by the author or obtained from U.S. Forest Service photo files.

The report was significantly improved after reviews by Paul Flanagan, John Hazard, Bruce Hostetler, and Boyd Wickman.

And last, but certainly not least, I express my appreciation and gratitude for the patience and support provided by my wife Lori, and my family, especially when a 3-year project ended up taking 6 years.

The Author

DAVID C. POWELL was a silviculturist in the Supervisor's Office of the Malheur National Forest in John Day, Oregon from November 1987 to October 1991. He is currently Forest Silviculturist for the Umatilla National Forest in Pendleton, Oregon.

Cover Photo

The photograph shows a western spruce budworm moth on the foliage of a white fir in the Blue Mountains of northeastern Oregon.

Title Page Drawing

The drawing shows a ruby-crowned kinglet feeding on a spruce budworm larva. At least 26 bird species have been documented as budworm predators, but it's likely that more species than that play such a role. Mountain chickadees and red-breasted nuthatches are particularly important budworm predators in the Blue Mountains.

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Management Summary

This report describes a study to determine the effects of western spruce budworm defoliation on mixed-conifer forests in the south-central Blue Mountains (Malheur National Forest). Budworm populations reached outbreak levels in the early 1980s. The area defoliated by budworm feeding increased rapidly to a peak in 1986, and then declined dramatically in 1987.

Late in 1987, the Forest initiated a special project to determine: 1) how much tree damage occurred during the outbreak; 2) how budworm impacts were related to certain tree, stand, and site characteristics; and 3) how future timber yields will be affected by budworm impacts sustained between 1980 and 1989. This report describes the results of that project. It also provides a history of recent budworm outbreaks, and describes two management practices that contributed to the extent of the 1980s outbreak—fire suppression and selective harvesting.

During 1988 and 1989, remeasurements were completed for 130 inventory plots whose species composition in 1980 consisted of 50% or more budworm host trees (white fir, subalpine fir, Douglas-fir, Engelmann spruce, and western larch). In addition to typical inventory data, defoliation and topkill information was recorded for each host tree. Increment cores were collected from 942 trees and analyzed at a dendrochronology laboratory to obtain growth and age information.

Information about defoliation, topkill, and tree mortality was analyzed for these 17 factors: tree species, tree diameter, tree height, tree age, stand density, live crown ratio, crown class, site productivity, elevation, slope gradient, aspect, physiographic position, plant association, budworm host percentage, defoliation history, defoliation severity (1986–1989), and insecticide treatment history.

In addition to instances where budworm killed host trees directly, indirect mortality from bark beetles, dwarf mistletoe, and other causes was also examined. The effect of budworm defoliation on tree growth was evaluated using information from the increment cores. The potential effects of budworm-caused tree damage on future volume production were analyzed using the Blue Mountain Prognosis model.

Some of the results of this study were:

- Between 1936 and 1980, the area of mixed-conifer forest more than doubled, with a corresponding decline in the acreage of ponderosa pine forest. On average, each acre of mixed-conifer forest supported more budworm host trees in 1989 than it did in 1968, particularly for white fir. Those changes in forest composition, resulting primarily from wildfire suppression and historical harvesting practices, were an important reason for the magnitude of budworm defoliation between 1980 and 1990.

- The area of budworm-caused defoliation was about three times greater at the height of the 1980s outbreak than at a comparable point in the previous epidemic (1944–1958). Portions of the defoliated area were treated with insecticides during both outbreaks.

- Douglas-fir sustained more defoliation and mortality than white fir, although white fir had the most topkill. Other hosts (Engelmann spruce, subalpine fir, and western larch) comprised only 3.4% of the sampled trees; they had very little defoliation or topkill, and no budworm-induced mortality.

- Small trees, especially those in the overtopped and intermediate crown classes, had the most defoliation, topkill, and mortality.

- In 1982, 1983, 1985, and 1987, portions of the Malheur National Forest were treated with chemical or bacterial insecticides to suppress budworm populations. There were no significant differences between treated and untreated areas in the amount of budworm-caused defoliation, topkill, and mortality.

- Between 1980 and 1988–1989, tree mortality on the inventory plots increased from 6 to 21 percent, and much of the increase was due to budworm defoliation. Even after accounting for the increased mortality, tree density was still quite high in 1989, when it averaged over 1,200 live trees per acre for the mixed-conifer plots.

- Douglas-firs infected with dwarf mistletoe were apparently killed by spruce budworm more often than uninfected trees.

- Tree mortality caused by Douglas-fir beetles and fir engraver beetles increased during the late 1980s; analysis of precipitation records suggests that budworm-induced stress probably had a greater impact on bark-beetle activity than a presumed drought.

- The budworm-related radial growth reduction for 1989 alone was about 40%; cumulative growth reduction for the period of 1984–1989 was about 27%.

- In 1990, volume reductions attributable to budworm impacts ranged from 3.2 to 15.2 percent, varying by Forest Plan model component. Reductions for the model component occupying the greatest acreage (502) were a substantial 12.9 percent. Further analysis of computerized growth simulations showed that the 1980s budworm outbreak resulted in a loss of about 9 years of growth.

INTRODUCTION

Mixed-conifer forests are abundant in the Blue Mountains of northeastern Oregon and southeastern Washington (fig. 1). They provide wood products, forage, water, wildlife habitat, scenic beauty, recreational opportunities, and many other natural resources. It is uncertain if mixed-conifer forests can continue to supply those benefits in the near future because of recent impacts from insects and pathogens, particularly insects (fig. 2). Since 1980, nothing has affected the health and vigor of mixed-conifer forests more than an insect called the western spruce budworm (appendix 1 provides a list of scientific names for all organisms mentioned in this report).

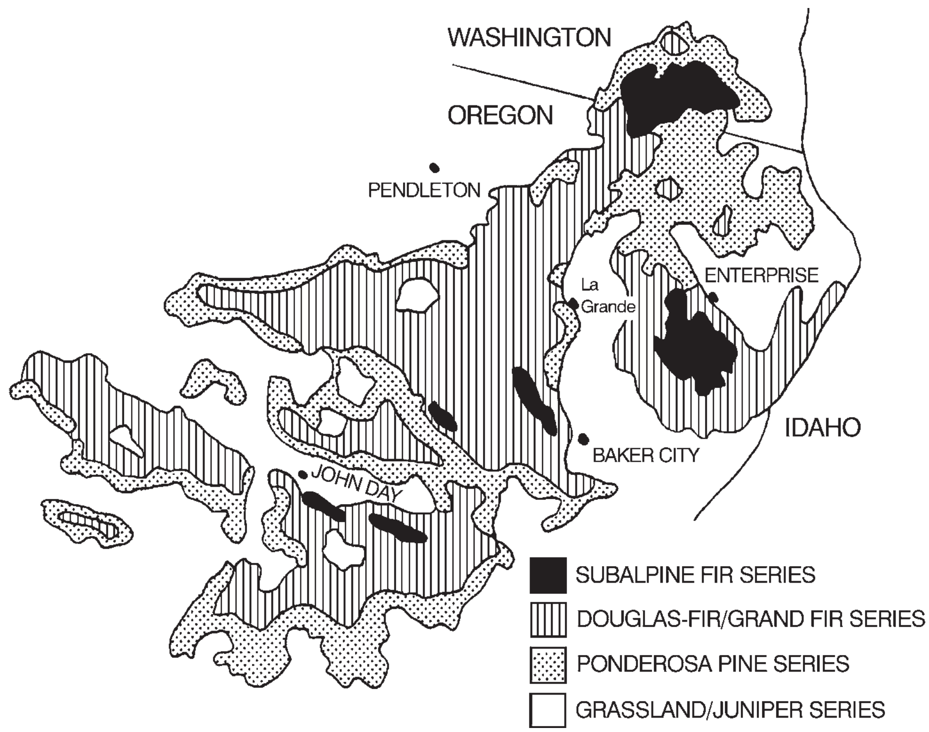
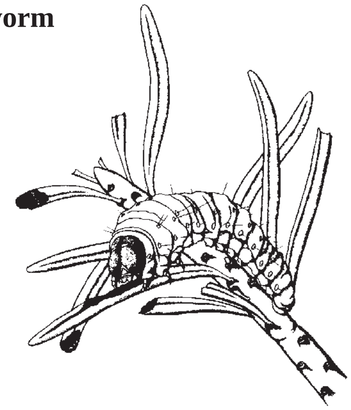


Figure 1—Distribution of climax forest types in the Blue Mountains. The Blue Mountains are a large ecoregion encompassing northeastern Oregon and adjacent parts of southeastern Washington and west-central Idaho (Omernik and Gallant 1986). Mixed-conifer forest (shown here as the Douglas-fir/grand fir series) is the most common vegetation type in the Blue Mountains. In presettlement times, many mixed-conifer sites supported forests of pine and larch because frequent fires prevented most of the grand firs and Douglas-firs from surviving. [Source: modified from Kuchler 1964.]

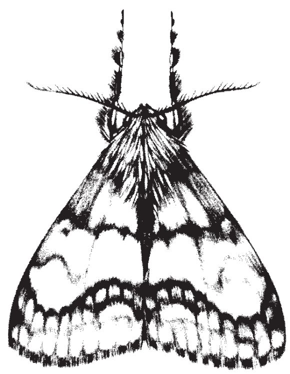
Evaluating Budworm Impacts

By the mid 1980s, budworm populations had reached unprecedented levels on the Malheur National Forest (NF), which is located in the south-central portion of the Blue Mountains (fig. 3). As it became apparent that the budworm outbreak was causing significant impacts in mixed-conifer forests, the Forest initiated a special project to determine the extent and severity of budworm damage.

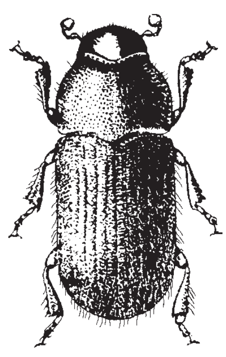
Western spruce budworm feeds on Douglas-fir, white fir, grand fir, subalpine fir, Engelmann spruce, and, to a limited extent, western larch. Adults are small grayish moths that lay eggs on the underside of conifer needles. Larvae tunnel into young needles and new buds, leaving a silken webbing behind. Outbreaks affected extensive areas on the Malheur NF, with more than 460,000 acres defoliated at the height of the 1944–1958 outbreak, and over 1.3 million acres defoliated in 1986 during the 1980s outbreak (see fig. 6).



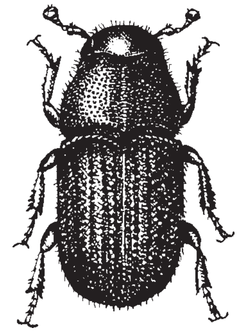
Douglas-fir tussock moth defoliates true firs and Douglas-fir from the top down, killing trees or setting them up for future attack by bark beetles. Outbreaks are cyclic—the Malheur NF was affected in 1937–39, 1947–48, 1963–65 (Wickman and others 1973), and 1992–93. The 1963–65 outbreak affected about 66,000 acres before being sprayed with DDT in June, 1965 (see fig. 6).



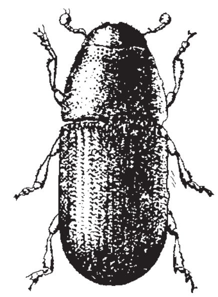
Douglas-fir beetle kills Douglas-firs by girdling them and introducing a blue-stain fungus. Trees weakened by fire, disease, drought, defoliation, or other stresses are especially vulnerable to attack. On the Malheur NF, Douglas-fir beetle caused considerable amounts of tree mortality on the heels of the 1980s budworm epidemic—more than 115,000 acres were affected in 1989 (see fig. 32).



Mountain pine beetle kills lodgepole, ponderosa, whitebark, and western white pines. It attacks by burrowing toward the tree's cambium. Healthy trees repel an attack by producing enough resin to wash the beetles out. In a successful attack, the beetle penetrates to the cambium within a few hours, where it introduces a blue-stain fungus that hitched its way there on the beetle's body. The blue-stain fungus eventually spreads throughout the sapwood and helps kill the tree. In the Blue Mountains, millions of overstocked lodgepoles were killed by mountain pine beetle between 1972 and 1978. On the Malheur NF, more than 110,000 acres were affected in 1989 (fig. 32).



Western pine beetle kills old ponderosa pines, especially those weakened by drought or dwarf mistletoe. In recent years, it has been attacking dense, second-growth ponderosa pines in the Blue Mountains. Like mountain pine beetle, this insect carries the blue-stain fungus. Western pine beetle sometimes reaches outbreak levels. A particularly severe outbreak occurred in the southern Blues in 1932, when entire stands up to 10 acres were killed, and losses of 15% or more of the stand volume occurred on extensive areas (Cowlin and others 1942, Weidman 1936). Outbreaks affected almost 10,000 acres on the Forest in 1988.



Fir engraver attacks white and subalpine firs that have been weakened by defoliation, drought, root disease, or other factors causing tree stress. These beetles caused extensive tree mortality on the Malheur NF in the late 1980s during a widespread budworm outbreak—more than 120,000 acres were affected in 1989 (see fig. 32).

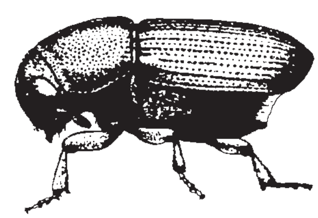


Figure 2—Important forest insects of the Blue Mountains in northeastern Oregon.

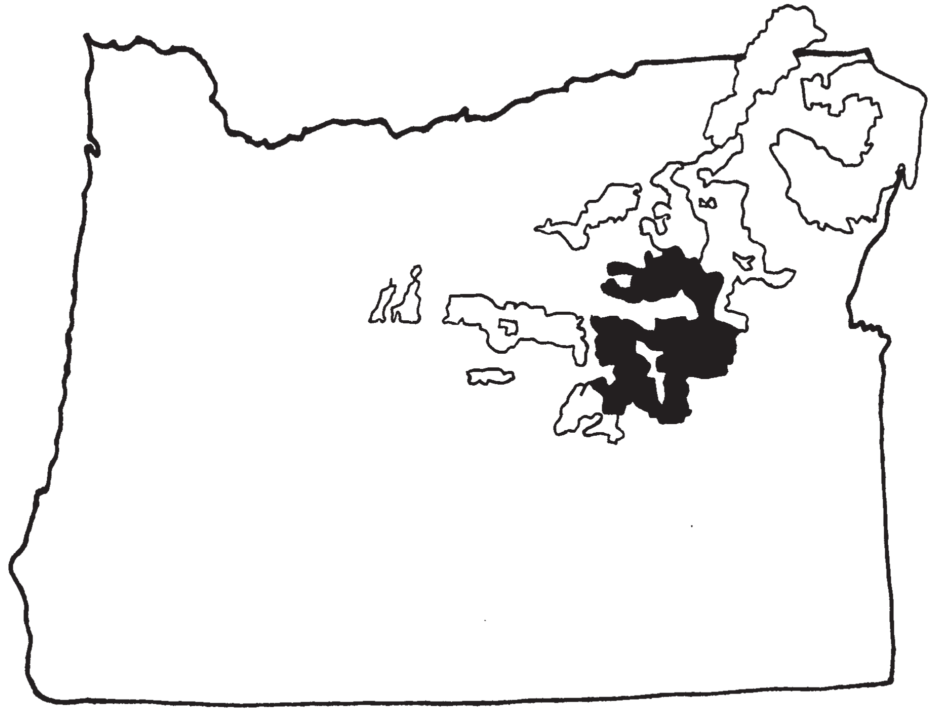


Figure 3—The Malheur National Forest (shaded in black) is one of four national forests located in the Blue and Ochoco Mountains of northeastern Oregon.

Special Project Objectives

The special project to evaluate budworm impacts had the following objectives.

- Describe the history of budworm outbreaks on the Malheur NF, and discuss how wildfire suppression and selective harvesting may have contributed to the severity of the recent outbreak.
- Describe the natural role that budworm plays in the forested ecosystems of the Blue Mountains.
- Determine the types and amounts of budworm-related tree damage that occurred during the recent outbreak (1980 to 1992).
- Describe how budworm impacts were related to certain tree, stand, and site characteristics such as crown class, tree age, and aspect.
- Determine if future timber yields will be affected by budworm impacts sustained between 1980 and 1989.
- Describe alternative approaches for avoiding or mitigating budworm impacts.
- Provide land managers with some supplemental information such as fire effects data for mixed-conifer forests, and summaries of important budworm literature.

An Historical Perspective on Budworm Outbreaks

> Those who cannot remember the past are condemned to repeat it. *George Santayana, American philosopher and poet*

Budworm is usually an unobtrusive inhabitant of mixed-conifer forests containing white fir or grand fir,* Douglas-fir, Engelmann spruce, or subalpine fir (fig. 4). But occasionally, after weather and other environmental conditions become ideal for its growth and survival, budworm populations explode in what is called an outbreak. When conditions are not favorable for rapid population increases, budworm is held in check by ants, birds, spiders, yellowjackets, and other natural enemies (Torgersen and others 1990). Forests comprised mostly of pines or western larch have little defoliation risk because those species are not fed upon by spruce budworm (fig. 5).

* *A note about white/grand fir*: The Malheur NF lies in a transitional zone between grand fir and white fir (Steinhoff 1978). Firs on the northern third of the Forest are primarily grand fir, while those on the southern part are either white fir, or a white fir/grand fir hybrid. Since most of the Forest has trees with white fir characteristics, land managers have traditionally referred to all low-elevation fir as white fir. I will do the same in this document.

Insect Detection Surveys

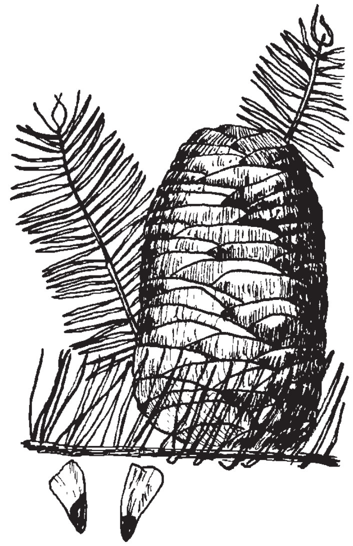
The Pacific Northwest Region of the U.S. Forest Service began monitoring the impacts caused by important forest insects in 1947, when the first aerial-detection survey was completed (Dolph 1980). An aerial sketch mapping program was initiated to provide information about a budworm outbreak that began in 1944. In 1947 and 1948, only the Blue Mountains and other areas with active budworm defoliation were surveyed. Beginning with the 1949 survey, all commercial forest land in both Oregon and Washington was sketch mapped, and the effect of insects other than budworm was also recorded (Whiteside 1956).

The Post-1980 Budworm Outbreak

The present budworm outbreak apparently began in 1980, when the Forest Service's annual insect survey identified 13 areas of defoliation in the Blue Mountains, one of which was located near the Middle Fork of Canyon Creek on the Malheur NF (McConnell and others 1980). It's also possible that budworm feeding was first noticed four years before then, when 380 acres of budworm defoliation were identified near Dixie Mountain on Long Creek Ranger District (Dolph 1980). It is unknown if the 1976 budworm mapping was ever verified on the ground; if the mapping was correct, then the 1976 aerial sketch map could have provided an "early warning" signal of an impending outbreak.

Douglas-fir is common at lower elevations of the mixed-conifer zone. It has short needles on small stalks (petioles); shiny, pointed, reddish-brown buds; and twigs with distinctive leaf scars where older needles used to be. Its cones hang downward and have three-pointed or "rat-tail" bracts poking out from between the scales. Douglas-fir has become much more common over the last 80 years as a result of fire suppression. Mature Douglas-firs resist fire due to their thick bark, but thin-barked poles and saplings are easily damaged by burning. Douglas-fir suffers considerable damage from budworm feeding, but is not preferred as much as white fir by that important defoliator.

White fir, grand fir, or a hybrid with characteristics between the two, is the most common tree species in mixed-conifer stands of the Malheur NF. It has flat or up-curved needles with white bands on both sides of the needle (white fir), or just the bottom side (grand fir). Its gray bark is thin and smooth on young trees, and has large blisters containing an aromatic, sticky resin called balsam. White fir, the favorite food of spruce budworm, has flourished in the fir stands that have encroached on ponderosa pine sites over the last 80 years. By controlling natural underburns, land managers were inadvertently swapping ponderosa pines and western larches for white firs and Douglas-firs.

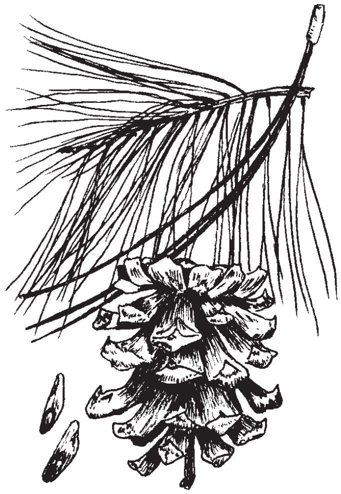


Engelmann spruce is uncommon in the low-elevation Blue Mountains. It has sharp, inch-long needles that are square in cross section; thin, scaly, orange or brown bark; and medium-sized cones with thin, papery scales. Although it resists rots and other diseases, Engelmann spruce is occasionally killed in great numbers by spruce beetles. Spruce beetle outbreaks are often triggered by windthrow that kills some of the larger trees in a stand. Although spruce suffers serious budworm damage in other areas of the West, that was not the case for remeasured inventory plots on the Malheur NF. None of the spruce trees on remeasured plots were killed by budworm, and few of them experienced serious topkill or defoliation.

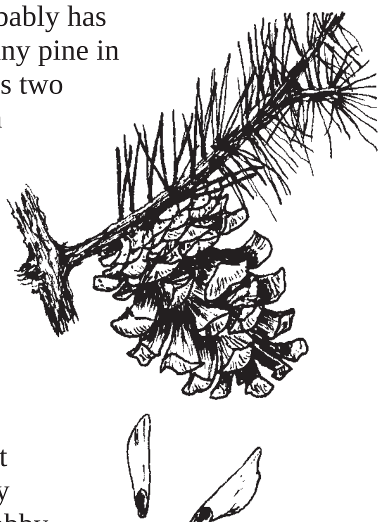
Subalpine fir is uncommon because very little of the Blue Mountains is high enough to support forests that are characteristic of the subalpine zone (see fig. 23). It has a slender, spirelike crown that sheds the heavy snows of the high country where it grows. Its needles are gray-green and are produced from all sides of the twig. The thin, gray bark also contains resin blisters like those of white fir. Its purplish cones are similar to those of other firs in that they are produced upright, rather than hanging down like most conifers. Although subalpine fir suffers serious budworm damage in other areas of the West, that was not true for remeasured inventory plots on the Malheur NF.

Figure 4—Common trees of the mixed-conifer zone that are hosts of the western spruce budworm.

Ponderosa pine is one of the most widely distributed conifers of western America. Its long, green needles occur in bundles (fascicles) of two or three. The woody, prickly cones are green when immature, and purplish or brown when mature. The bark is black on young trees ("blackjacks"), and an attractive yellow, orange, or cinnamon color on old trees ("yellowbarks"). Ponderosa pine depends on fire to clear away accumulations of needles and twigs so its seeds can find moist mineral soil, and to kill encroaching firs that prevent seedlings from getting the unobstructed sunlight they need. This valuable species grows especially well on warm, sunny slopes, even those at relatively low elevations.



Lodgepole pine probably has the widest range of any pine in North America. It has two short needles in each bundle, and gray or orange bark occurring as small, thin flakes. Lodgepole pine often regenerates after stand-replacing wildfires, when it forms dense, even-aged thickets. It has adapted to fire by producing small, knobby cones that require heat to open. The closed (serotinous) cones are not universal; their presence varies from area to area. This slender, short-lived tree is well adapted to disturbed sites, frost pockets, and other harsh environments. Lodgepole pine seedlings establish easily on the mineral soil seedbeds created by wildfire, prescribed burning, or timber harvesting.



Western white pine is not as common in the Blue Mountains as in the heart of its range—northern Idaho. It has slender, delicate needles produced in bundles of five. The cones are longer than those of ponderosa pine. Its bark is blackish, purplish, or cinnamon colored, and typically breaks up in a platy, checkerboard pattern. West-ern white pine is not plentiful today, chiefly because of losses from white pine blister rust and timber harvesting. It can be reestablished on suitable sites by planting rust-resistant stock.

Western larch helps define the lower Columbia River basin, an area encompassing western Montana, northern and central Idaho, eastern Washington, and northeastern Oregon. Its short needles occur in tufts of a dozen or more. Unlike most other conifers, this tree sheds all of its needles each fall after they turn a bright, lemon-yellow color. The small cones have short bracts protruding from between the scales. Larch is similar to ponderosa pine in that mature trees easily survive low-intensity fires, mostly because of their thick bark and high, sparse crowns. Although budworm does feed on western larch (Fellin and Schmidt 1973), it is not a preferred food source and larch is seldom considered to be a host species.

Figure 5—Common trees of the mixed-conifer zone that are not hosts of western spruce budworm.

The 1944–1958 Budworm Outbreak

The Blue Mountains have experienced two budworm outbreaks during the last 50 years—the present one that began in 1980, and an earlier outbreak which was discovered in its early stages on the Heppner Ranger District of the Umatilla National Forest in 1944 (Whiteside 1956). By 1945, it is likely that budworm-caused defoliation was also occurring on the Malheur and Wallowa–Whitman National Forests, although maps displaying the location of budworm damage were not available until 1947. On the Malheur NF, this previous outbreak was eventually controlled by a combination of natural factors and application of a chemical insecticide (DDT) in 1955 and 1958.

Early Budworm Outbreaks

Although detailed records are not available for periods before aerial sketch mapping began in 1947, some information does exist about older budworm outbreaks. Dolph (1980) noted that minor budworm defoliation was observed in central Oregon near Mitchell in 1931.

Wickman and others (1994) recently identified possible outbreaks by analyzing the ring patterns of host and nonhost trees growing on the same site. He inferred that a severe outbreak was present in the northern Blue Mountains between 1898 and 1909; other outbreaks apparently occurred during 1870–78, 1838–42, 1822–30, and 1775–1785. Outbreaks were also active during those same periods in northern New Mexico (Swetnam and Lynch 1993), which indicates that budworm fluctuations may have been synchronous over wide areas of the West.

Recent History of Defoliating Insects

Figure 6 summarizes the area affected by two important defoliators—western spruce budworm and Douglas-fir tussock moth. It shows that budworm was causing problems more than 30 years before the present outbreak began in 1980, and that the 1980s budworm outbreak affected considerably more area than the 1944–1958 epidemic.

Budworm Resurgence

The 1980s budworm outbreak has followed an unexpected pattern—it grew rapidly to a major peak in 1986, dropped to low levels from 1987 to 1989, and then climbed again in 1990–91 (fig. 6). The 1990–91 increase is referred to as a budworm resurgence, which is somewhat uncommon but has been observed in Canada and other areas of western North America (Blais 1962). Budworm defoliation dropped once again in 1992, and disappeared entirely in 1993. Although it is not certain yet, the precipitous decline in 1993 suggests that the budworm outbreak that began in 1980 may have finally come to an end.

Douglas-fir Tussock Moth

Cyclic outbreaks of Douglas-fir tussock moth are also common—portions of the Malheur NF were affected in 1937–39, 1947–48, and 1963–65 (Wickman and others 1973). Pheromone-trap surveys completed from 1990 to 1992 showed that tussock-moth populations were rising rapidly on some areas of the Forest (Willhite 1993), and new outbreaks began in 1992. By 1993, tussock-moth defoliation occurred on about 46,000 acres, primarily on the Burns Ranger District.

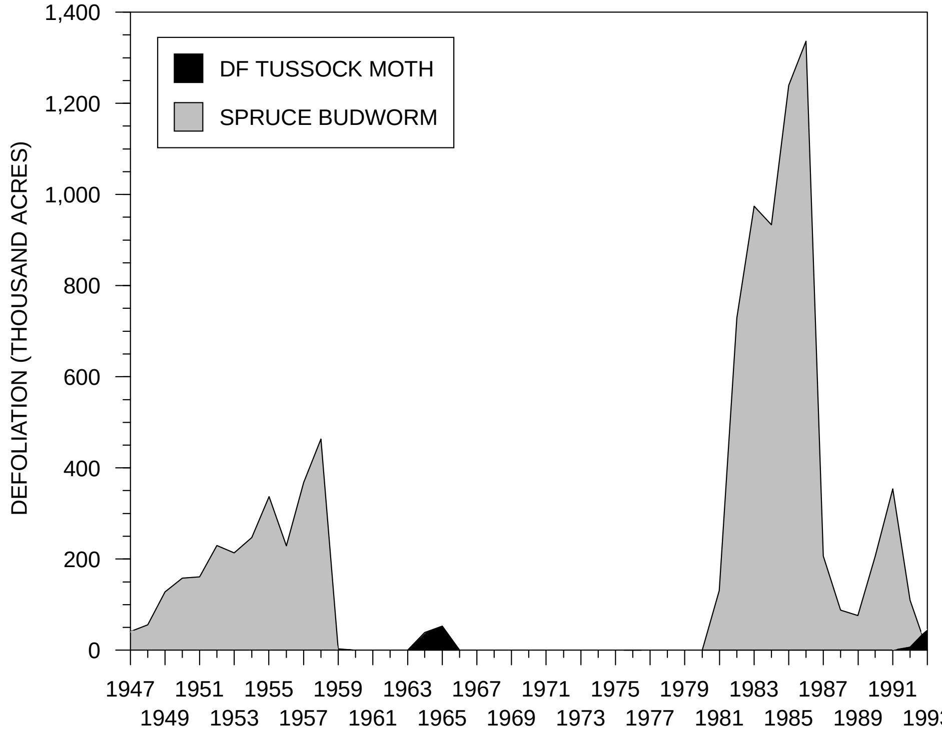


Figure 6—Area defoliated by western spruce budworm and Douglas-fir tussock moth on the Malheur NF, 1947–1993. The Blue Mountains have experienced two budworm outbreaks during the last 50 years—the present one that began in 1980, and an earlier outbreak that began in 1944 (Whiteside 1956). The 1980s budworm outbreak has followed an unexpected pattern—it grew rapidly to a major peak in 1986, dropped to low levels from 1987 to 1989, and then climbed again in 1990–91 during a period of budworm resurgence. Budworm defoliation dropped in 1992, and disappeared entirely in 1993. Although it's not certain yet, the precipitous decline in 1993 suggests that the recent budworm outbreak may have finally come to an end. Two tussock-moth outbreaks occurred during this period: a major one in the mid 1960s, and the present one that began in 1992. [Sources were Dolph (1980), and unpublished acreage summaries for aerial-sketch maps from 1980 to 1993.]

The 1963–1965 Tussock Moth Outbreak

A major tussock-moth outbreak occurred in the mid 1960s (see fig. 6) on the southern half of the Malheur NF and a small portion of the adjoining Ochoco National Forest. Mixed-conifer stands in the Silver Springs (Snow Mountain), Gold Hill, King Mountain, Antelope Mountain and Vance Creek areas were defoliated between 1963 and 1965. The outbreak collapsed after 65,945 acres were sprayed with DDT between June 10 and July 1, 1965 (Perkins and Dolph 1967).

When early explorers, missionaries, and emigrants first crossed the Blue Mountains in the middle part of the 1800s, they encountered a vegetation mosaic that reflected the long-term influence of fire. Many areas were dominated by open, parklike forests of ponderosa pine, often with a luxuriant undergrowth of tall grasses reaching as high as their horse's belly (fig. 7). Those attractive landscapes had been created and maintained by low-intensity surface fires (fig. 8) occurring at frequent intervals, usually every 8–20 years (Agee 1993, Anderson and others 1987, Cooper 1961, Franklin and Dyrness 1973, Hall 1977, Marouka 1993, Weaver 1947b).

Figure 7—An open pine stand with a grassy undergrowth. Pioneer journals (Evans 1990), early forestry surveys (Gannett 1902, Munger 1917), and fire history studies (Hall 1977) indicate that much of the Blue Mountains had presettlement forests resembling the area shown in this photograph. By suppressing underburns, land managers were inadvertently allowing many of these areas of open pine (typically referred to as "parklike pine") to be replaced with white firs, Douglas-firs, and other budworm host trees.

Distribution of Parklike Pine

The Blue Mountains did not have a monopoly on open, parklike pine; it was present in almost every forested region of the western United States, including northeastern California (Laudenslayer and others 1989), western Montana (Gruell and others 1982, Habeck 1990), central Idaho (Brock and Brock 1993), Colorado's Front Range (Marr 1967, Veblen and Lorenz 1991), and Arizona and New Mexico (Woolsey 1911). Fire was an important ecological process in areas with parklike pine; for example, fires in California's presettlement pine type occurred about every 8 years between 1685 and 1889 (Show and Kotok 1924).

Figure 8—A low-intensity prescribed fire burning at night. Underburning was an important ecological process for sustaining open, parklike stands of ponderosa pine. Underburns were slowly-spreading fires with short flame heights (less than 3 feet) that consumed dried grass, needles, twigs, downed trees, and underbrush. They were often started by lightning, although native American ignitions were important too. Underburns favored the thick-barked ponderosa pines and western larches, while discriminating against the thin-barked white firs and Douglas-firs (Agee 1993, Hall 1977, Maruoka 1993). In the early 1990s, Bob Mutch and other fire scientists recommended that prescribed fire use be increased tenfold as an option for addressing forest health concerns in the Blue Mountains (Mutch and others 1993). But proposals to greatly expand use of prescribed fire raised concerns about protection of snags and down wood, causing mechanical treatments to also be considered.

Native American Burning

Although some of the underburns were started by lightning storms in mid or late summer (Plummer 1912), many others were ignited by native Americans (Cooper 1961, Johnston 1970, Robbins and Wolf 1994). When analyzing early journals from the western U.S., Gruell (1985) found that over 40 percent of the fires were described as being started by native Americans.

Recent studies concluded that native Americans were far from passive hunters and gatherers, as they were so often depicted in western novels and movies. Their activities had a major influence on the structure and composition of western vegetation. For example, they used hundreds of plants and animals for food, fiber, shelter, forage, and medicine. Fire was often their main tool for creating and maintaining the habitats needed by those species (Martinez 1993).

Harvesting Food With Fire

Fire was used by native Americans to harvest food crops, to clear brush for improved hunting access, and for entertainment. An example is that Oregon Indians used smoke to harvest pandora moths infesting pine forests—the caterpillars would drop from the trees to the ground and were then gathered for food (Pyne 1982). [It is interesting that most of the life stages of this insect were used for food—the Klamath and Modoc tribes dug up the pupae (called "bull quanch"), whereas the Piute tribe gathered and dried the mature caterpillars and combined them with vegetables in a stew-like dish called "peage" (Patterson 1929).]

Piute Forestry

The importance of native American burning was frequently noted in early Forest Service reports about western forests; the following excerpt is a good example (Meinecke 1916).

> ...the assumption is that our forests today, having been untouched by man and exposed to the same factors of their surroundings since times immemorial, must represent more or less exactly the same character they had 100 or 1,000 years ago. But we have practically no genuinely virgin forests; in the great majority of commercial accessible stands, man has for centuries practiced some kind of primitive forestry by setting fires. This "Piute forestry" has changed the aspect of many stands so completely that the term "virgin forests" is far from being correctly applied. At best, one can speak of scattered virgin stands here and there.

Declining Native American Use of Fire

It is possible that Blue Mountain forests may have been more "primeval" at the time of white settlement than they were previously. When Columbus landed in 1492, it is estimated that North America (exclusive of Mexico and central America) supported at least 3.8 million native Americans. By 1800, their numbers had been reduced to a million or less by measles, smallpox, cholera, influenza, and other European diseases (Denevan 1992). Even though their populations were declining, native Americans may have expanded their use of fire in the early 1700s to promote forage for the horses that they had just acquired for the first time (Mosgrove 1980).

Interpreting Historical Accounts

The effects of fire were occasionally described in the journals of early Euro-American explorers, missionaries, and emigrants. When reviewing their journal accounts, some of which are provided on the next three pages, it is important to consider them in an appropriate context (Forman and Russell 1983).

Many of the journals were written during a period with environmental conditions particularly conducive to fires. For example, eastern Oregon underwent a severe drought from 1839 to 1854 (Keen 1937), when early Oregon Trail emigration occurred and many journals were written. It is likely that fires were more prevalent during that dry period. By 1861, however, weather conditions had moderated and eastern Oregon experienced a particularly wet year, resulting in extensive flooding.

Early Journal Accounts

Portions of many early journals are contained in a recent book entitled *Powerful Rockey: The Blue Mountains and the Oregon Trail, 1811–1883* (Evans 1990). Some passages from *Powerful Rockey* that describe fire and vegetation are provided below; any misspellings or punctuation errors from the original journals are retained in the excerpts.

> ...the grass has been lately consumed, and many of the trees blasted by the ravaging fire of the Indians. These fires are yet smouldering, and the smoke from them effectually prevents our viewing the surrounding country, and completely obscures the beams of the sun.
> *Journal of John Kirk Townsend, August 31, 1834*.

Townsend's journal was one of several that described the effect of fires started by native Americans.

> They [mountains] are mostly covered with high bunch grass, which at this season is quite dry. This often gets on fire, burning for miles and days together. One of these burnings is in sight of us today. It is on the opposite side of the river from us, or I should feel alarmed. The fire in the mountains last night was truly grand. It went to the tops of them spreading far down their sides. We were obliged to go over after our cattle at dark and bring them across the stream. The fire extended for several miles, burning all night, throwing out great streamers of red against the night sky. This morning there is none visible.
> *Journal of Esther Hanna, August 15-16, 1852*.

Hanna's comments illustrate how far-reaching the fires were, and how fast they moved when burning through bunchgrass and other fine fuels.

> After dinner, when we had ascended the first hill, we looked back upon the country we had passed through. I can almost say I never saw anything more beautiful, the river winding about through the ravines, the forests so different from anything I have seen before. The country all through is burnt over, so often there is not the least underbrush, but the grass grows thick and beautiful. It is now ripe and yellow and in the spaces between the groves (which are large and many) looks like fields of grain ripened, ready for the harvest.
> *Journal of Rebecca Ketcham, September 6, 1853*.

Ketcham's journal eloquently describes the open, grassy, pine stands that were apparently quite common during presettlement times (fig. 7).

> Came to trees, at first quite thin & without underbrush having fine grass. But as we arose we came to a densly timbered country, mostly pine & fir. The most beautiful tall straight trees. Our traviling through the timber was quite difficult as the path wound back and forth and many logs lay across it.
> *Journal of Medorem Crawford, September 12, 1842*.

Crawford's observations demonstrate that the Blue Mountains supported more than just open pine stands.

Captain Fremont Describes Blue Mountain Forests in 1843

Captain John C. Fremont surveyed the Oregon Trail in the northern Blue Mountains during fall of 1843. His journals provide detailed information about Blue Mountains vegetation, although his tree names are confusing. (His European larch was actually western larch; his balsam pine was probably grand fir; and his white spruce was undoubtedly Engelmann spruce.) It is interesting that he found larch to be abundant; the same statement would not be true today for most of the Blue Mountains.

Fremont's journals are also valuable because they provide quantified information about tree dimensions—his journal entry for October 20th mentioned that tree diameters averaged 38 to 46 inches, with pines occasionally reaching 80 inches in diameter. Excerpts from his journal for 3 days in October of 1843 are provided below.

> ...the mountains here are densely covered with tall and handsome trees; and, mingled with the green of a variety of pines, is the yellow of the European larch (*pinus larix*), which loses its leaves in the fall. From its present color, we were enabled to see that it forms a large proportion of the forests on the mountains, and is here a magnificent tree, attaining sometimes the height of 200 feet, which I believe is elsewhere unknown. [October 17, 1843.]
>
> ...we made an early start, continuing our route among the pines, which were more dense than yesterday, and still retained their magnificent size. The larches cluster together in masses on the sides of the mountains, and their yellow foliage contrasts handsomely with the green of the balsam and other pines. After a few miles we ceased to see any pines, and the timber consisted of several varieties of spruce, larch, and balsam pine, which have a regular conical figure. These trees appeared from 60 to nearly 200 feet in height; the usual circumference being 10 to 12 feet, and in the pines sometimes 21 feet. In open places near the summit, these trees become less high and more branching, the conical form having a greater base. [October 20, 1843.]
>
> We continued to travel through the forest, in which the road was rendered difficult by fallen trunks, and obstructed by many small trees, which it was necessary to cut down. Some of the white spruces which I measured today were twelve feet in circumference, and one of the larches ten; but eight feet was the average circumference of those measured along the road. I held in my hand a tape line as I walked along, in order to form some correct idea of the size of the timber. Their height appeared to be from 100 to 180, and perhaps 200 feet, and the trunks of the larches were sometimes 100 feet without a limb; but the white spruces were generally covered with branches nearly to the root. All these trees have their branches, particularly the lower ones, declining. [October 21, 1843.]
> *Journal of Captain John Charles Fremont, October 17-21, 1843*.

How the Blue Mountains Got Their Name

It is widely believed that the Blue Mountains were named for the bluish haze which enveloped them during late summer and fall, when fires were burning (Mutch and others 1993). The two journal entries below (Beckham 1991, Evans 1990) speculate that their name commemorates the color imparted by extensive pine stands. In either case, fire was an important reason for the name because it was not only responsible for smoke, but also for the pine forests that would have been rare without underburning.

> It is probable that they have received their name of the Blue mountains from the dark-blue appearance given to them by the pines.
> *Journal of Captain John Charles Fremont, October 17, 1843*.

> I presume these mountains take their name from their dark blue appearance being densely timbered with pine timber, which being ever green gives the forest a sombre appearance, besides the limbs of the trees are all draped with long festoons of dark colored moss or mistletoe.
> *Journal of John or David Dinwiddie, August 30, 1853*.

Early Forest Surveys

Early surveys can provide valuable clues about presettlement conditions, although the surveys were not well quantified. General statements such as “the forest floor is open, free from underbrush in any quantity, so much so that it is possible to ride in almost any direction through the forest without following trails” (Foster 1908) were common in early surveys. Several early surveys are described next.

1900-Era Forest Survey

The Geological Survey examined Oregon’s forests almost a hundred years ago. At the time of their survey, federal Forest Reserves were administered by the Department of Interior; the U.S. Forest Service had not been created yet. The survey found Grant County to be 45% forested, with a total timber volume of 2.37 billion board feet and an average volume of 2,800 board feet per acre. Harney County was only 4% forested, with a total timber volume of 336 million board feet and an average volume of 1,300 board feet per acre. All of the timber volume for both counties was shown as western yellow (ponderosa) pine. Fire’s effect on vegetation was clearly recognized during the survey, as described in the following passage (Gannett 1902).

> ...the burns are greatest and most frequent in the most moist and most heavily timbered parts of the State, and are smaller and fewer where the rainfall is less and where the timber is lighter. This is owing to the density and abundance of the undergrowth in the heavily forested regions, which feeds the fire and vastly increases its heat. In the comparatively sparsely timbered southern portions of the Coast Range and the Cascades and in the Blue Mountains, where the forests are largely or mainly of yellow pine in open growth, with very little litter or underbrush, destructive fires have been few and small, although throughout these regions there are few trees which are not marked by fire, without, however, doing them any serious damage.

Oregon's Ponderosa Pine Forests in 1910–1911

The first comprehensive study of Oregon's ponderosa pine forests was completed between 1910 and 1915 by the U.S. Forest Service (Munger 1917). The study found that more than 71 billion board feet of pine occurred on about 10 million acres of commercial forest land (see map in top half of fig. 14). The total area of ponderosa pine in Oregon, including noncommercial stands, was about 14 million acres, almost a quarter of the State and half of its forested land (Donk and others 1921).

Blue Mountains Ponderosa Pine in 1910–1911

Oregon's largest concentration of ponderosa pine was in the Blue Mountains; they had 42.7% of the commercial acreage and 43.9% of the volume. Grant County ranked fourth of Oregon's counties—about 8.2 billion board feet of pine was present on about 1.2 million acres. Munger's study also examined fire history, stand conditions, insect and disease impacts, and a variety of other topics. The following excerpts from his report describe stand conditions and fire effects in ponderosa pine forests of the Blue Mountains (Munger 1917).

> In most of the pure yellow-pine forests of the State the trees are spaced rather widely, the ground is fairly free from underbrush and debris, and travel through them on foot or horseback is interrupted only by occasional patches of saplings and fallen trees. The forests are usually not solid and continuous for great distances, except along the eastern base of the Cascades, but are broken by treeless "scabrock ridges," or natural meadows.
>
> In the Blue Mountains the herbage is rather more luxuriant and varied than on the eastern slopes of the Cascades and their outstanding ranges. In the early summer the open yellow-pine forests are as green with fresh herbage as a lawn, except here and there where the green is tinged with patches of yellow or purple flowers. Some of this luxuriant herbage is pine grass (*Calamagrostis* sp.), a plant which is not eaten by stock except very early in the season; but much of the ground cover makes excellent range for cattle and sheep.
>
> In the Blue Mountains western larch (*Larix occidentalis*) is its [western yellow pine] usual companion and grows with it in an intimate and harmonious mixture. In the moister situations white fir (*Abies concolor*) is a common associate, as is also Douglas fir (*Pseudotsuga taxifolia*) in most parts of the State. In the Blue Mountains it is common for the south slopes to be covered with a fine stand of yellow pine, while the north slopes are covered almost entirely with larch, white fir, and Douglas fir.
>
> In the Blue Mountains the reproduction of yellow pine is very abundant, both in the virgin forest and after cuttings. Perhaps it is more prolific here than anywhere else. In this region where an area has not been burned over by a surface fire for a number of years, there is quite commonly a veritable thicket of little trees from a few inches to several feet high. Actual counts have shown that there are sometimes 14,000 seedlings on a single acre, the ages ranging from 13 to 21 years.

In pure, fully stocked stands in the Blue Mountains region there are commonly from 20 to 30 yellow pines per acre over 12 inches in diameter, of which but few are over 30 inches. Over large areas the average number per acre is ordinarily less than 20. In mixed stands the number of yellow pines of merchantable size is naturally less, though the total number of trees of all species is as a rule larger, the moist soil on which the mixed forest grows being able to carry a denser stand.

Yellow pine grows commonly in many-aged stands; i.e., trees of all ages from seedlings to 500-year-old veterans, with every age gradation between, are found in intimate mixture. Usually two or three or more trees of a certain age are found in a small group by themselves, the reason being that a group of many young trees usually starts in the gap which a large one makes when it dies.

Light, slowly spreading fires that form a blaze not more than 2 or 3 feet high and that burn chiefly the dry grass, needles, and underbrush start freely in yellow-pine forests, because for several months each summer the surface litter is dry enough to burn readily. Practically every acre of virgin yellow-pine timberland in central and eastern Oregon has been run over by fire during the lifetime of the present forest, and much of it has been repeatedly scourged. It is sometimes supposed that these light surface fires, which have in the past run through the yellow-pine forests periodically, do no damage to the timber, but that they "protect" it from possible severe conflagrations by burning up the surface debris before it accumulates. This is a mistake. These repeated fires, no matter how light, do in the aggregate an enormous amount of damage to yellow-pine forests, not alone to the young trees, but to the present mature merchantable timber.

A careful cruise of every tree on 154.5 sample acres in typical yellow-pine stands in several localities in the Blue Mountains showed that 42 out of every 100 trees were fire-scarred.

Ordinarily, a fire in yellow-pine woods is comparatively easy to check. Its advance under usual conditions may be stopped by patrolmen on a fire line a foot or so wide, either with or without backfiring. The open character of the woods makes the construction of fire lines relatively easy, and in many places horses may be used to plow them.

Malheur NF Ponderosa Pine in 1906

The Malheur NF had extensive areas supporting open stands of ponderosa pine, possibly some of the finest pine stands in the western United States (Erickson 1906):

The forest in the region south of the Strawberry range that bears excellent yellow pine and tamarack covers approximately 800,000 acres. The yellow pine is more abundant and is found in more suitable situations on this reserve than I have seen its occurrence in any other part of Oregon. It grows tall and straight, maintains a uniform taper, and furnishes a large percentage of clear length. Trees thirty to fifty inches in diameter, with height of 150 feet, are not uncommon.

Fire’s Impact on Pine Forests

Two of the studies described earlier illustrate the differing perceptions of fire’s role in ponderosa pine forests. Gannett (1902) surveyed the federal forests before they were viewed as a source of commodities; he found many trees with fire scars (fig. 9), although fire had not done “them any serious damage.” Munger (1917) also found few stands without some sign of fire’s influence, but he viewed fire as a scourge which caused an “enormous amount of damage to yellow-pine forests.” Munger’s comments reflect the commodity orientation of his era; yellow pine forests were to be managed as a sustainable source of valuable wood products, and fire was perceived as little more than an obstacle to reaching that goal.

Figure 9—Many ponderosa pines have basal scars caused by underburning, which was common before wildfire suppression efforts began around 1910. Ponderosa pine is well adapted to handle the effects of low-intensity fire. At a diameter of about 2 inches, it begins to develop a fire-resistant bark with a dead outer layer that insulates the sensitive cambium tissues from heat.

Fire As A Cause of Forest Damage

Munger's (1917) opinion of fire's role in ponderosa pine forests was shared by other investigators working in the western United States, as demonstrated by the following passage from *The Role of Fire in the California Pine Forests* (Show and Kotok 1924).

> Physical conditions in the pine forests of California have led to the frequent recurrence of fires for centuries, but the fact that magnificent forests still cover large areas and give the appearance of well-stocked, vigorous stands has blinded the public to the harm that fires have done and are steadily working throughout the whole region. Were it possible for the observer to visualize the entire area on which pine has grown, and to behold it truly fully stocked, he would then see by comparison that the present California pine forests represent broken, patchy, understocked stands, worn down by the attrition of repeated light fires.

Malheur NF Fire History

Fire suppression efforts began immediately after creation of the Malheur NF in 1908. During the first decade of its existence, several large burns occurred on the Forest (fig. 10). In 1910, a bad fire year throughout the western U.S., a total of 28,769 acres burned. Another 10,637 acres burned in 1915, followed by 30,828 acres in 1919. The next two decades had few large fires. But in 1939, following a severe drought in the mid 1930s, 10,734 acres burned (USDA Forest Service 1961).

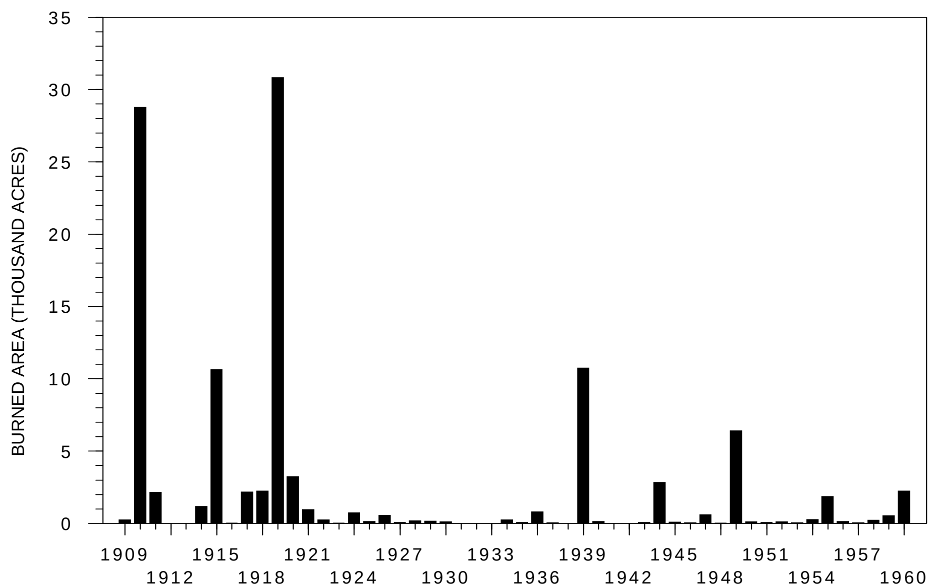


Figure 10—Burned area on the Malheur NF, showing acreage burned by wildfire between 1909 and 1960. [Source was USDA Forest Service 1961.]

Fires During Euro-American Settlement

Large fires were common during settlement of the Pacific Northwest. Many fires were set by the emigrants, either accidentally or intentionally. Miners often set fires to clear away brush and forest debris, thereby exposing rock outcrops for inspection by prospectors (Veblen and Lorenz 1991). Correspondence from a northern California national forest indicates that some early fires were started by livestock permittees to remove brush and promote grass growth (Harley 1918).

Effect of Sheep Grazing on Fire Spread and Intensity

Even though emigrants caused some fires, they also contributed to conditions that limited fire intensity and spread. For instance, immense bands of sheep grazed in the Blue Mountains during the latter part of the nineteenth century, which caused enduring changes in the vegetative composition (Coville 1898, Tucker 1940).

An early survey of sheep ranges found moist mountain meadows that were entirely devoid of vegetation and experiencing severe soil erosion. A complete collection of the plants growing in a heavily-grazed meadow found not a single perennial species, and no annuals exceeding 2 inches in height. Few shrubs other than snowbrush ceanothus had not been damaged by sheep browsing; even the small ponderosa pines were fed upon (Griffiths 1903).

After sheep removed most of the herbaceous vegetation from beneath forest stands, it was very difficult for fires to spread through them. That was particularly true for open stands of ponderosa pine because herbaceous vegetation was an important fuel component.

Underburning in Danger of Extinction

Natural underburns are now endangered or extinct following a long period of fire suppression. Land managers responded to wildfire with an arsenal of slurry “bombers,” mountaintop fire lookouts, aerial reconaissance flights, radar-assisted lightning detectors, and crews of elite smokejumpers and specially-trained “hotshot” firefighters. In many respects, fire suppression has been effective enough to be considered the most successful program in the U.S. Forest Service’s history.

Changes in Forest Resiliency

Many land managers would agree that wildfire suppression was a policy with good intentions, but it was a policy that failed to consider the ecological implications of a major shift in species composition. White firs and Douglas-firs can get established under ponderosa pines in the absence of underburning, but they may not have enough resiliency to make it over the long run, let alone survive the next drought. This means that many of the mixed-conifer stands that have replaced ponderosa pine are destined to become weak, and weak forests are susceptible to insect and disease outbreaks (Hessburg and others 1994).

Changes in Insect and Disease Susceptibility

By controlling natural underburns, land managers allowed fire-resistant pines and larches to be replaced with shade-tolerant, late-successional species. Many of the replacement species are susceptible to the effects of western spruce budworm, Douglas-fir tussock moth, Indian paint fungus, Armillaria root disease, and other insects and pathogens.

Indian paint fungus, a widespread pathogen of true firs in the Blue Mountains (Seidel and Beebe 1983, Filip and Schmitt 1990), can cause substantial amounts of tree decay (fig. 11). The budworm susceptibility for major tree species of mixed-conifer forests is apparently related to their shade tolerance and successional status (Table 1).

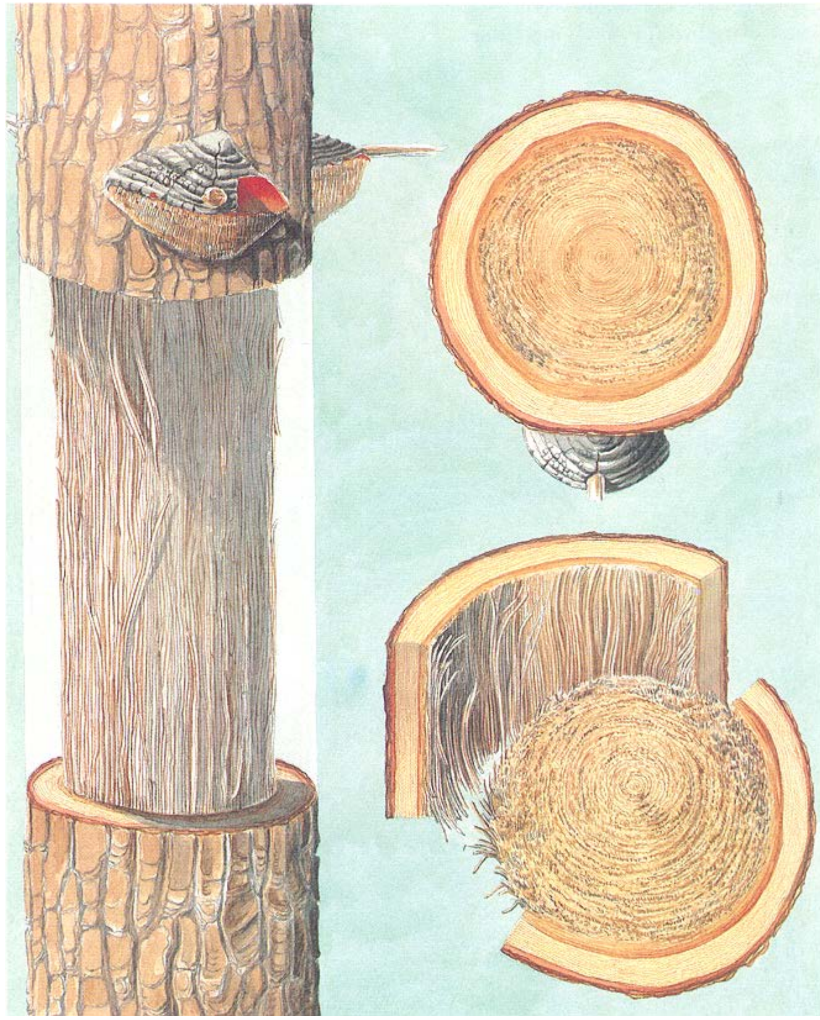


Figure 11—Decay in a conifer tree caused by Indian paint fungus. Indian paint fungus is a common pathogen of older white fir trees in the Blue Mountains. The fungus usually enters the trunk after a long growth period in a dying branch. When many branches die at about the same time, the fungus may convert the entire central column of the trunk into a stringy, fibrous mass of decayed material.

Plant Succession in Pine–Fir Forests

The successional roles of ponderosa pine and white fir were recognized by early silvicultural researchers, as explained in the following comments about pine–fir forests of the Sierra Nevada mountains in central California (Dunning 1923).

> Where natural conditions of site favor white fir, this species is destined to succeed yellow pine unless the normal succession is disturbed by fire or other accidents. Fir seeds germinate more abundantly than pine under stands of yellow pine, whose litter and shade exclude their own seedlings, and the young [fir] trees endure suppression longer. Moreover, height growth of fir is more rapid, and the total height attained is greater than for yellow pine. In the past occasional fires have been primarily responsible for sustaining yellow pine on fir sites. Fir seedlings and young trees are far more susceptible to fire damage than the pine because of their thinner bark

with balsam cysts, more inflammable foliage, and small resinous terminal buds which are far less resistant than those of yellow pine. The fir is more often eliminated by fungi entering through fire scars than is pine. Exposure of mineral soil and openings created by fire favor yellow pine. Striking examples of the succession of white fir with fire exclusion may be seen in many places, where the mature stand is composed of practically pure yellow pine, while the reproduction beneath it is over 90 per cent white fir.

Table 1—Shade tolerance, successional status, and budworm susceptibility ratings for trees of mixed-conifer forests in the Blue Mountains.

SHADE TOLERANCE	SUCCESSIONAL STATUS	BUDWORM SUSCEPTIBILITY
Subalpine Fir (most)	Subalpine Fir (latest)	White/Grand Fir (most)
White/Grand Fir	White/Grand Fir	Douglas-fir
Engelmann Spruce	Engelmann Spruce	Subalpine Fir
Douglas-fir	Douglas-fir	Engelmann Spruce
Western White Pine	Western White Pine	Western Larch (least)
Ponderosa Pine	Ponderosa Pine	Pines (nonhosts)
Lodgepole Pine	Western Larch	
Western Larch (least)	Lodgepole Pine (earliest)	

Sources: Daniel, Helms and Baker (1979) for shade tolerance; author's judgment for successional status; and results of this study for budworm susceptibility. Species ratings are based on the predominant situation for each trait. A trait can vary during the lifespan of an individual tree, and from one individual to another in a population—ponderosa pine can tolerate some shade when young, but requires almost full sunlight when mature.

Changes in Forest Health

Perhaps the recent deterioration of forest health is nature's response to vegetation changes that occurred after fire was prevented from playing its natural role. How significant were the changes? Figure 12 shows that the ponderosa pine type declined by more than half between 1936 and 1980, the mixed-conifer type almost tripled during that period, whereas the lodgepole pine type remained relatively constant. Figure 13 shows that, on average, each acre of mixed-conifer forest supported more budworm host trees in 1989 than in 1968, especially for white fir.

Loss of Ponderosa Pine

The species trends in figures 12 and 13 reflect a steady loss of ponderosa pine since the early 1900s (fig. 14). An early survey completed around 1910 found that stands in a watershed at the head of one branch of the John Day River contained 84% ponderosa pine, 9% western larch, and 7% Douglas-fir, white fir, and lodgepole pine (Munger 1917). Another survey completed in the late 1930s found that the ponderosa pine type "is remarkably pure, averaging 94 percent ponderosa pine in Oregon and 92 percent in Washington. Stands are characteristically uneven-aged and open, with little heavy underbrush. The ground cover is chiefly grass or low shrubs" (Cowlin and others 1942).

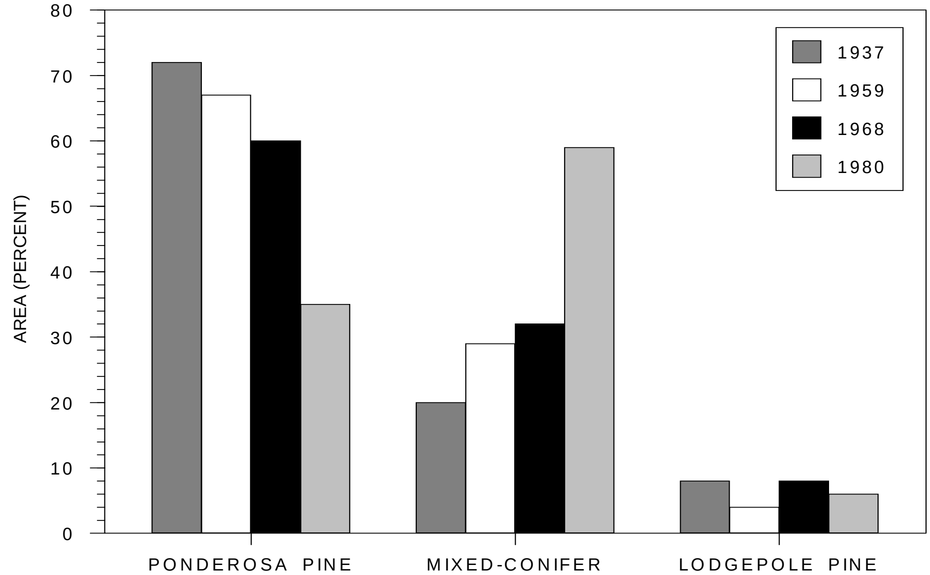


Figure 12—Changes in forest cover types for the Malheur NF. The ponderosa pine forest type declined by more than half between 1936–37 and 1980, the mixed-conifer type increased by an equivalent amount during the same period, whereas the lodgepole pine type remained relatively constant. This figure shows that prime budworm habitat (mixed-conifer forest) increased by 195% between 1936–37 and 1980, which was an important reason for the magnitude of budworm defoliation between 1980 and 1992 (see fig. 6). [Sources were Jones and others (1961), Lauridsen (1937), Moravets (1936), Teply (1980), and USDA Forest Service (1970).]

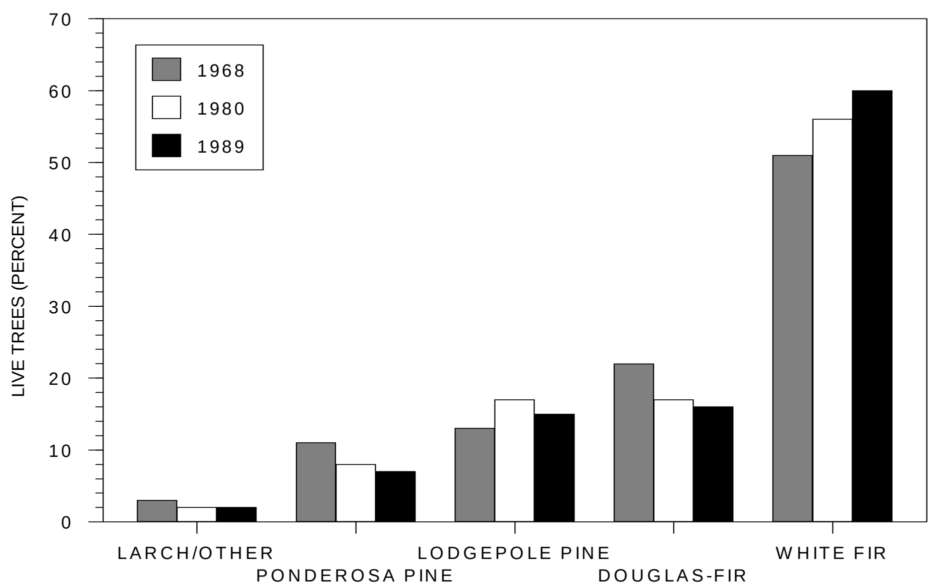


Figure 13—Change in species composition for selected mixed-conifer inventory plots on the Malheur NF. The percentage of ponderosa pine, Douglas-fir, and larch/other trees declined between 1968 and 1989, whereas lodgepole pine had both increases and decreases during that period. But the most obvious change was for white fir—it increased by 18% from 1968 to 1989. This figure provides another reason for severe budworm defoliation in the 1980s—each acre of mixed-conifer forest supported a higher proportion of budworm's preferred food source (white fir) in 1989 than in 1968. [Based on 51 inventory plots measured in 1967–1968, 1980, and 1988–1989.]

Figure 14—The distribution of ponderosa pine around 1910–1911 (above), and mixed-conifer forests around 1980 (below), in Oregon. The upper map shows that a high proportion of the Blue Mountains was covered with ponderosa pine forests during an early survey completed in 1910–1911 (modified from Munger 1917). The lower map shows the distribution of mixed-conifer forests by 1980 (modified from Seidel and Cochran 1981). It is obvious that much of the Blue Mountains area supporting mixed-conifer forest in 1980 was previously dominated by ponderosa pine. Forest inventory statistics corroborate the trend displayed on these maps (see fig. 12).

Changes in Ecological Sustainability

Fire was traditionally viewed as an undesirable disturbance, but it was an important ecological process in presettlement pine forests. In the dryer ecosystems found east of the Cascade Mountains, natural decomposition of needles, twigs, and other forest litter occurs slowly. Low-intensity fire was important for periodically cycling the litter's rich supply of nutrients (Crane and Fischer 1986). Cool burns result in slight increases in available nitrogen, whereas severe fires cause high levels of nitrogen loss. High nitrogen losses often cause a decline in site productivity (Harvey and others 1989, Harvey and others 1994).

Fire As A Thinning Agent

Fire was also an important thinning agent (Weaver 1947a, 1957). Thinning was needed because ponderosa pine stagnates when growing in dense, crowded stands. If dense stands were not thinned by fire, their density was eventually reduced by bark beetles or pathogens (fig. 15). Since fire's influence was so pervasive, underburned pine stands were stable, ecologically sustainable systems (fire-dependent communities).

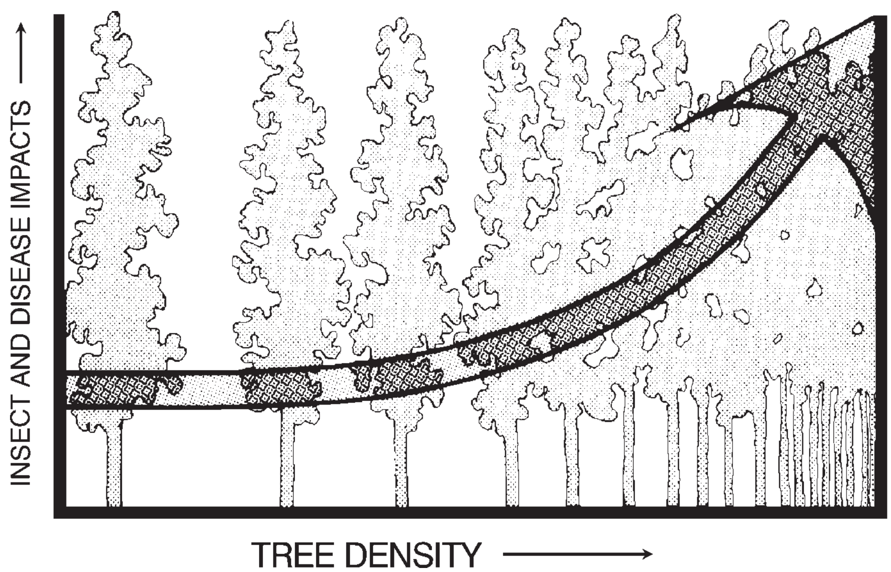


Figure 15—Insect and disease impacts vary with stand density. Because open stands have higher vigor levels than dense stands, they tend to be more resistant to insect and disease impacts. Maintaining a wide stand spacing results in a condition where the trees are not competing with each other. Vigorous trees can withstand attack from many different insects and pathogens.

Effects of Fire Suppression

After fires were suppressed, the effects were eventually dramatic. Multi-storied stands of budworm hosts got established, often at high densities. Thick layers of organic matter accumulated beneath the invading fir trees, tying up nitrogen and other nutrients that are cycled slowly without fire. Little natural mortality occurred, and the trees that died were usually the small pines and larches that succumb to suppression before the firs. Fuels accumulated at an alarming rate. Herbage production declined substantially, affecting both native and introduced ungulates. Stream flows were reduced by a third or more because dense tree stands use more water than open ones (Covington and Moore 1994).

Changes in Fire Intensity

Increased insect attacks are just one effect of fire suppression; perhaps a more dramatic symptom was the catastrophic wildfires of 1989 and 1990 (Glacier, Corral Basin, Snowshoe, Sheep Mountain, and Whiting Springs on the Malheur NF). Catastrophic fires occurred because fire suppression allowed fuel loads to reach unnatural levels, and because mixed-conifer forests tend to have dense, multi-layered canopies, which provide "ladder" fuels allowing a ground fire to climb into the tree crowns (fig. 16). Crown fires are intense and generally kill the whole stand. Even though current technology allows low- and moderate-intensity fires to be controlled, it is almost impossible to extinguish high-intensity wildfires in heavy fuels—they burn until the fuel is gone or until the weather changes (fig. 17).

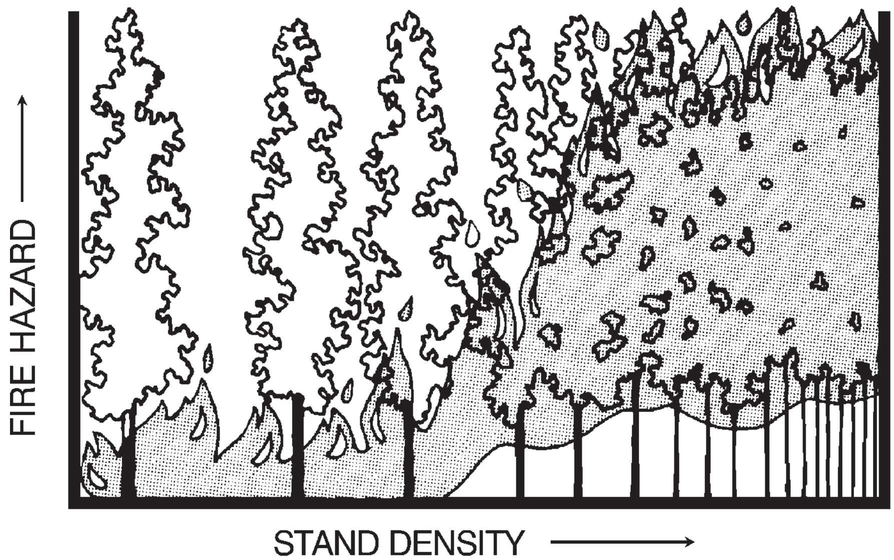


Figure 16—Fire intensity varies with stand density. When a fire moves through an open stand with widely-spaced trees, it stays on the ground as a low-intensity burn. But when fire encounters a dense, closely-spaced stand, it is much more likely to leave the ground and begin moving through the intermingled tree crowns, which usually kills the stand.

Awareness of Fire-Caused Changes

This section described how fire suppression contributed to dramatic changes in forest composition. Were those changes recognized only recently? Apparently, many of the changes caused by fire suppression have been recognized for quite some time. The following passage describes fire-related changes occurring shortly after establishment of the Blue Mountains National Forests (Evans 1912).

> There are patches of "scabland," characterized by very shallow soil, many rock fragments and a total absence of vegetation except in the spring months. It is interesting to note that some of these areas are being occupied by sagebrush where a few years ago, there was none. A possible explanation is that the annual fires of the Indians kept it killed out and now it has a chance to develop. Yellow pine is slowly encroaching upon the sagebrush, the chief factor in its rate of advance being moisture, provided fire is kept out. The same statement

> will hold true in regard to the other open areas as well. As fast as the reproduction has pushed out from under the protection of the parent trees, the periodical fires have killed it back, thus keeping the timber line practically stationary. In recent years, conditions have improved, and it is noticeable that the pine is reaching out, although slowly. The north slopes [are] being occupied by a thick stand of fir reproduction. Even pine is gaining a foothold here, and is gradually creeping across the ridge to the south slopes.

Was Fire Suppression Justified?

The following questions and observations were made by a prominent fire researcher over fifty years ago (Weaver 1943).

> It is obvious that the present policy of attempting complete protection of ponderosa pine stands from fire raises several very important problems. How, for instance, will the composition of the reproduction be controlled? If ponderosa pine is desired on vast areas how, unless fire is employed, can other species such as white fir be prevented from monopolizing the ground? On the other hand, if it is decided to permit such species as white fir to come in under mature ponderosa pine, how much of the public's money are foresters justified in spending in trying to keep fire out? Even with unlimited funds, personnel, and equipment, can they give reasonable assurance that they can continue to keep such extremely hazardous stands from burning up? If they feel reasonably sure of this, can they then give assurance that the timber products of such stands will be more valuable than those that might otherwise be derived from ponderosa pine and will in addition justify the high protection costs?

Figure 17—A high-intensity crown fire. In dense forests with large amounts of fuel, fires are very intense and travel rapidly from one tree crown to another. Crown fires were an important process for perpetuation of lodgepole pine and western larch forests, although any particular area seldom experienced a stand-replacing crown fire more often than once every 200 or 300 years.

Effects of Selective Harvesting on Budworm Habitat

Fire suppression allowed multi-storied stands to develop across much of the Malheur NF (fig. 18). They typically had an overstory of old-growth ponderosa pine and western larch, and an understory of Douglas-fir, white fir, and occasionally lodgepole pine. When those stands were harvested, much of the ponderosa pine was removed for these reasons:

- The pine was usually old (often 200 years or more) and was adding little or no timber volume because of its slow growth. Since old pines often have low vigor and little resistance to insect attack, they were harvested before being attacked and killed by western pine beetle or mountain pine beetle. One reason for low vigor in old-growth pine trees was competition from a dense understory, an understory that would not have been present if underburning had been allowed to play its natural role.

- Old-growth ponderosa pine has historically had a much higher selling value than associated species such as Douglas-fir, white fir, western larch, and lodgepole pine. Because of its economic advantage, harvesting ponderosa pine provided an abundance of Knutson–Vandenberg (K–V) receipts, which could then be used for tree planting, thinnings, wildlife and range projects, and other land management treatments within the timber sale area.

- As forestry intensified in the early 1950s to meet increasing lumber demands after World War II (MacCleery 1992), mixed-conifer stands began to be managed. Mature pines and larches were removed from the overstory, followed by a thinning in the immature understory of Douglas-fir and white fir. That strategy seemed to make good sense. It avoided the cost of tree planting, an expensive practice. It avoided the undesirable appearance associated with clearcutting. It maintained the semblance of a green, forested setting. And it capitalized on the previous growth of the understory trees, many of which had been there for 60 years or more. The understory trees were a gift of nature (i.e., not a result of human management). Why shouldn't they provide the next "crop" of timber products?

Early Timber Harvests in the Blues

Some level of selective harvesting has been occurring ever since the Blue Mountains were settled by European emigrants. The first commercial logging in the Northwestern pine region of eastern Oregon and Washington began around 1890 (Weidman 1936), although limited harvesting occurred during the preceding 25 years to meet the needs of miners and early settlers. Some of the first roads reaching into the Blue Mountains were wagon roads for hauling wood and rails out to farms and ranches. Timber met a variety of needs, including logs for homes, posts and poles for corrals, and rails for fencing. The resinous, durable woods of ponderosa pine and western larch were ideal for meeting many homesteading needs (Robbins and Wolf 1994, Tucker 1940).

Timber removals accelerated after gold was discovered in Griffin Gulch, located a few miles southwest of Baker City, in the fall of 1861. Prospectors poured into the Blue Mountains shortly thereafter, quickly establishing Auburn, Canyon City, Granite, Sumpter, Susanville, and other mining settlements. By 1890, Baker, Union, and Grant counties had a combined population of 23,900 (Lindgren 1901).

Figure 18—Trees that can tolerate shade are able to get established under ponderosa pines, such as the white firs and Douglas-firs clustered around the base of this pine. If the overstory pines and larches are eventually harvested, a multi-layered stand of late-successional trees remains, and most of them are highly susceptible to infestation by budworm and Douglas-fir tussock moth.

Malheur NF Harvest History

Controlled timber harvesting began on the Malheur NF soon after its establishment in 1908. Prior to 1917, when the Oregon Lumber Company built a sawmill at Bates, the Forest provided small sales for local consumption. Although few timber sales were offered in the early years, the ones that were often included large volumes and covered extensive acreages. For example, the Bates sawmill was established following a 124 million board foot offering in 1916, which covered

14,600 acres on the lower Middle Fork of the John Day River (then in the Whitman NF). Logging continued at relatively low levels until 1928, when the Edward Hines Lumber Company was awarded a long-term contract for 890 million board feet in the Seneca area. Except for a decline during the timber recession of the late 1970s and early 1980s, timber harvests have increased steadily since then. An increase during the early 1940s reflects high demand during World War II (fig. 19).

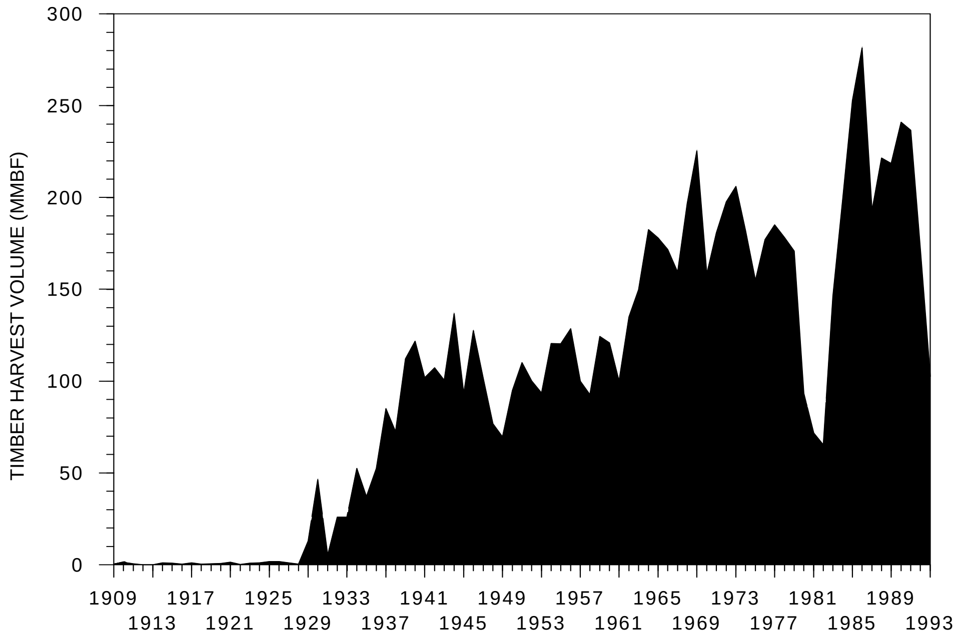


Figure 19—Timber volume harvested on the Malheur NF. Except for a decline during the timber recession of the late 1970s, and the current downturn associated with timber sale appeals, the overall harvest trend has been steadily upward. [Sources were USDA Forest Service (1961), and harvest records available at the Malheur NF Supervisor's Office.]

Diameter Limit Cutting

Due to market conditions, early partial cuttings were typically a "diameter-limit" harvest with the largest trees being removed. Diameter-limit cutting gradually altered the forest composition by removing the marketable trees (large-diameter ponderosa pines, larches, and Douglas-firs), leaving behind a high proportion of unmerchantable firs and Douglas-firs. The following passage describes how partial cutting was applied in the early ponderosa pine forests of Oregon (Munger 1917).

> The system of cutting which seems to be ideal for this type of forest is a form of selection cutting. Periodic cuttings are made, in each of which all the overmature and thoroughly ripe trees in the stand and all the defective ones are removed; and the saplings, poles, and young, thrifty trees are left standing to form the basis for the next crop. No tree is removed until it has reached its majority, so to speak, and no old, slow-growing tree is allowed to stand and occupy space which should be devoted to young and rapid-growing trees. It is customary to set an appropriate diameter limit of from 16 to 22 inches, the majority of the trees above which limit are cut, and those below left.

Why Was Diameter-Limit Cutting Used?

Why was diameter-limit cutting used if it favored firs instead of pine and larch? Under the market conditions of that era, selective cutting was viewed as a wise use of forest resources. It removed mature trees that had some value, thereby initiating a rudimentary level of forest management. Low-value trees were harvested to the extent that markets would allow. Many low-value species were left in the hope that some of them would become merchantable by the next entry in 40–60 years. The following passage describes this situation for western white pine, but it was also true for ponderosa pine forests (Haig and others 1941).

> The low values are due to high susceptibility to heart rot of western hemlock, grand fir, and some other species, and to the fact that the selling price of lumber manufactured from these species is often insufficient to meet production costs even if nothing were paid for the standing timber. Where trees of such species are not defective, the Forest Service policy has been to leave them uncut in the hope that at some future time they can be sold at a profit. But leaving these low-value species on areas that are cut over encourages their reproduction and tends to decrease the proportion of western white pine in the reproduction—an undesirable result both silviculturally and economically.

Effects of Partial Cutting

In many respects, partial cutting was the opposite of how natural processes operated in mixed-conifer stands. Underburns discriminated against the long-crowned, thin-barked invaders (grand fir and Douglas-fir), while favoring the thick-barked trees with short, open crowns (ponderosa pine and western larch)(Table 2). In contrast, partial cutting removed fire-resistant pines and larches while retaining the late-successional species that are susceptible to a variety of insects and pathogens.

The late-successional species that were favored by partial cutting had less value for timber products than ponderosa pine. Early Blue Mountains foresters recognized that partial cutting could have an undesirable impact on species composition and timber values, as described below.

> White fir, though of slower height growth, is far more tolerant than bull pine, reproduces fairly freely, and under normal conditions would naturally supplant the pine in time. This condition has been greatly aggravated in the portions that have been lumbered by cutting the pine and leaving the white fir. The fir, often already on the ground under the pine, springs up, and pine reproduction is thus impossible (Kent 1904).
>
> In all sales on this Forest, care should be exercised in marking the timber not to leave the cutting area in such condition that a valuable stand be supplanted by inferior species. White fir, though occasionally used for fuel when no better species are available, makes poor fuel wood, while for saw timber it is all but valueless owing to the fact that nearly all mature trees are badly rotted by a prevalent polyporus, and the wood season-checks badly. Unless care is taken this species is prone to supplant such species as yellow pine and tamarack since it is much more tolerant of shade in early life (Foster 1907).

Table 2—Bark thickness, crown length, and fire resistance rankings for common trees of the mixed-conifer zone in the Blue Mountains.

BARK THICKNESS	CROWN LENGTH	FIRE RESISTANCE
Western Larch (thickest)	Western Larch (shortest)	Western Larch (highest)
Ponderosa Pine	Western White Pine	Ponderosa Pine
Douglas-fir	Lodgepole Pine	Douglas-fir
White/Grand Fir	Ponderosa Pine	Western White Pine
Western White Pine	Douglas-fir	White/Grand Fir
Engelmann Spruce	White/Grand Fir	Lodgepole Pine
Lodgepole Pine	Engelmann Spruce	Engelmann Spruce
Subalpine Fir (thinnest)	Subalpine Fir (longest)	Subalpine Fir (lowest)

Sources: Haig and others (1941), and Minore (1979). Species rankings are based on the predominant situation for each trait. A species trait is not absolute—it can vary during the lifespan of an individual tree, and from one individual to another in a population. For example, white fir's bark is thin when young, but relatively thick when mature (see fig. 84).

Vegetation Changes Recognized Early

The potential implications of selective harvesting and fire suppression were clearly recognized during inventories completed by the Forest Service's forest survey unit. The following comments are from a report summarizing the results of the 1950s forest inventories for eastern Oregon counties (Gedney 1963).

> If present trends continue, the proportion of ponderosa pine will be less in the future than at present. In 29 percent of all the pine sawtimber types, there is no understory of pine, only other species—Douglas-fir, white fir, and lodgepole pine. In another 27 percent of the pine sawtimber stands, the understory is a mixture of young ponderosa pine and other species. On more than half of this area, species other than pine predominate. Unless something happens to change this relationship, or unless more intensive forest management is undertaken, about 40 percent of the pine sawtimber type is likely to shift to some other type.

Budworm Feeding Ladders

What were land managers left with after harvesting the old-growth ponderosa pine from a mixed-conifer stand? Often, it was the multi-layered stand structure that provides an ideal feeding ladder for dispersing budworm larvae (fig. 20). After dispersing on silken threads from high in the forest canopy, some larvae are intercepted by smaller host trees before falling to the forest floor, where they would have been eaten by ants, small mammals, and other natural enemies of budworm.

Recent Harvest Trends By Species

How common was the practice of harvesting more ponderosa pine than other species? Figure 21 shows that almost three-fourths of the timber volume harvested on the Malheur NF between 1970 and 1992 was ponderosa pine. Since the ponderosa pine type occupies about half as much acreage as the mixed-conifer type (see fig. 12), it is also evident that much of the ponderosa pine volume was removed from mixed-conifer stands.

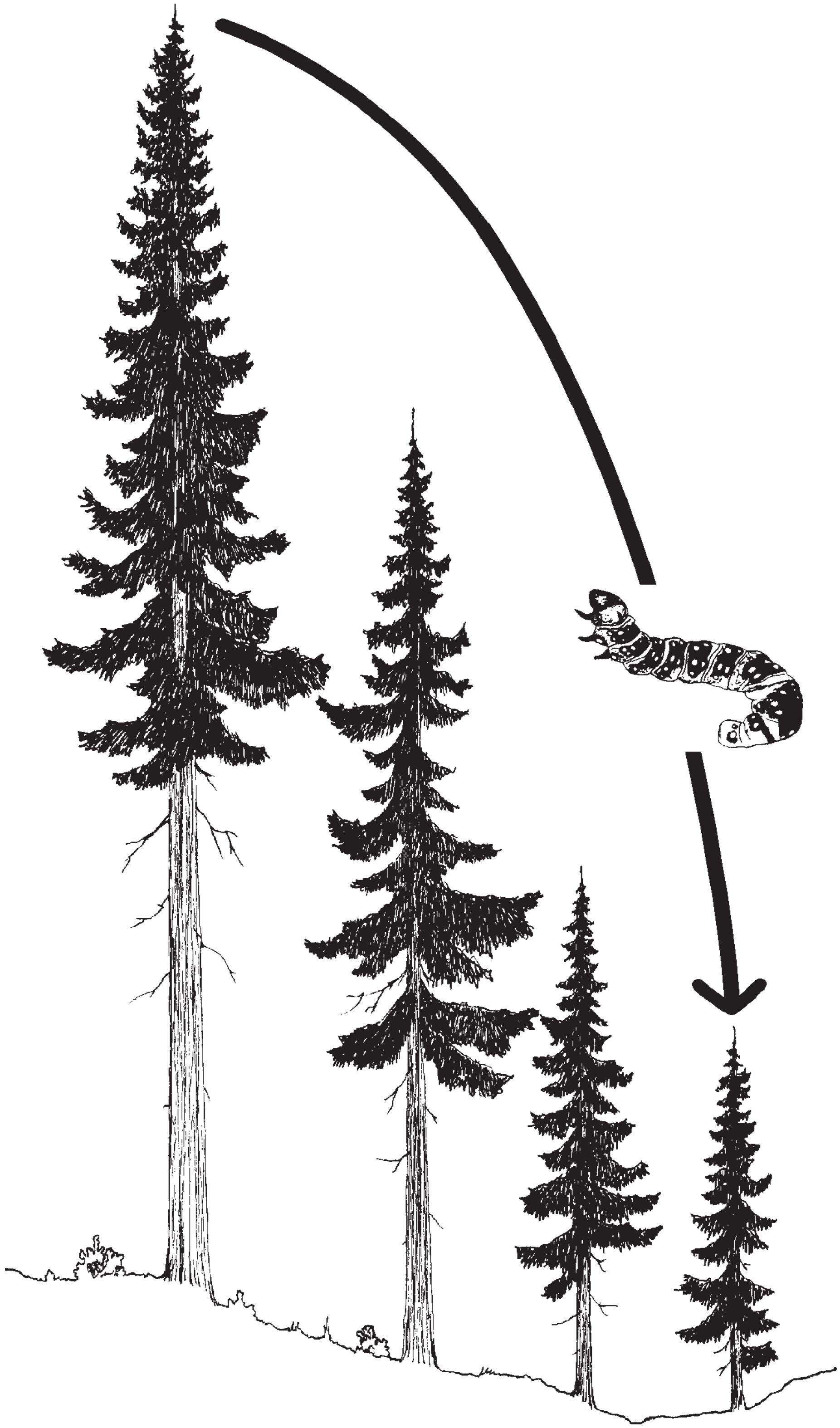


Figure 20—Budworm feeding ladder effect in multi-storied stands. In stands comprised of two or more canopy layers, budworm impacts are usually concentrated on the smaller trees. Some budworm larvae disperse from taller trees and are intercepted by understory stems before reaching the forest floor, where they would have died from exposure or been preyed upon by ants, spiders, beetles, birds, small mammals, and other natural enemies of budworm.

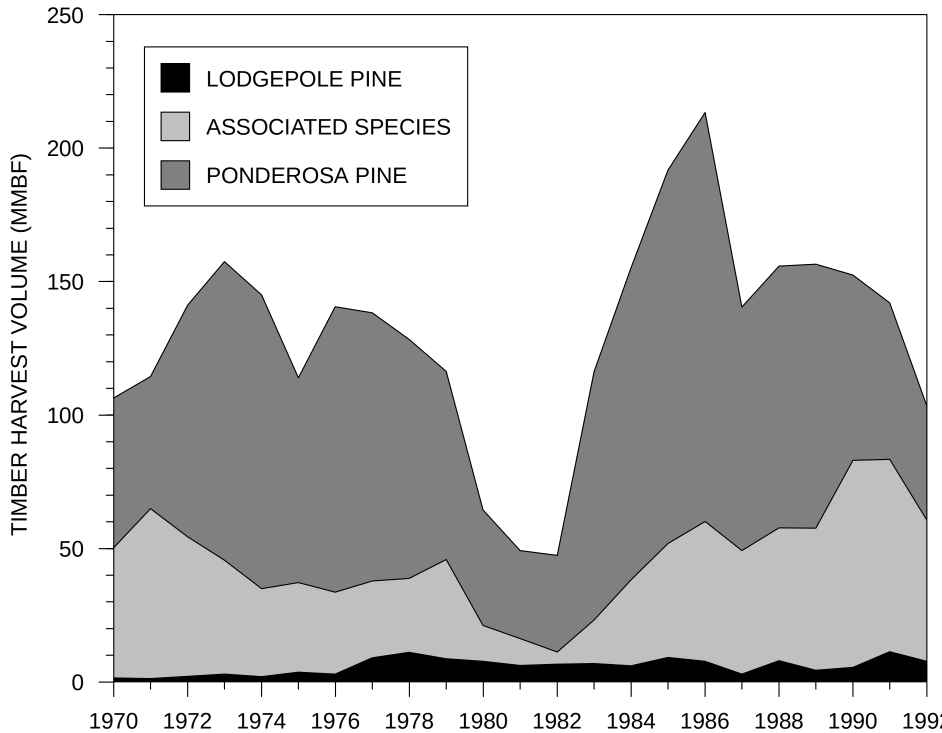


Figure 21—Timber volume harvested on the Malheur NF in fiscal years 1970–1992 ("associated species" include Douglas-fir, white fir, western larch, and other species except ponderosa or lodgepole pines). During the 23-year period included in this chart, 72% of the Forest's harvested volume was ponderosa pine. Since ponderosa pine stands occupied only 35% of the Forest's land base in 1980 (see fig. 12), this figure shows that much of the pine volume was actually removed from the mixed-conifer type. The harvest pattern shown here helped accelerate the replacement of ponderosa pine stands with mixed-conifer forest, which contributed to significant increases in the area of western spruce budworm habitat. [Chart was based on timber harvest records available at the Malheur NF, Supervisor's Office.]

"Many land managers would agree that wildfire suppression was a policy with good intentions, but it was a policy that failed to consider the ecological implications of a major shift in species composition. White firs and Douglas-firs can get established under ponderosa pines in the absence of underburning, but they may not have enough resiliency to make it over the long run, let alone survive the next drought. This means that many of the mixed-conifer stands that have replaced ponderosa pine are destined to become weak, and weak forests are susceptible to insect and disease outbreaks."

Effects of Fire Suppression on Budworm Habitat (page 19)

The Ecological Role of Budworm Outbreaks

Ecological theory has traditionally held that ecosystems exist in a state of equilibrium, and that they return quickly to a condition of stability or homeostasis following a disturbance. Recent ecological research refutes that theory by showing that nature is in a continual state of flux. Change and turmoil, rather than constancy and balance, is the rule. We now know that the concept of a forest evolving to a stable (climax) stage, which then becomes its naturally permanent condition, is false (Stevens 1990). Wildfires, wind storms, insect outbreaks, disease epidemics, and other natural processes are the harbingers of change; they prevent most forests from ever reaching a climax stage.

Insects Provide Diversity

Insects and pathogens are not only important agents of change, but they also play a vital role in ecosystem function (Wickman 1992). They cause tree mortality, which in turn affects natural succession and the diversity of plant communities in an area. They create many of the dead trees that provide important habitat for a wide variety of wildlife species. In the Blue Mountains, standing dead trees (snags) are used for nesting or shelter by 39 bird and 23 mammal species; downed, dead trees are used by 179 wildlife species (Thomas 1979).

Nutrient Cycling and Down Wood

Nutrient cycling and production of down woody material are two important ecological processes influenced by insects and pathogens (Wickman 1992). Both of those processes contribute to the long-term productivity of forest ecosystems, particularly as they affect the habitat of soil-inhabiting fungi called mycorrhizae. In fact, when considering the variety of ecological benefits provided by these organisms, it is questionable whether they should be viewed as pests (fig. 22).

Historical Range of Variation

Are extensive insect impacts an indicator of an unhealthy forest ecosystem? And what does a wide-ranging budworm outbreak mean in an ecological sense? Since ecosystems are constantly undergoing change, we need to evaluate their health in a similar context. Perhaps an appropriate yardstick of ecosystem health is natural variation: are the changes caused by budworm consistent with the historical range of variation for similar ecosystems and vegetation conditions? For the mixed-conifer forests of the southern Blue Mountains, the answer is probably "no." It seems that 80 years of fire suppression and 50 years of selective harvesting have resulted in vegetation conditions that differ significantly from those of presettlement times (Table 3).

Recent ecological assessments of the Blue Mountains ecoregion found that many river basins support vegetation whose composition and structure are currently outside the historical range of variation (Caraher and others 1992, O'Laughlin and others 1993).

Figure 22—Insects and pathogens are important components of biodiversity. Forests support an amazing diversity of life, ranging from soil microbes to large, long-lived, woody plants. Insects and pathogens are an important element of that diversity. Not only do they contribute to nutrient cycling, site productivity, and other ecosystem processes, but they create wildlife habitat (dead trees) and are a source of food for many wildlife species.

Table 3—Change in selected stand attributes for ponderosa pine forests near Austin, northeastern part of the Malheur NF, 1910–1980.

STAND ATTRIBUTE	1910–11	1980	Change
Live Trees Per Acre (1"+ DBH)	56.5	427.7	+ 657%
Ponderosa Pine Percentage	67.3	71.3	+ 6%
Live Basal Area; Square Feet Per Acre (1"+)	94.6	88.4	– 7%
Ponderosa Pine Percentage	83.6	57.6	– 31%
Quadratic Mean Diameter (Inches)	17.5	6.2	– 65%
Stand Density Index (trees/acre at 10" QMD)	138.6	196.8	+ 42%
Live Trees Per Acre >21" DBH (Percent)	28.1	2.3	– 92%
Pine Trees Per Acre >21" DBH (Percent)	24.4	1.8	– 93%

Sources: 1910–1911 data is for ponderosa pine plots near Austin–Whitney (Munger 1917, page 20); 1980 data is for two Malheur NF inventory plots near Austin and at the same elevation (4500–4800 feet) as Munger's plots.

Ecosystem Resilience

How did fire suppression and partial cutting contribute to ecosystems that are out of balance? Both of those practices contributed to a loss of ecosystem resilience by reducing vegetation diversity and complexity, especially at a landscape scale. The Blue Mountains supported a variety of forest conditions in presettlement times, ranging from open pine forests to dense stands of white fir, spruce/fir, western larch, or lodgepole pine (fig. 23). Even nonforest communities with grasses or shrubs were more common then than they are today. Fire suppression and selective harvesting have perhaps had the single greatest impact on landscape diversity in eastern Oregon (Hessburg and others 1994).

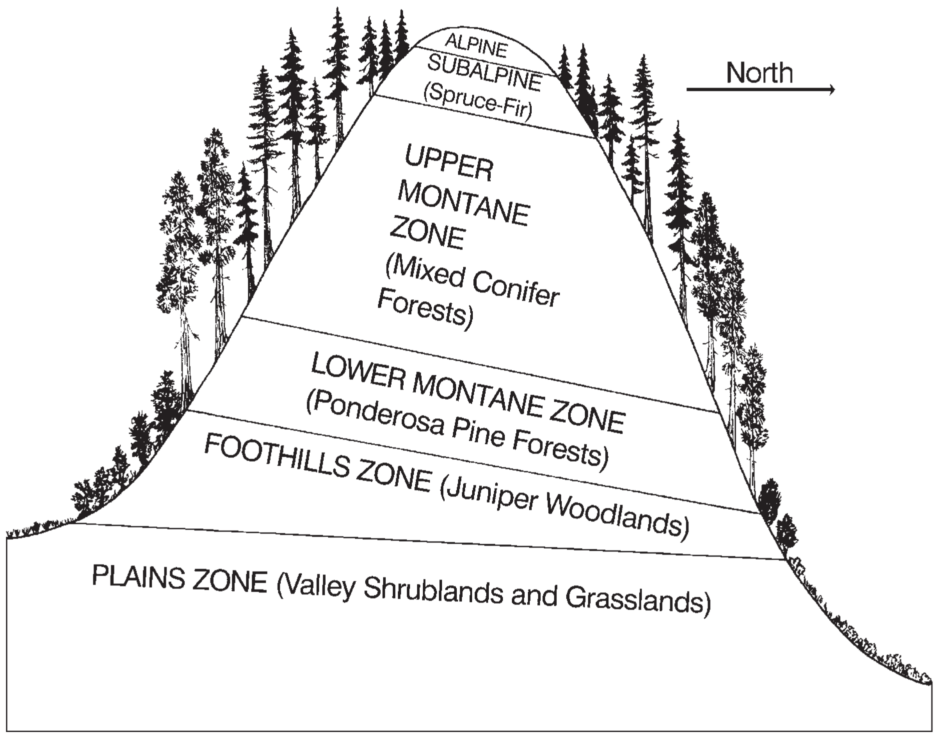


Figure 23—Vegetation zones of the central and southern Blue Mountains. Vegetation types tend to occur in well-defined zones as you move up or down a mountain slope. Since northerly exposures are cooler than south-facing aspects, the zones tend to occur at lower elevations on north slopes. The *plains zone* occurs at low elevations; it contains grasslands and shrublands because moisture is too low to support forests except along waterways. The *foothills zone* is usually dominated by western juniper, often with a mixture of mountain-mahogany shrublands and grassy scablands. Located just above the western juniper woodlands is the *lower montane zone*, which contains forests of ponderosa pine. Lower montane sites are too dry to support white fir or Douglas-fir forests except in riparian zones. The *upper montane zone* is extensive in the Blue Mountains, where it provides ideal environments for western spruce budworm. It includes mixed-conifer forests of Douglas-fir, white fir, western larch, ponderosa pine, lodgepole pine and, occasionally, western white pine. High elevations support a *subalpine zone* with Engelmann spruce and subalpine fir, or an *alpine zone* near mountain summits, where trees are absent. Neither subalpine nor alpine environments are common in the relatively low-elevation Blue Mountains.

Ecological Simplification

When European emigrants introduced livestock grazing, suppressed underburns, and influenced other natural processes, the resulting changes were akin to an ecological simplification. Aspen stands; riverine forests of black cottonwood; riparian communities of thinleaf alder, river birch, and willows; certain types of shrubland; and other ecosystem components were reduced or lost altogether (fig. 24). One of those changes was certainly predictable—resilient pine stands were replaced with highly stressed forests comprised mostly of budworm-host trees. Forest diversity was reduced further when selective harvesting began removing the overstory pines and larches.

Figure 24—Aspen clone in the Blue Mountains. As a result of fire suppression, aspen is less common today than it used to be. Although aspen was never abundant in the Blue Mountains, its distribution has suffered without fire. Aspen regenerates primarily from root sprouts or suckers, which are produced after most of the overstory trees have been killed by fire, pathogens, or timber harvest. When fire was curtailed as a landscape-level process, aspen was forced to seek ecological refuge along ephemeral streams, around moist meadows, and on other semi-riparian sites. Allowing fire to play its natural role in the Blue Mountains would not only benefit ponderosa pine and western larch, but could also rejuvenate aspen on many sites.

Budworm Responds to Vegetation Changes

As these vegetation shifts accelerated, the habitat for budworm and other insects and pathogens continued to build, eventually reaching levels that are apparently greater than ever before. When considered from that perspective, conflagration fires and catastrophic budworm impacts are an ecologically appropriate response to the vegetation changes. Instead of minor budworm outbreaks affecting limited areas, the Blue Mountains recently experienced an outbreak occurring over wide areas. Perhaps the recent outbreak was a symptom of a problem (an abundance of mixed-conifer forest), rather than the problem itself.

Budworm Invigoration

Several recent environmental controversies have been concerned with human alteration of forested ecosystems and the resultant impacts on one or more wildlife species (an example is the northern spotted owl in western Oregon). Although public concern tends to focus on declining species, particularly those which are threatened or endangered with extinction, human activity has also led to the emergence of invigorated species that are apparently doing better now than they ever have in the past. Examples of invigorated species might include coyotes, raccoons, house sparrows, red-winged blackbirds, bull thistles, and west-ern junipers, to name just a few. Unfortunately, previous management practices have probably contributed to an invigoration of western spruce budworm, which defoliated much more area during the 1980s outbreak than it did in the previous one (1944–1958; see fig. 6).

Global Climate Change and Budworm Susceptibility

Recent studies indicate that man's production of carbon dioxide could be leading to a period of global warming. If global warming occurs, it could have significant effects on western forests. Ponderosa pine and other trees adapted to warm, dry environments would undoubtedly suffer less damage than white fir and similar species that need relatively moist conditions. Open stands have little competition between trees for nutrients and water; they would fare better in the harsher environments associated with global warming.

Reestablishing ponderosa pine and western larch on sites that are suitable for their survival and growth, and a thinning or prescribed fire program to keep those stands open and vigorous, would probably do much to address global warming concerns. Using a plan like that one would not only restore much of the pine and larch that was removed by partial cutting (see fig. 21), but it could also create healthy forests with an increased resistance to a variety of insects and pathogens.

A note about global warming: It has not been conclusively proven that global warming is already underway, or that its onset is imminent. It is not possible to make accurate predictions about long-term climatic trends. For example, scientists warned that the Earth was entering a major period of global cooling in the mid 1970s, when we were heading "toward extensive northern hemisphere glaciation" (Hays and others 1976). In less than two decades, a very short time period in a climatic sense, scientific concern has shifted from global cooling to global warming.

Study Design, and Sampling and Analysis Methods

The study described here can best be termed an observational study, case study, or descriptive survey. An observational study differs from a controlled experiment in several important ways (Snedecor and Cochran 1989). In an experiment, the investigator controls the treatments to which the subjects are exposed and also prevents their exposure to extraneous or confounding factors. Conversely, an observational study involves circumstances where an investigator lacks the power to create the groups to be compared; the choice of observations or data to be collected and analyzed cannot be controlled in an experimental sense.

This Study Was Not An Experiment

For this budworm study, it was not possible to assign the forest inventory plots to carefully controlled defoliation groups. The plots already existed and were exposed to a wide variety of natural budworm defoliation that was essentially uncontrolled by humans, except for any influence exerted by the insecticide treatments. However, insecticides were not applied to all of the defoliated area, the treatments were not completed in the same year or with the same insecticide, and the insecticide applications did not eradicate budworm or its impact: they typically suppressed budworm populations and associated tree impacts for a period of three or four years at best.

Limitations of Observational Studies

Due to the limitations of an observational study, readers should be cautious when using the results contained in this report. Any apparent correlations are merely clues to possible cause–effect relationships (Schreuder and Thomas 1991). This study basically imposed a sampling scheme on pre-existing inventory plots with the result that potential relationships are being explored after the fact, rather than designing a controlled experiment and accepting whatever results from it.

Using the Study Results

How the study results are used may depend on the level of uncertainty that one is willing to accept. Because they were derived from an observational study, some of the results may have a relatively high degree of uncertainty. On the other hand, the study was based on methodologies and sampling units (long-term inventory plots) commonly used in national forest management. The results may have less uncertainty for typical national forest management situations.

Remeasuring Mixed-Conifer Inventory Plots

By the mid 1980s, as it became apparent that budworm defoliation was causing significant impacts, the Forest's leadership team began considering options for acquiring information about budworm's effect on mixed-conifer forests. They decided that some of the Forest's existing inventory plots would be remeasured, a strategy offering the following advantages:

- The plots were last measured in 1980, which also happened to be the year that budworm populations began building to outbreak levels (McConnell and others 1980). The 1980 measurements could then provide a snapshot picture of host-type conditions as they existed immediately before the onset of budworm-caused defoliation.

- The 1980 measurements could provide a known benchmark from which to compare changes, many of which were presumably caused by budworm defoliation. The availability of a baseline measurement removes any need to estimate what pre-damage conditions were like. In other studies of budworm impact, the investigators have used a computer model to "backdate" measured conditions to pre-outbreak levels (Beveridge and Cahill 1984), or they have attempted to correlate information from aerial sketch maps with budworm-related tree damage (Harvey 1982). A potential problem with these back-dating processes is the uncertainty about whether any observed differences are due to the treatment or effect being analyzed, or due to the backdating process itself or how the process was used.

- 51 of the 130 remeasured plots were initially established in 1967 or 1968. For those plots, the remeasurements in 1988–1989 represent the third successive observation involving the same trees on the same plot area. Measurements spanning more than 2 decades could be used to assess mortality trends, for monitoring changes in species composition, and to make other comparisons that benefit from using the same set of trees on the same plot areas.

Plot Selection Criterion

Since budworm defoliation is potentially most damaging in stands with a high proportion of host trees, it was decided to remeasure inventory plots whose composition consisted of 50% or more budworm host species. For the purpose of selecting remeasurement plots, the following tree species were considered to be hosts of spruce budworm: white fir, subalpine fir, Engelmann spruce, Douglas-fir, and western larch.

Selected Plots

There were 402 inventory plots measured in 1980, of which 139 satisfied the "50% host species" criterion described above. Nine of the 139 candidates were located in wilderness areas established after the 1980 inventory; those plots were not considered for remeasurement because wilderness areas are not representative of managed host type.

Survey Design

The 1980 forest inventory used a traditional stratified sample—strata sizes were obtained from aerial photo delineations completed in 1979; ground plots were measured in 1980 to characterize strata attributes. Each of the 1980 inventory plots consisted of a 10-point plot cluster designed to cover approximately one acre (fig. 25). Three of the sample points (points 1–3) were considered "intensive" because a wide variety of information was collected for each sample tree. The other seven points were "extensive" because limited information was collected.

Since tree height and other information for evaluating budworm impacts was unavailable on the extensive points, it was decided to remeasure only the 3 intensive points on each inventory plot.

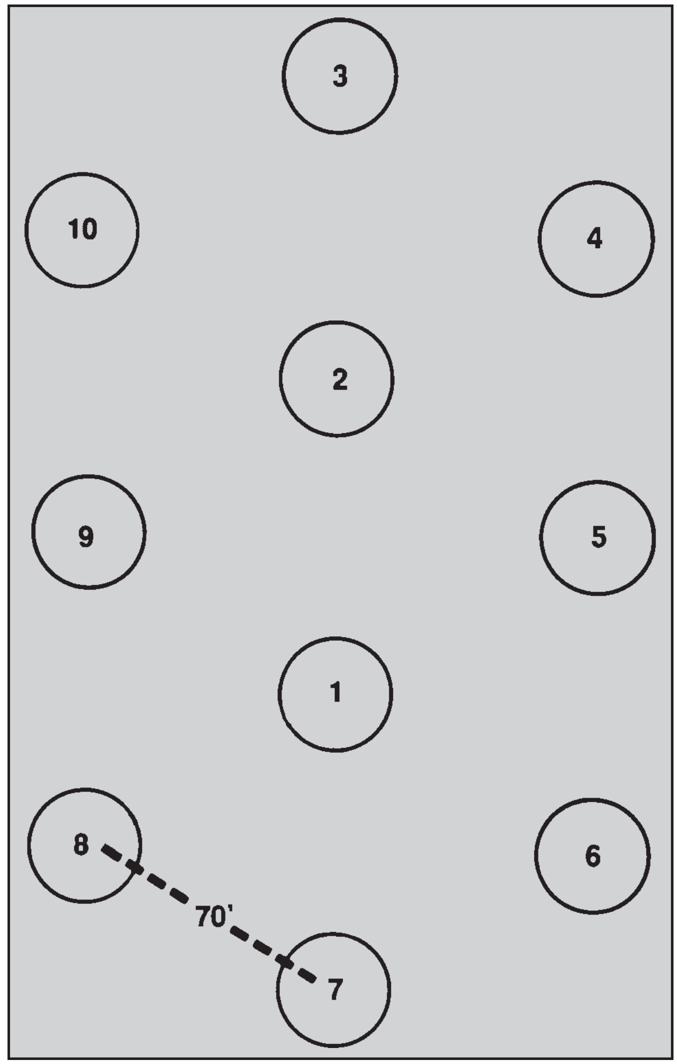


Figure 25—Diagram of a forest inventory plot. Plots used in the 1967–68 and 1980 inventories were a cluster of 10 sample points covering about an acre. Each point was located at the apex of an equilateral triangle with 70-foot sides. Measurements were collected on a variable-radius and a fixed-area plot at each point. For this study, only the first three points (1–3) were remeasured because the other 7 points did not provide complete tree information.

Sampling Methodology

The three intensive points for 130 forest inventory plots were remeasured during the 1988 and 1989 field seasons. Each point consisted of 2 subplots—a variable-radius plot (horizontal point sample) utilizing a basal-area factor of 40, and a fixed-area plot covering 1/300 of an acre. Sample trees 5 inches DBH and larger were selected with horizontal point sampling, which uses probability proportional to the cross-sectional area of a tree bole at 4.5 feet above the ground (basal area). Sample trees less than 5 inches in diameter were selected on a circular, fixed-area plot.

Appendix 2, which was prepared by John W. Hazard, describes the survey design used for the 1967–68 and 1980 inventories. It also describes the statistical analyses used for the budworm impact study, and the reliability of results reported in this report.

Information Collected

A variety of site and tree information was collected on the remeasured inventory plots, including the items described below.

Elevation (determined to nearest hundred feet).
Aspect (recorded as an azimuth, in degrees).
Slope Gradient (average of uphill and downhill readings).
Topographic Position (8 classes; stream bottom to ridgetop).
Undergrowth Plant Composition (canopy cover by species).
Tree Species.
Tree History (live, mortality, sound dead, nonsound dead, etc.).
Tree Diameter (taken at 4.5 feet above the ground, in inches).
Tree Height (total height, in feet).
Number of Stems (for grouping seedlings on the fixed plots).
Tree Growth (determined from increment cores).
Tree Age (determined from increment cores).
Crown Ratio (9 classes; 10 percent live crown ratio per class).
Crown Class (dominant, codominant, intermediate, etc.).
Damage/Death Causes (codes for 28 causes were used).
Dwarf Mistletoe Rating (used 6-class rating system).
Topkill (percent of tree height with topkill due to budworm).
Defoliation (foliage percentage missing due to budworm feeding).

Defoliation was measured by first splitting the host-tree crown into thirds, and then obtaining an ocular estimate of missing foliage for each crown third. Before completing any of the budworm-impact analyses, a defoliation value was derived for each host tree by computing a weighted mean of the crown thirds. The crown thirds were weighted using the average proportion of foliar biomass present in each third; the average biomass proportions were obtained from Crookston (1991).

To ensure that information was collected consistently—especially defoliation and topkill percentages, the canopy coverage of undergrowth plants, and other items requiring an ocular estimate—all measurements were completed by the same person (author).

Site Indices

One or more of the trees on each inventory plot were used to calculate site index, a productivity measure based on the height of dominant and codominant trees at a specific reference age (generally 50 years). Sample trees of the following species were used to calculate site indices (source of site index equations given in parentheses): white fir (Cochran 1979b), Douglas-fir (Cochran 1979a), western larch (Cochran 1985), Engelmann spruce (Brickell 1966), ponderosa pine (Barrett 1978), and lodgepole pine (Dahms 1975). It is seldom possible to compare site indices from one tree species to another because of differences in the site index relationships—reference ages vary by species, and some site curves use breast-height age, while others use total age.

Yield Capability Estimates

In order to compare productivity between tree species, mathematical equations were used that relate site indices to a yield capability value. Yield capability is the potential growth rate, in cubic feet per acre per year, of a fully-stocked stand on an area with a given site index. Yield capability equations were the same ones used in the Forest Service's stand examination program (USDA Forest Service 1987a).

Increment Core Collection

Radial growth and age were not determined in the field because severe budworm defoliation can reduce tree growth to the point where it is very difficult to discern annual rings, even with the aid of a magnifying glass. For that reason, 942 increment cores were collected during field sampling for analysis at a dendrochronology laboratory. In the field, cores were stored in plastic holders that allowed plot, point, and tree identifications to be recorded for them.

Increment Core Measurement

After field sampling, the increment cores were sent to the Dendrochronology Center at the Forestry and Range Sciences Laboratory in La Grande, Oregon, where they were removed from the plastic trays, glued into grooved wooden blocks, and sanded to fully expose their annual rings. Following this preparation phase, the cores were measured on a Bannister incremental measuring machine connected to a computer for recording and storage of the ring-width information (fig. 26). Annual increment was measured to the nearest 0.01 millimeter.

Figure 26—Budworm defoliation often causes severe growth reductions. In order to interpret the narrow growth rings of defoliated trees, cores were examined with a microscope at a dendrochronology laboratory.

Radial Increment and Age

Diameter growth was assumed to be complete by August 15th; if a core had been collected before that date, radial increment was not measured for the current year because the ring was assumed to be incomplete. For cores from older trees, annual growth was measured for the last 90 years only; total age was determined for every core. Cores from four extremely suppressed saplings could not be interpreted, even with full microscopic magnification.

Increment Core Shrinkage

Since increment cores begin shrinking immediately after removal from the tree, 76 cores collected during 1988 were marked in such a way that their shrinkage could be determined later. Why was shrinkage important? One item of information to be acquired from each core was radial increment, which involves measuring the distance (growth) between each annual ring. Obviously, radial growth values would vary depending upon whether the core was measured in a fresh condition, or after drying and shrinking had occurred. Shrinkage was minor—it averaged only 3% for the 76-core sample, and varied little depending on whether shrinkage was determined for the entire core (pith to cambium), or for the moister sapwood portion only. Douglas-fir cores had more shrinkage (3.5%) than white fir (2.5%); cores from other species averaged about 3%.

Missing Growth Rings

Constraints on time and funding did not allow the 938 usable cores to be analyzed for missing rings (see Swetnam and others 1985). Forgoing such an analysis was believed to pose little risk for misinterpreting core data because recent research indicates that missing rings are uncommon, and that nonhost species such as ponderosa pine may have more missing rings than budworm-host trees (Swetnam and Lynch 1989).

Analysis of Remeasurement Information

After completing the 1988–1989 remeasurements, plot information was loaded into computerized databases or spreadsheets for editing and analysis. Data from the 1980 measurements were also loaded for each plot; in addition, earlier information was available for some of the plots that had been established during the 1968 forest inventory. Incorporating those older measurements allowed growth trends and other historical comparisons to be made. The impact of budworm effects on future timber volume was estimated using the Blue Mountain variant of the Stand Prognosis model (see page 74).

Using Averages During Data Analysis

The budworm-impact information in this report was developed using weighted means. A mean value for budworm-caused defoliation, topkill, and mortality was calculated for 125 of the 130 remeasured inventory plots. Five plots were not used in the analysis because they had been heavily logged between the 1980 and 1988–89 measurement periods. Plot-based means were weighted using the trees/acre expansion factor associated with each sample tree. Plot weights were developed by dividing the strata areas by the number of plots in each stratum. Refer to appendix 2 for further details.

Analysis of Geographic Information

Plot remeasurements provided most of the information that was needed to evaluate budworm impacts. But some analyses required information about the spatial distribution of budworm defoliation, or the location of areas that had been treated during budworm-suppression projects. Most of this information was available on digital or paper maps, and was manipulated using a geographic information system called MOSS. Some of the map-based information was unavailable on the Malheur NF, and was obtained from the Forest Pest Management group in Portland, Oregon (see acknowledgments).

Analysis of Budworm Impacts

Information about budworm impacts was summarized for 17 descriptive factors related to tree, stand, and site characteristics affecting budworm susceptibility and vulnerability. Many of the analysis factors had been used for budworm studies in other areas of the western U.S. (Wulf and Cates 1987). Analysis factors were selected that would help land managers answer questions like these:

- How did budworm impacts (defoliation, topkill, and mortality) vary by diameter, height, age, crown class, and for other tree characteristics?

- How did budworm impacts vary with changes in elevation, site productivity, physiographic position, aspect, and for other site and stand factors?

- Did host trees in areas that were treated with an insecticide to suppress budworm populations have less damage than trees in untreated areas?

Impacts of the Budworm Outbreak

What happened during the 1980s budworm outbreak? Trees and stands were affected in a variety of ways, many of which are described below.

Defoliation

An adult western spruce budworm is a small, grayish moth. It causes tree damage in the larval (caterpillar) stages of its life cycle. Damage occurs when the larvae consume a tree's foliage and buds in a process called defoliation (fig. 27). Budworm-caused defoliation was assessed on the Malheur NF in 1988 and 1989; the results of that assessment are presented in this section of the report, beginning on page 56.

Topkilling

Topkilling occurs when budworm larvae consume the foliage and buds near the top of a tree, thereby killing that part of its stem (fig. 28). Even if defoliation is not severe enough to kill the top, height growth is reduced or eliminated during each year that feeding occurs. Budworm-caused topkilling was assessed on the Malheur NF in 1988 and 1989; the results of that assessment are presented in this section of the report, beginning on page 56.

Direct Mortality

Direct mortality occurs when budworm defoliation occurs long enough to kill trees directly (fig. 29). During the 1980s outbreak, budworm had a pronounced effect on tree mortality in mixed-conifer forests of the Blue Mountains (fig. 30). Budworm-induced mortality was assessed on the Malheur NF in 1988 and 1989; the results of that assessment are presented in this section of the report, beginning on page 56.

Indirect Mortality

Indirect mortality occurs in two situations: 1) when defoliation stress predisposes trees to be killed by bark beetles, drought, or other causes; and 2) when trees which were stressed before defoliation began—such as Douglas-firs infected with dwarf mistletoe, or any host tree weakened by suppression—died after being defoliated by budworm. Some examples of indirect mortality are provided by figures 31–34.

Reduced Tree Growth

Growth reductions occur after a tree has lost enough foliage to inhibit photosynthesis, which is the biochemical process that trees use to create wood fiber. Radial growth usually starts declining during the year that budworm feeding begins, and is progressively reduced with each additional year of defoliation. After an outbreak collapses, defoliated trees require several years to replace their missing foliage. During that period, growth rates slowly recover to their pre-outbreak level. Tree growth was analyzed and the results are provided by figures 35–40.

Reduced Volume Production

Fiber production declines as defoliated trees experience reduced diameter and height growth. Figure 41 shows that form defects increased significantly between 1980 and 1989; much of that increase resulted from the multiple leaders caused by topkill. Forks, crook, sweep, and other form-related defect occurs after topkilling causes lateral branches to turn upward and attempt to gain dominance as a tree's new top (fig. 42). The effect of budworm impacts on future timber yields is also assessed in this section of the report (see page 74).

Figure 27—Defoliation occurs as budworm larvae (caterpillars) feed on host trees. This Douglas-fir seedling is missing at least half of its normal foliage as a result of budworm defoliation. Although host trees in all size categories were defoliated to some extent during the 1980s budworm outbreak, smaller trees sustained significantly more damage (see fig. 44). Generally, seedlings of this size had less missing foliage than saplings (trees with diameters of 1.0 to 4.9 inches). This seedling has short spaces between each set of branches on the stem (the spaces are called internodes), which indicates that it is suppressed. Suppressed and intermediate trees were much more likely to be killed by budworm than taller, dominant trees (see fig. 50).

Figure 28—When budworm defoliation persists near the top of a host tree's crown, topkill is often the result. Many of the small Douglas-firs shown here have dead tops caused by budworm defoliation. As budworm larvae feed in the upper part of a tree, they also destroy most of the developing cones, reducing seed production and natural regeneration capacity. Dead tops with a basal diameter of three inches or more are likely to result in stem decay (Ferrell and Scharpf 1982). Topkill is also responsible for stem deformity (fork, crook, or sweep) affecting a tree's merchantable volume (see figure 41). In addition to topkill, defoliation caused by herbivorous insects can cause significant and sustained tree-growth reductions (fig. 35) and ultimately tree mortality (fig. 29); mortality tends to be a function of both the magnitude and persistence of defoliation.

Figure 29—Occasionally, budworm kills a substantial number of the host trees in an area. This photograph shows a distant view of Starr Ridge on Bear Valley Ranger District. In the late 1970s, most of the old-growth ponderosa pine in this area was harvested using helicopters. The residual stands were comprised mostly of Douglas-firs, many of which were infected with dwarf mistletoe. Note that budworm did not provide a uniform, evenly-distributed thinning—trees were often killed in groups.

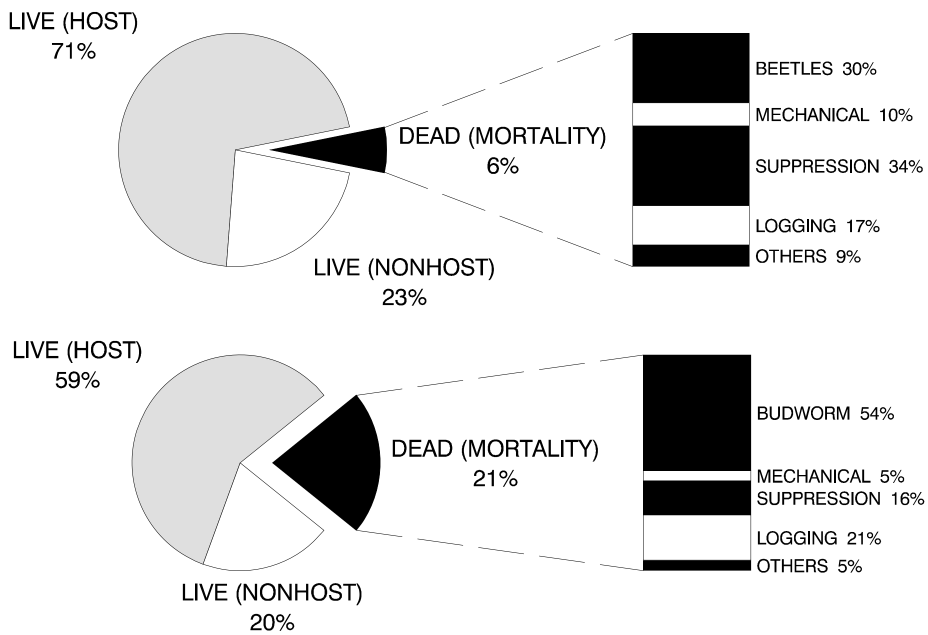


Figure 30—Proportions by tree class, and causes of mortality, for 130 mixed-conifer inventory plots measured in 1980 and 1988–1989. In 1980 (top half of figure), only 6% of all trees had been recently killed (mortality), with bark beetles and suppression being the two main causes. By 1988–1989 (bottom half of figure), mortality had increased substantially to 21% of all trees; bud-worm was responsible for more than half of the mortality, but logging and suppression also caused significant losses.

Figure 31—Defoliation, drought, root diseases, and other causes of stress can increase a tree's susceptibility to attack by bark beetles. The white firs in the center of this photograph were killed by fir engraver beetles; fir engraver and Douglas-fir beetle caused widespread damage on the Malheur NF during the late 1980s and early 1990s (see figures 2 and 32). An important cause of stress during the 1980s was spruce budworm defoliation—it not only contributed to fir engraver attacks, but was also responsible, in large part, for the widespread mortality caused by Douglas-fir beetle. Trees defoliated by budworm are also more likely to be killed during a tussock-moth outbreak; several small tussock-moth outbreaks occurred on the Malheur NF in 1992 and 1993.

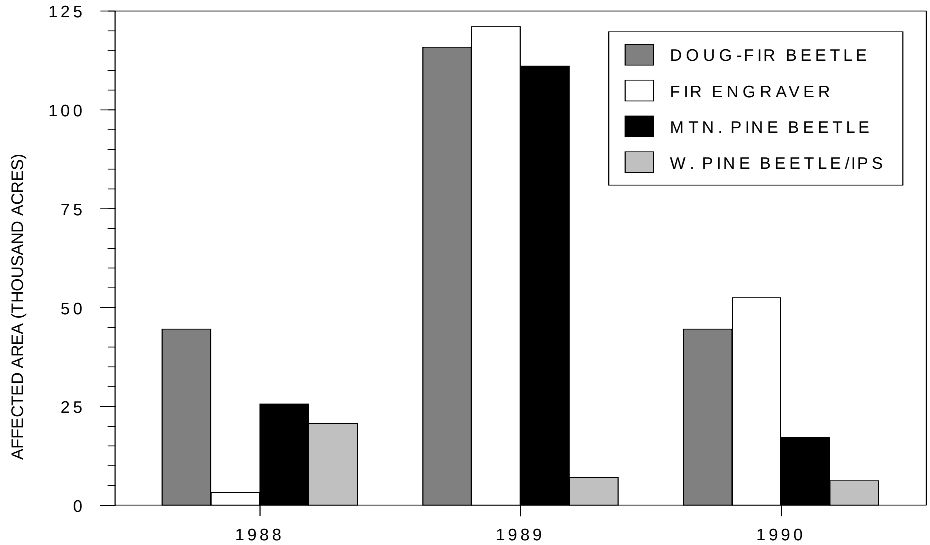


Figure 32—Tree mortality caused by bark beetles on the Malheur NF, 1988–1990. The acreage of bark-beetle mortality shown here occurred because stands had been weakened by budworm defoliation, and by reduced precipitation between 1986 and 1990. But which of those factors had the most influence? Figure 33 provides precipitation information for two stations located near the Malheur NF, and it suggests that bark-beetle mortality was affected more by budworm stress than by precipitation.

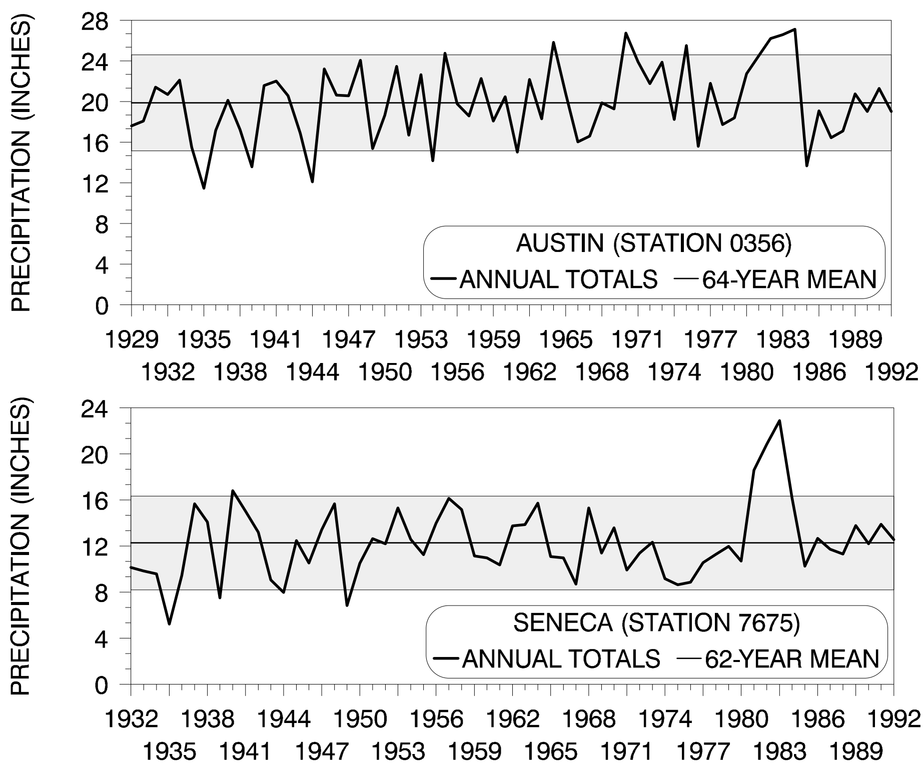


Figure 33—Precipitation record for Austin and Seneca, Oregon. These weather stations are located on the northern (Austin) and southern (Seneca) parts of the Malheur NF. During the 1985–1992 "drought," precipitation ranged from 8% below (Austin) to .3% above (Seneca) the long-term means. Normal precipitation (not unusually high or low) is defined as 80% of the variation around the station's long-term mean (the gray zone in the charts above); all of the late 1980s precipitation values fall in the normal range.

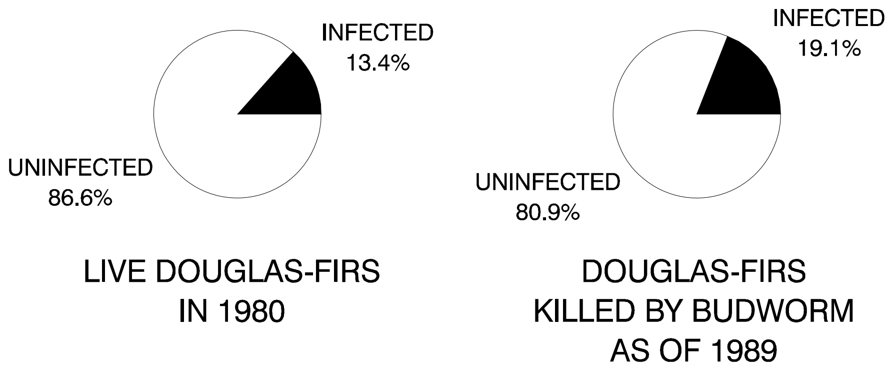


Figure 34—Effect of dwarf mistletoe infection on budworm-induced tree mortality. In 1980, 13% of the live Douglas-firs on 130 mixed-conifer inventory plots were infected with dwarf mistletoe (left chart). When those plots were remeasured in 1988–1989, 19% of the Douglas-firs that were killed by spruce budworm had dwarf mistletoe infections in 1980 (right chart). This figure indicates that Douglas-firs infected with dwarf mistletoe were killed by budworm more often than would be expected based on the infection frequency for live trees. Presumably, infected Douglas-firs were killed more often than uninfected trees because dwarf mistletoe causes physiological stress, which would predispose those trees to budworm-induced mortality. Research studies have not shown statistically significant interactions between dwarf mistletoe and budworm in Douglas-fir stands (Filip 1993).

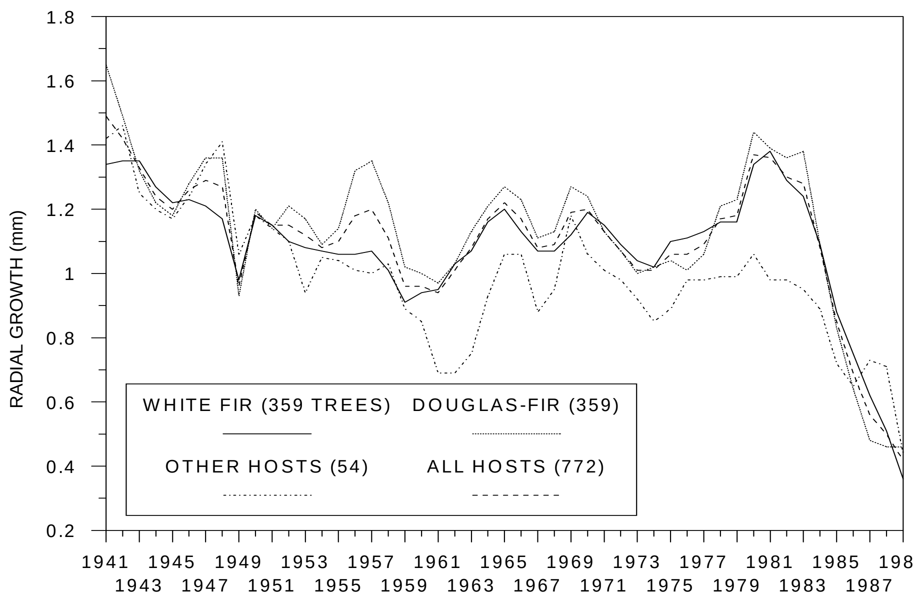


Figure 35—Radial growth for budworm host species, 1941 to 1989. Growth of white fir, Douglas-fir, and other hosts (Engelmann spruce, subalpine fir, and western larch) has generally followed a similar pattern during this 50-year period. Beginning about 1960, radial growth for other hosts was considerably less than for white fir or Douglas-fir. Host-tree growth began declining rapidly in 1983 or 1984, which is when budworm defoliation began to have an effect on radial increment. As of 1989, growth was still heading down for white fir and other hosts, whereas Douglas-fir increment had levelled out. Since radial increment has not yet turned upward for any species, no more than half of the budworm-induced growth losses are shown in this figure.

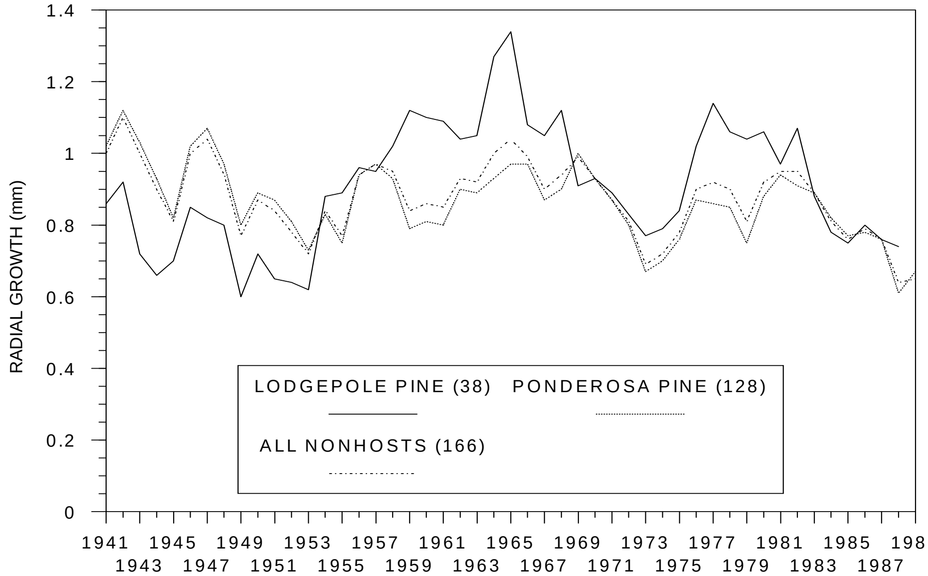


Figure 36—Radial growth for nonhost species from 1941 to 1989. Unlike the situation for host trees (figure 35), the growth of ponderosa pine and lodgepole pine has not always followed the same pattern during this 50-year period. Before the early 1950s, lodgepole pine growth was slower than ponderosa pine growth; after about 1957, lodgepole pine increment was usually higher than ponderosa pine's by a substantial amount. Lodgepole pine growth was not included for 1989 because of its small sample size—only 5 of the 38 lodgepole pines had a 1989 growth value.

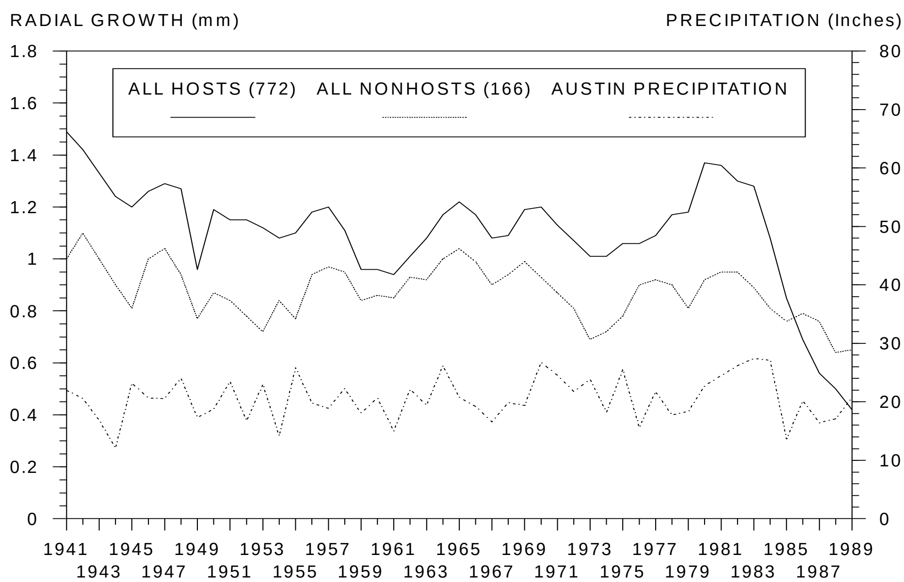


Figure 37—Radial growth for host and nonhost trees, and precipitation for Austin, Oregon, for 1941–1989. Host-tree growth was always higher than nonhost growth until about 1985, after which budworm defoliation caused substantial reductions. The growth of both host and nonhost trees has generally followed a pattern similar to that of precipitation. Note that the spruce budworm epidemic of 1944–1958 had no apparent effect on radial growth, or at least no discernable effect when considering all 772 host trees. But when growth is analyzed for certain plots known to have been affected by the 1944–1958 outbreak, an effect is apparent (figure 38).

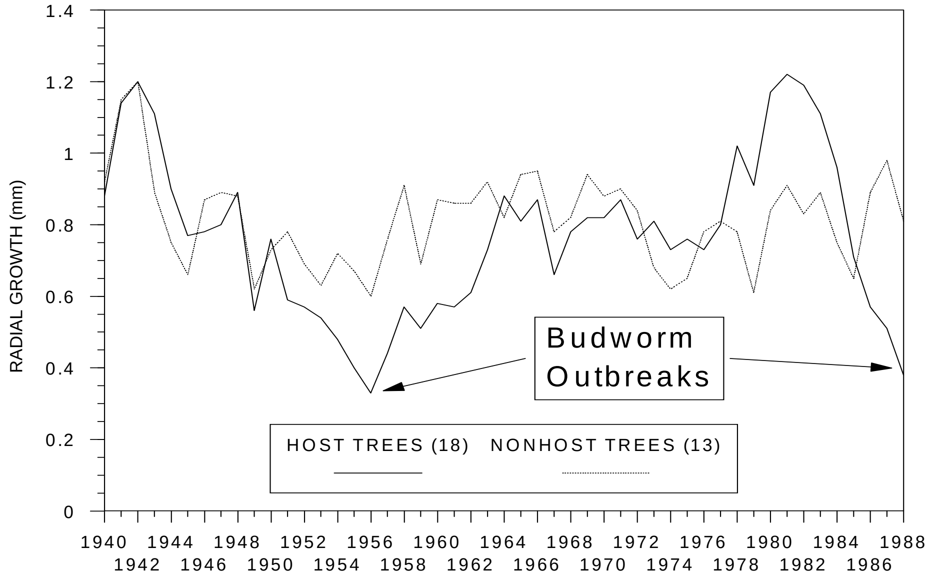


Figure 38—Radial growth for host and nonhost trees on inventory plots affected by the 1944–1958 budworm outbreak. The Blue Mountains had two outbreaks during the last 50 years—one from 1944 to 1958, and the present one that began in 1980 (see fig. 5). Can any effect of the 1944–1958 outbreak be seen in the radial increment of host trees? Figure 37 showed that if all 772 host trees are considered together, there is no apparent effect. This chart shows radial increment for host and nonhost trees from plots that were severely defoliated during the 1944–1958 outbreak. Not only is the earlier outbreak clearly evident, but the 1980s epidemic is obvious too.

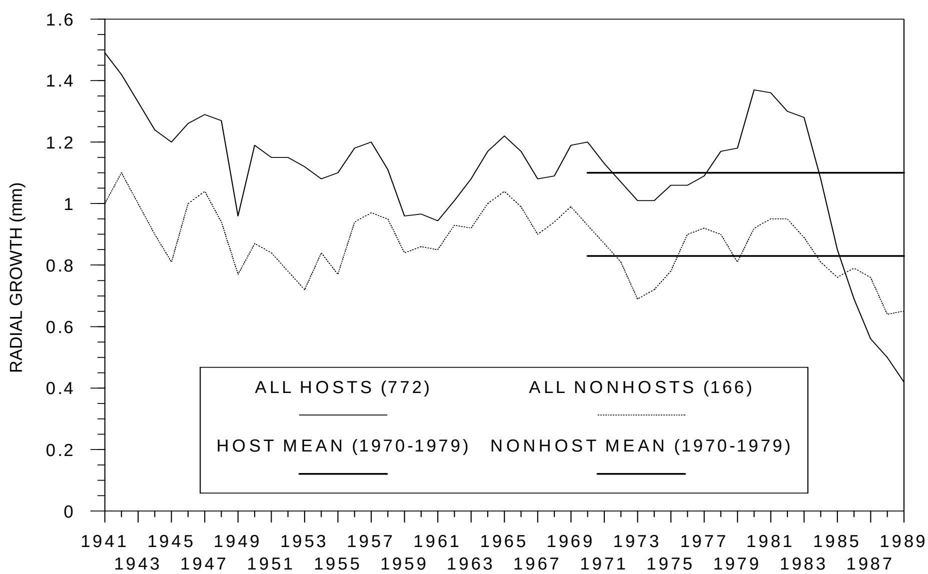


Figure 39—Host and nonhost tree growth for 1941–1989, and mean growth for 1970–1979. In 1989, host trees were growing 62% less than their mean for 1970–79, whereas nonhost trees were growing 22% below their 1970–79 mean. If nonhost growth reflects the effect of precipitation and factors other than budworm, then the growth loss from defoliation would be about 40% (62% – 22%). Host trees were growing below their 1970–79 mean from 1984 to 1989; during that period, cumulative growth loss amounted to 38%. Cumulative growth loss for nonhost trees was only 11%, which indicates that budworm-related losses for 1984–1989 were about 27% (38% – 11%).

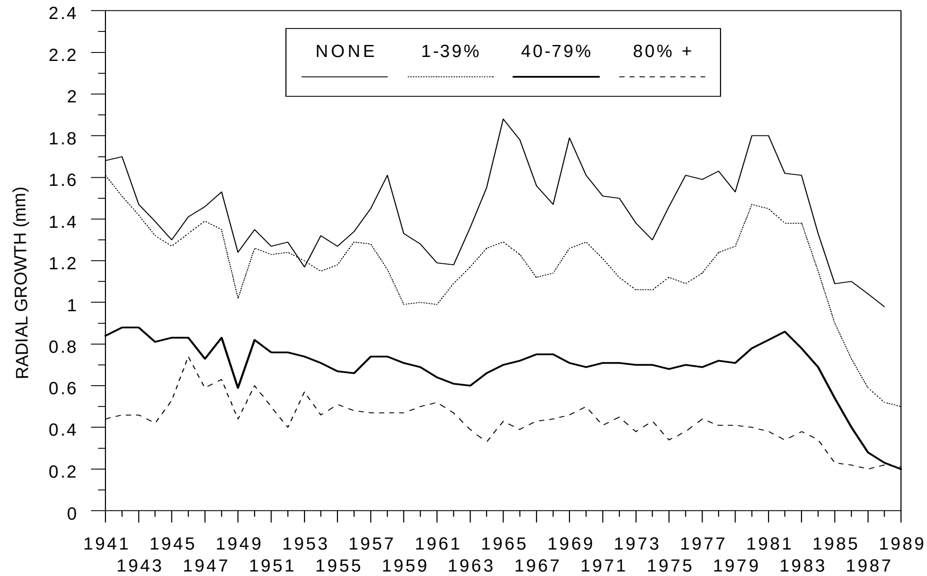


Figure 40—Radial growth for host trees by defoliation percentage. This chart reinforces the relationship between crown class and defoliation (fig. 50): dominant trees had little defoliation and have always grown well, whereas intermediate and overtopped trees had heavy defoliation and have always grown slowly. Trees with no missing foliage in 1988–89 were growing 35% less than their 1970–79 mean in 1988. In 1989, trees with 1–39% defoliation were growing 57% less than their 1970–79 mean; trees with 40–79% defoliation were growing 71% less; and trees with defoliation of 80% or more were growing 50% less. Growth in 1989 is not included for trees with no defoliation due to a small sample size.

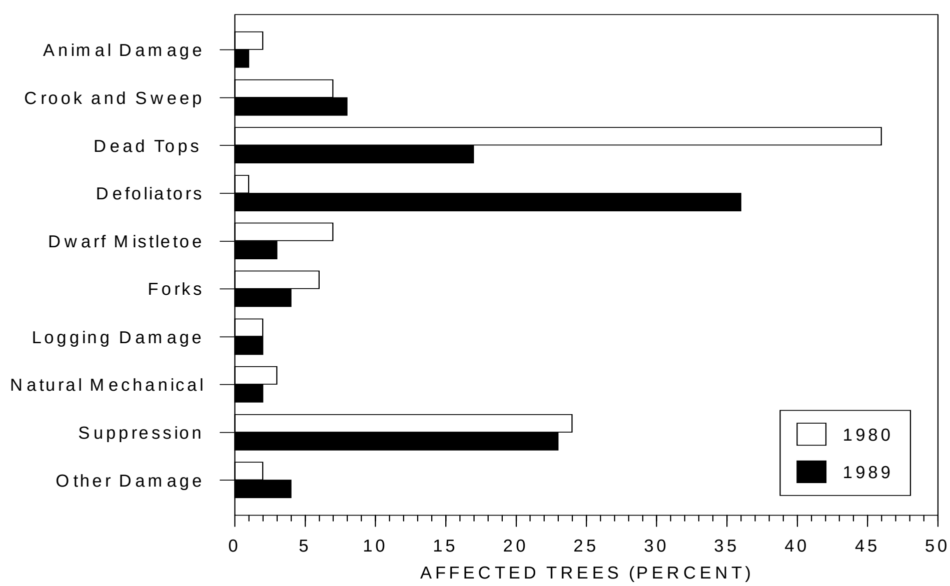


Figure 41—Comparison of live-tree damages in 1980 and 1988–1989. There was little change between 1980 and 1989 for many damages, but the percentage of trees affected by defoliation increased significantly. The proportion of trees with dead tops seems to have declined dramatically. That is actually not the case because if a host tree had both topkill and defoliation, the most serious of the two was coded as the primary damage. Since 89% of the sampled host trees had topkill of 10% or less, defoliation was often coded as the more serious damage.

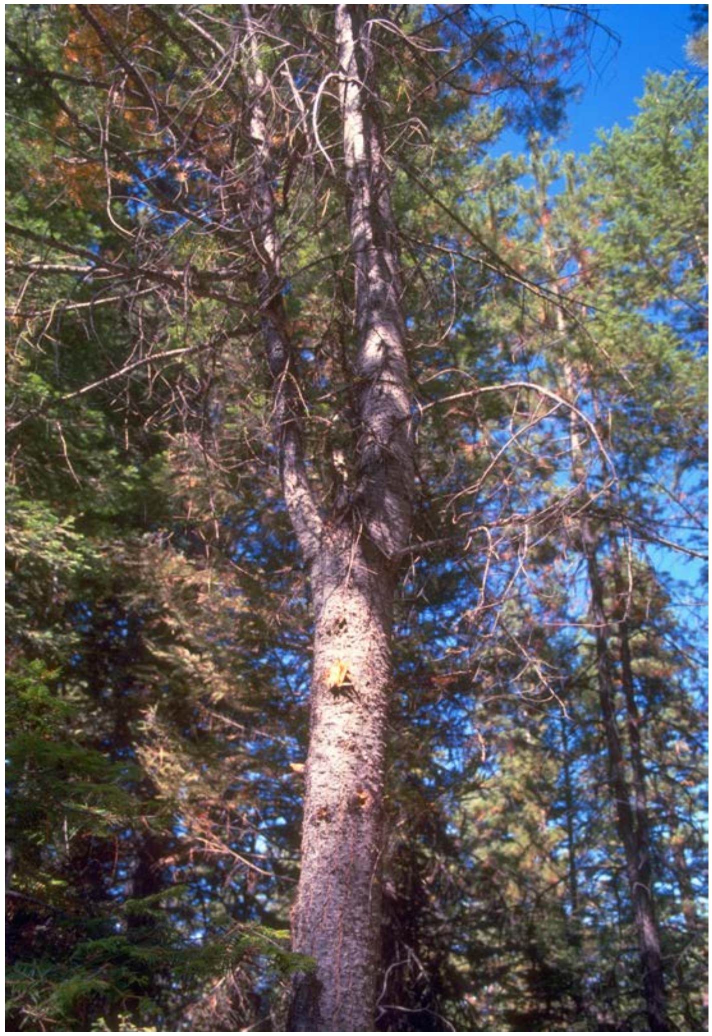


Figure 42—After budworm populations collapse and defoliation ceases, there can still be long-term repercussions from impacts associated with the outbreak. One frequent consequence of budworm-induced topkill is form defect, such as the large, deep fork in this Douglas-fir. A fork this low on the bole can significantly reduce a tree's merchantable volume. Research has shown that form defects (forks, crooks, sweeps, etc.) seldom result in volume losses exceeding 5% (Ferrell and Scharpf 1982), but board-foot reductions can be much higher than that for a defect like the one shown here. Not only are host trees with large topkills more susceptible to form defect, but they also have a much higher risk of stem decay (Filip and Schmitt 1990).

Analysis of Budworm-Caused Impacts

Budworm impacts were analyzed using the 17 factors described below. Each of the 17 factors was analyzed individually, as though all other factors were held constant or otherwise accounted for. But in reality, budworm reacts to its environment as a whole; the effect of any particular habitat component may be influenced by others. It is important to realize that many of the site and stand variables are interrelated. For those reasons, and because the sample data do not represent an unlimited range of site and stand conditions, any conclusions should not be formed on the basis of a single analysis factor. Readers should look for commonality among all of the variables, especially those that are closely related, before arriving at any conclusions.

Budworm Impacts By Tree Species

Budworm impacts were summarized for these host species or groupings (fig. 43): white fir (74% of the remeasured plots had white firs), Douglas-fir (89% of the remeasured plots), and other hosts (western larch, subalpine fir, and Engelmann spruce; 25% of the remeasured plots). Since other hosts comprised such a small proportion of the sample—only 3.4% of the trees sampled for budworm impacts—they were ignored when analyzing the other factors.

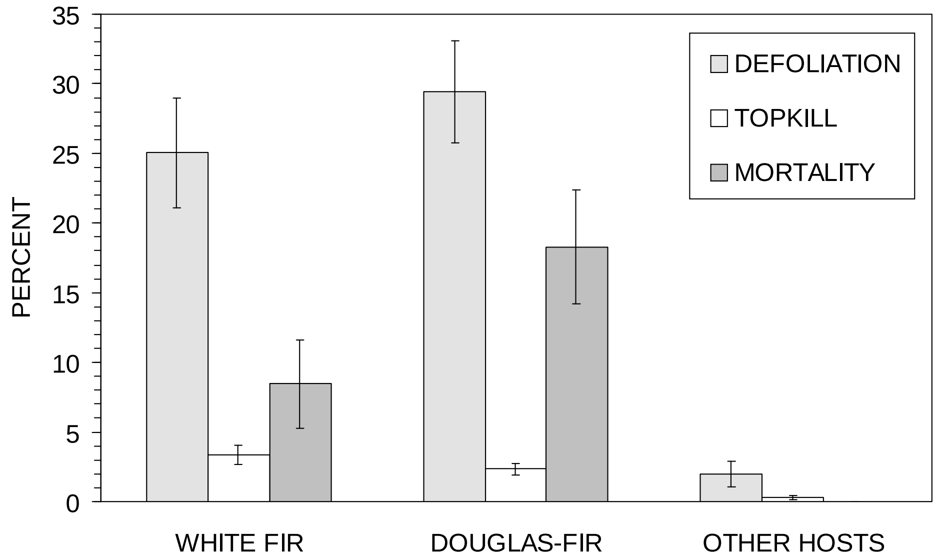


Figure 43—Budworm impacts by host species. Douglas-fir sustained the most defoliation, whereas white fir had the most topkill. Budworm-caused mortality was significantly greater for Douglas-fir than for white fir, and nonexistent for other hosts. The absence of budworm-induced mortality for other hosts was not surprising when considering their low levels of defoliation and topkill. These results differ somewhat from those for the northern Rocky Mountains, where defoliation is said to be greatest on grand fir (Carlson and Wulf 1989). They also differ somewhat from the budworm impacts observed during the 1944–1958 outbreak in the Blue Mountains. When Williams (1966) assessed budworm effects in mixed-conifer stands on the Wallowa National Forest in 1958–1959, he found that defoliation-related damage was greatest and most variable on grand fir, and least for Douglas-fir.

Defoliation means are the percentage of a tree's foliage that was missing as a result of budworm feeding. Topkill means are the percentage of a tree's height that consisted of a dead top caused by budworm. Mortality means are the percentage of all Douglas-fir and white fir trees (live and dead combined) that were killed by budworm feeding. Error bars are the standard error of the stratified mean estimate.

Budworm Impacts By Tree Diameter

Budworm impacts were summarized for four classes of tree diameter (fig. 44), as measured at breast height (DBH): seedlings (trees less than 1 inch DBH; 78% of the remeasured plots had host-tree seedlings), 1–4.9 inches DBH (60% of the remeasured plots), 5–9.9 inches DBH (70% of the remeasured plots), and 10 inches DBH and greater (94% of the remeasured plots).

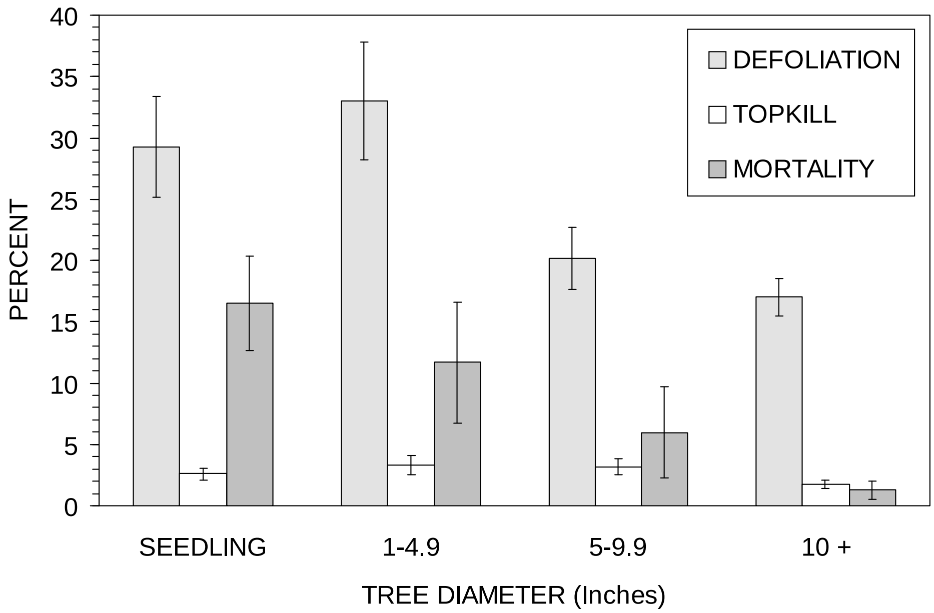


Figure 44—Budworm impacts by tree diameter. Defoliation was significantly greater for small trees (those less than 5" DBH) than for large ones. Topkill amounts were relatively constant, although large trees (10" DBH and greater) did have the lowest percentage. Budworm-induced mortality declined steadily as tree diameter increased, although the differences were not statistically significant except for large trees (10"+ DBH). This figure suggests that small trees are much more likely to be killed by budworm than large-diameter trees. Smaller trees had high mortality for two main reasons—they had poor vigor and were least able to withstand the effects of budworm feeding, and budworm larvae dispersing from taller trees tended to fall onto them and continue feeding in what is referred to as a "feeding ladder" effect (see fig. 20). Because small trees were killed most often, there were few opportunities to salvage the budworm-caused mortality.

Defoliation means are the percentage of a tree's foliage that was missing as a result of budworm feeding. Topkill means are the percentage of a tree's height that consisted of a dead top caused by budworm. Mortality means are the percentage of all stems (live and dead combined) that were killed by budworm defoliation. Means were computed using the Douglas-fir and white fir sample trees only (other hosts were excluded). Error bars are the standard error of the stratified mean estimate.

Budworm Impacts By Tree Height

Budworm impacts were summarized for 4 classes of tree height (fig. 45): 6 inches–10 feet (81% of the remeasured plots had host trees in that height category), 11–40 feet (66% of the remeasured plots), 41–80 feet (90% of the remeasured plots), and 81 feet and greater (49% of the remeasured plots). Seedlings smaller than 6 inches were not sampled during the plot remeasurements.

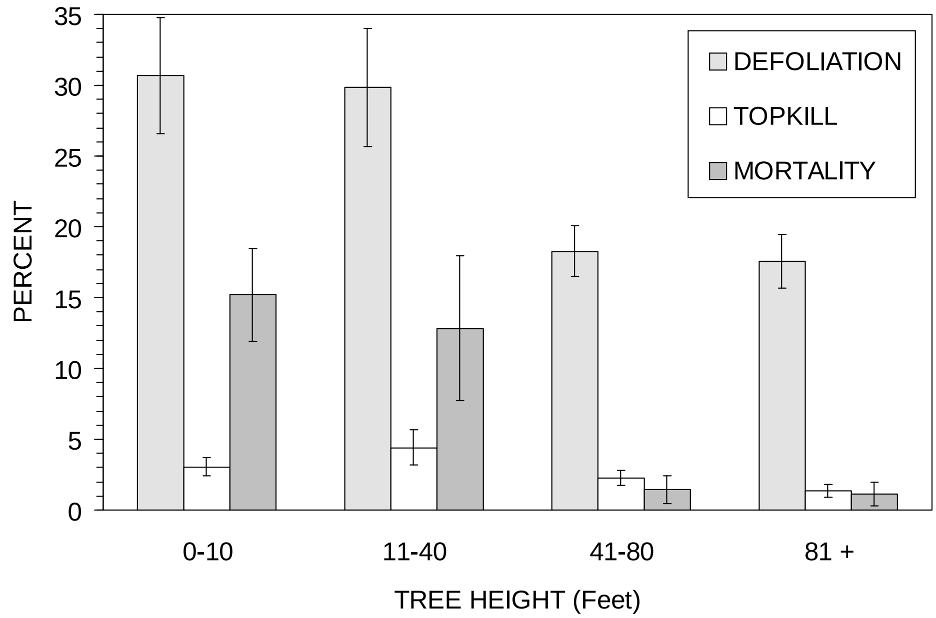


Figure 45—Budworm impacts by tree height. Trees less than 41 feet in height had relatively high amounts of defoliation, topkill, and mortality when compared to taller trees. This figure suggests that shorter trees are much more likely to be affected by budworm feeding than taller trees. Shorter trees sustained high mortality for two primary reasons—they had poor vigor and were least able to withstand the effects of budworm feeding, and budworm larvae dispersing from taller trees tended to fall onto them and continue feeding in what is referred to as a "feeding ladder" effect (see fig. 20).

Defoliation means are the percentage of a tree's foliage that was missing as a result of budworm feeding. Topkill means are the percentage of a tree's height that consisted of a dead top caused by budworm. Mortality means are the percentage of all stems (live and dead combined) that were killed by budworm defoliation. Means were computed using the Douglas-fir and white fir sample trees only (other hosts were excluded). Error bars are the standard error of the stratified mean estimate.

Budworm Impacts By Tree Age

Budworm impacts were summarized for 3 classes of tree age (fig. 46): 1–40 years (66% of the remeasured plots had host trees in that age range), 41–80 years (80% of the remeasured plots), and 81 years and greater (73% of the remeasured plots). Since age was available for live trees only, budworm-induced mortality could not be assessed for this factor.

For trees 3 inches or more in diameter, age was determined at 4.5 feet above the ground; for seedlings and saplings smaller than 3 inches DBH, it was determined between ground line and a height of 1 foot. Age was deter-mined from the increment cores for all trees that were large enough to provide a core; for smaller trees, age was determined by counting branch whorls.

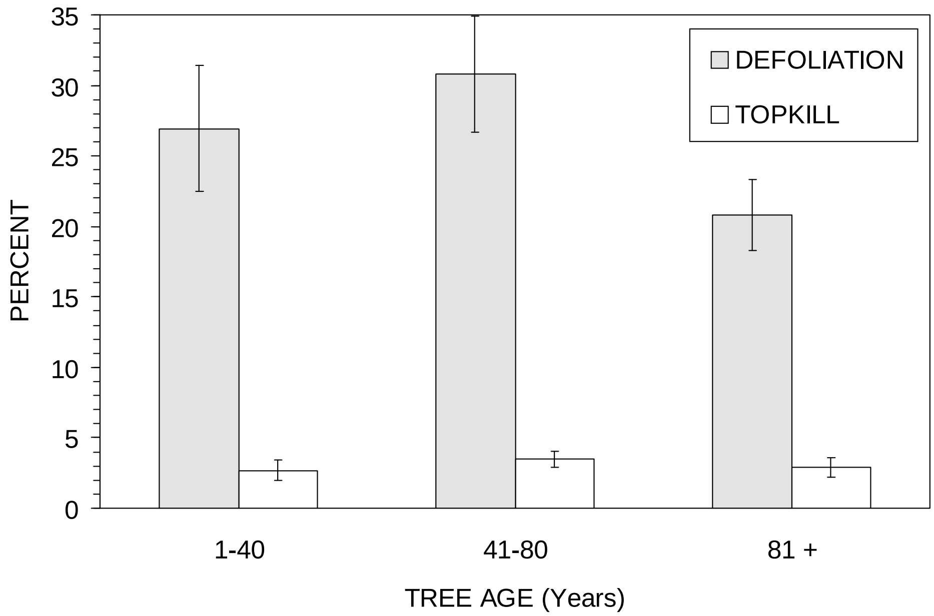


Figure 46—Budworm impacts by tree age. Some investigators believe that budworm susceptibility increases as trees mature (Carlson and Wulf 1989). Apparently, these results do not agree with that contention since the oldest trees had the least amount of defoliation, although differences between age classes were not always significant. Theoretically, old trees have high suscep-tibility because of low vigor, and because their larger size provides more foliar biomass as budworm habitat. In this study, younger trees had high susceptibility because they typically occurred in the overtopped and interme-diate crown classes, both of which have low vigor, and because most bud-worm habitat was provided by small trees as a result of their abundance—about 84% of the sampled trees were less than 20 feet tall.

Defoliation means are the percentage of a tree's foliage that was missing as a result of budworm feeding. Topkill means are the percentage of a tree's height that consisted of a dead top caused by budworm. Means were com-puted using the Douglas-fir and white fir sample trees only (other hosts were excluded). Error bars are the standard error of the stratified mean estimate.

Budworm Impacts By Stand Density

Budworm impacts were summarized for 3 classes of stand density (fig. 47): a stand density index (SDI) of 0–150 (18% of the remeasured plots had an SDI in that range), an SDI of 151–260 (41% of the remeasured plots), and an SDI greater than 260 (42% of the remeasured plots). Stand density index calculations included all trees (hosts and nonhosts) that were alive in 1980, including those which subsequently died from any cause, and trees that got established between the 1980 and 1989 measurements (ingrowth). (Note: stand density index is the number of trees per acre that a stand would have at a quadratic mean diameter of 10 inches.)

The three categories analyzed for this factor were intended to encompass stand densities below the "management zone" (SDIs of 0–150), densities within the management zone (SDIs of 151–260), and densities above the management zone (SDIs greater than 260) for mixed-conifer forests of the Blue Mountains (Cochran and others 1994).

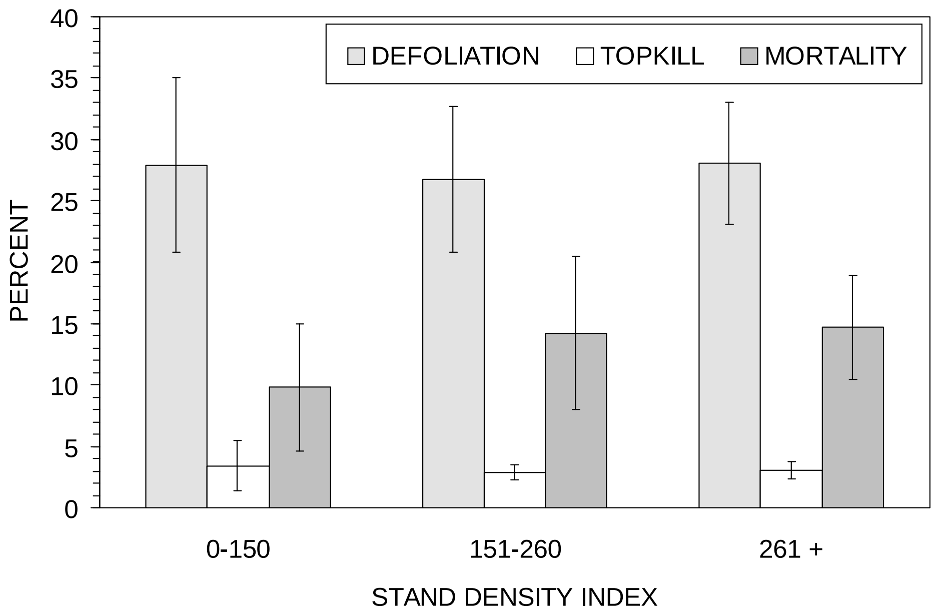


Figure 47—Budworm impacts by tree density. Some investigators believe that overstocked, dense forests are most susceptible to budworm damage (Carlson and Wulf 1989). These results seldom support that assertion because defoliation and topkill varied little with changes in density. Budworm-induced mortality was greater for plots having a stand density index of 151 or more when compared to plots with an index of 150 or less, although the differences were not statistically significant.

Defoliation means are the percentage of a tree's foliage that was missing as a result of budworm feeding. Topkill means are the percentage of a tree's height that consisted of a dead top caused by budworm. Mortality means are the percentage of all stems (live and dead combined) that were killed by budworm defoliation. Means were computed using the Douglas-fir and white fir sample trees only (other hosts were excluded). Error bars are the standard error of the stratified mean estimate.

Budworm Impacts By Live Crown Ratio

Budworm impacts were summarized for 3 classes of live-tree crown ratios (fig. 48): 10–30 percent crown ratio (51% of the remeasured plots had host trees in that category), 40–60 percent crown ratio (87% of the remeasured plots), and 70 percent crown ratio or greater (92% of the remeasured plots). Although budworm-caused mortality could not be assessed for this factor because dead trees have no live crown, research has shown that trees with small crown ratios have a high probability of being killed by budworm defoliation (Ferguson 1988).

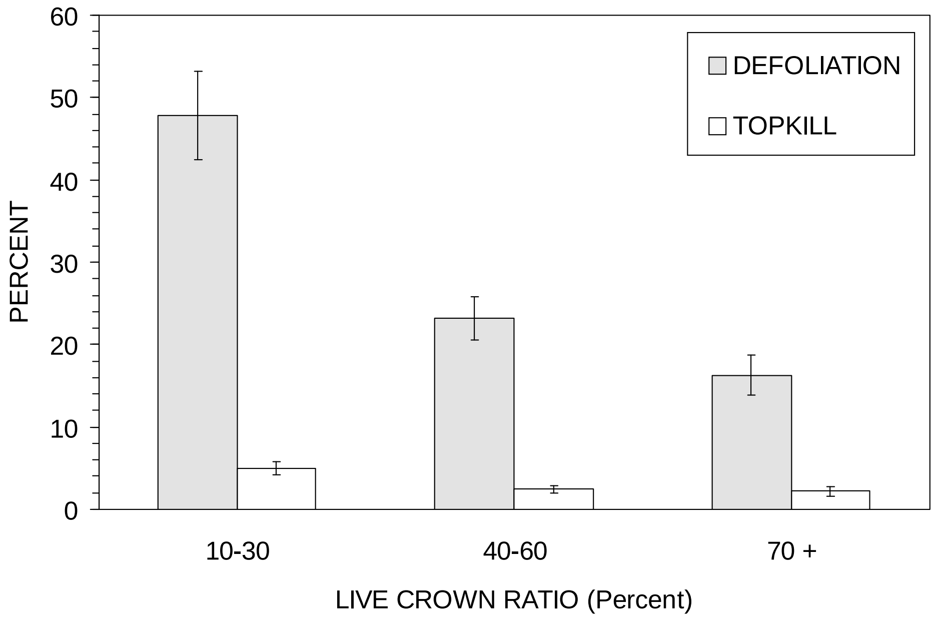


Figure 48—Budworm impacts by live crown ratio. This chart shows that trees with the smallest, shortest crowns were missing the greatest proportion of their foliage as a result of budworm defoliation; they also had the highest amount of topkill. Defoliation and topkill percentages declined as live crown ratio increased. The pattern of defoliation shown above is similar to the trend by crown class (fig. 50), probably because many trees in the overtopped and intermediate crown classes also had low crown ratios.

Defoliation means are the percentage of a tree's foliage that was missing as a result of budworm feeding. Topkill means are the percentage of a tree's height that consisted of a dead top caused by budworm. Means were computed using the Douglas-fir and white fir sample trees only (other hosts were excluded). Error bars are the standard error of the stratified mean estimate.

Budworm Impacts By Crown Class

Crown class is a measure of a tree's position in the forest canopy (fig. 49). Budworm impacts were summarized for 3 crown classes (fig. 50): suppressed or overtopped trees (78% of the remeasured plots had host trees in those crown classes), intermediate trees (80% of the remeasured plots), and dominant and codominant trees (98% of the remeasured plots).

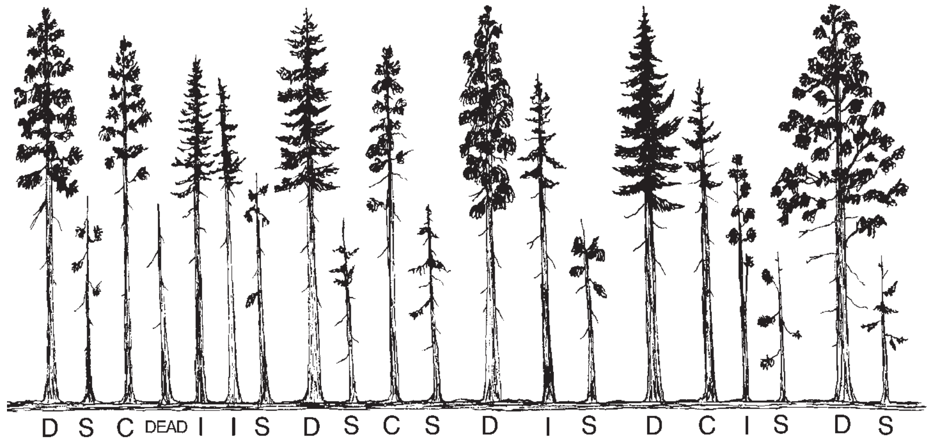


Figure 49—Crown classes. Crown classes classify a tree's position in the forest canopy. Dominant trees (D) have crowns that rise above the general canopy, where they enjoy full light from above and, to a certain degree, from the sides. Codominant trees (C) are not quite as tall; their crowns are usually hemmed in from the side. Intermediate trees (I) occupy a subordinate position; they have competition from the sides, but usually receive some overhead light through canopy holes. Suppressed trees (S) are overtopped entirely. Suppressed trees that can tolerate shade (such as true firs) may exist on the filtered sunlight they receive for many decades; suppressed trees that cannot tolerate shade (pines, etc.) will often die much more quickly than that.

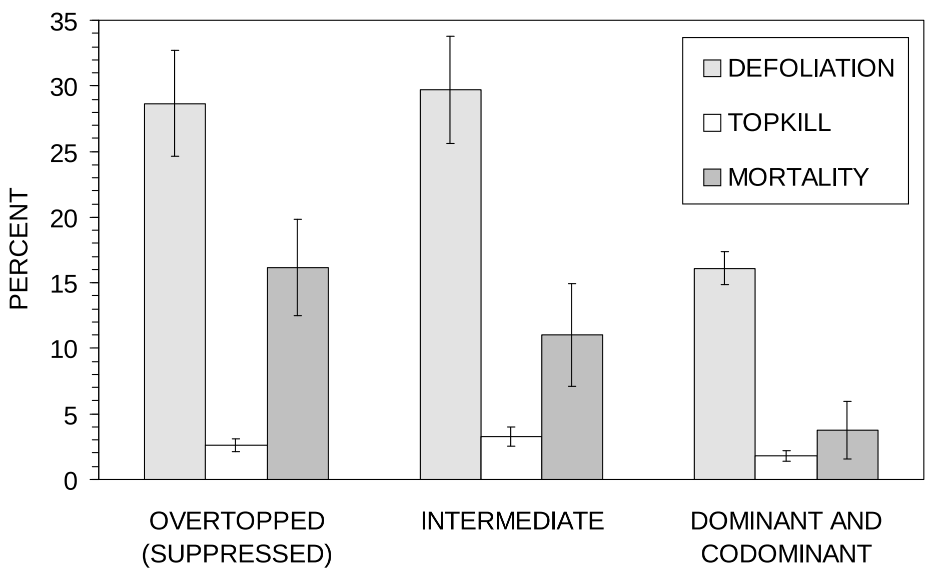


Figure 50—Budworm impacts by crown class. Defoliation was significantly less for upper-canopy trees (dominants and codominants) than for overtopped or intermediate trees. Topkill was minor in any instance, and varied little with changes in crown class. Mortality was strongly related to crown class—host trees in the overtopped and intermediate crown classes had significantly higher mortality than codominant and dominant trees. Defoliation means are the percentage of a tree's foliage that was missing as a result of budworm feeding. Topkill means are the percentage of a tree's height that consisted of a dead top caused by budworm. Mortality means are the percentage of all stems (live and dead combined) that were killed by budworm defoliation. Means were computed using Douglas-firs/white firs only (other hosts were excluded). Error bars are the standard error of the stratified mean estimate.

Budworm Impacts By Site Productivity

Budworm impacts were summarized for 3 classes of potential growth (fig. 51), in cubic feet per acre per year (cf/ac/yr): 20–39 cf/ac/yr (34% of the remeasured plots had a productivity value in that range), 40–59 cf/ac/yr (46% of the remeasured plots), and 60 cf/ac/yr and greater (21% of the remeasured plots). Productivity class was based on 444 site trees that were measured on the 130 inventory plots (see "Site Indices" and "Yield Capability Estimates" on pages 42–43). Productivity estimates may be conservative because 85% of the site trees were budworm hosts; underestimation of site index would be expected for host trees because their height is more likely to have been affected by previous defoliator damage. (Most site index curves caution users against selecting trees that may have sustained previous top damage.) From an ecological perspective, site index was not underestimated unless it is assumed that all future defoliator outbreaks will be suppressed, or that host trees will be an insignificant component of the future stands.

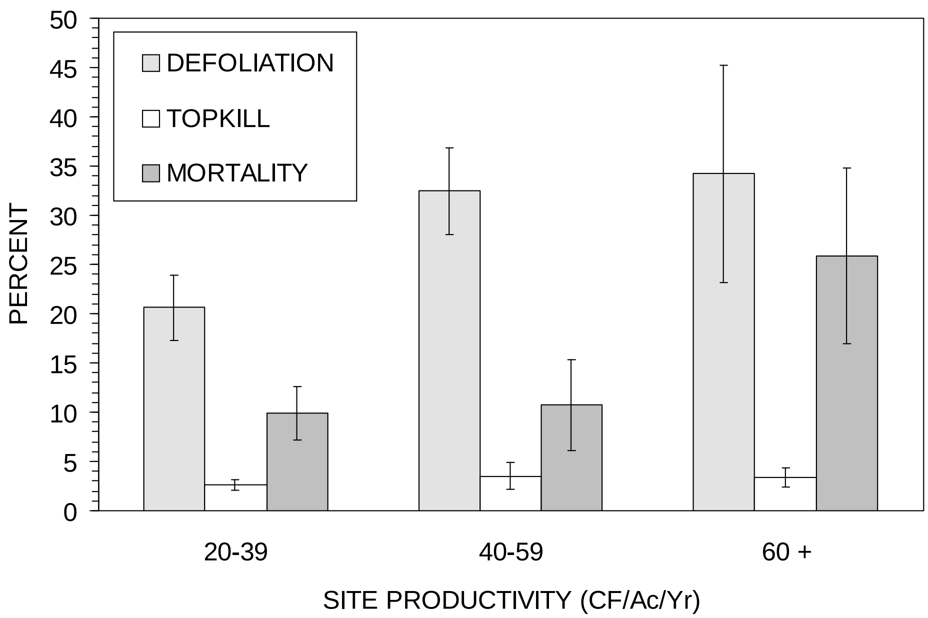


Figure 51—Budworm impacts by site productivity. Defoliation, mortality, and topkill impacts were greatest on sites with moderate or high productivity, although the differences between productivity categories were not always significant. Budworm-induced mortality was significantly greater for the highly productive sites (60 +) when compared to the low or moderate productivity groups. These results for the high-productivity category (60 +) are similar to those for the low, sheltered physiographic positions (fig. 55), indicating that the highly productive plots often occurred on those slope positions.

Defoliation means are the percentage of a tree's foliage that was missing as a result of budworm feeding. Topkill means are the percentage of a tree's height that consisted of a dead top caused by budworm. Mortality means are the percentage of all stems (live and dead combined) that were killed by budworm defoliation. Means were computed using the Douglas-fir and white fir sample trees only (other hosts were excluded). Error bars are the standard error of the stratified mean estimate.

Budworm Impacts By Elevation

Budworm impacts were summarized for 3 elevation classes (fig. 52): less than 4,900 feet (23% of the remeasured plots occurred in that elevational range), 5,000–5,900 feet (58% of the remeasured plots), and 6000 feet and greater (19% of the remeasured plots).

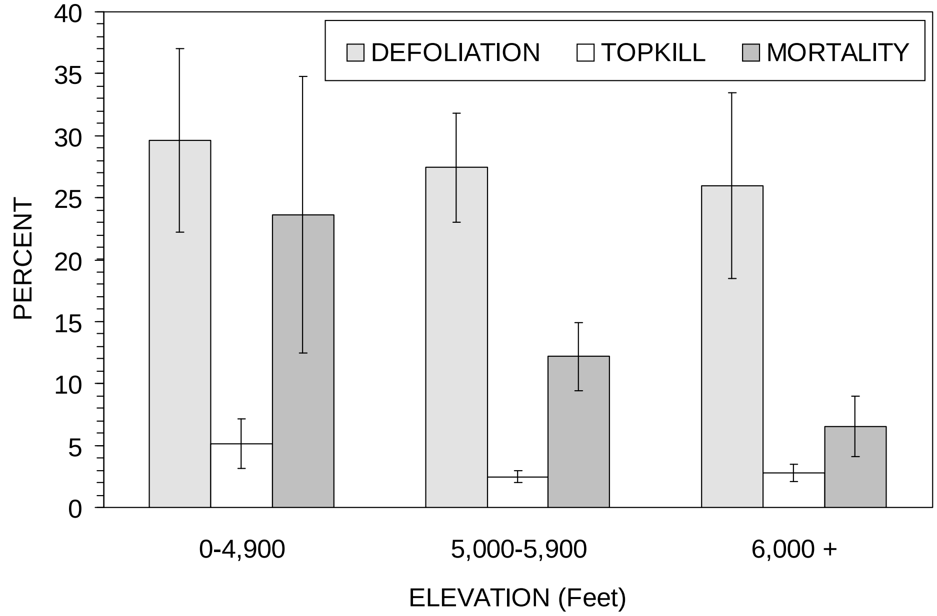


Figure 52—Budworm impacts by elevation. Defoliation and topkill did not differ significantly by elevation, although mortality certainly did. Mortality declined steadily with increasing elevation, although the differences between categories were not always statistically significant. Some investigators believe that budworm damage is less severe at high elevations (Carlson and Wulf 1989), and these results seem to support that assertion, particularly with regard to mortality.

Defoliation means are the percentage of a tree's foliage that was missing as a result of budworm feeding. Topkill means are the percentage of a tree's height that consisted of a dead top caused by budworm. Mortality means are the percentage of all stems (live and dead combined) that were killed by budworm defoliation. Means were computed using the Douglas-fir and white fir sample trees only (other hosts were excluded). Error bars are the standard error of the stratified mean estimate.

Budworm Impacts By Slope Gradient

Budworm impacts were summarized for 3 classes of slope steepness (fig. 53): 0–15 percent (26% of the remeasured plots occurred on slopes in that range), 16–30 percent (38% of the remeasured plots), and 31 percent and greater (36% of the remeasured plots).

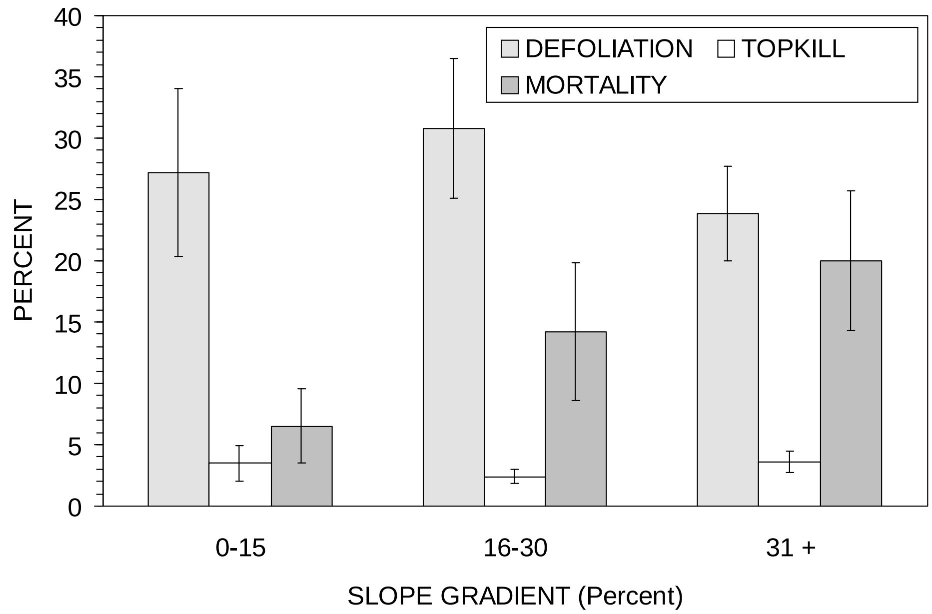


Figure 53—Budworm impacts by slope gradient. Defoliation and topkill did not differ significantly by slope gradient, although mortality certainly did. Mortality increased steadily with increasing slope steepness, but the differences between categories were not always statistically significant.

Defoliation means are the percentage of a tree's foliage that was missing as a result of budworm feeding. Topkill means are the percentage of a tree's height that consisted of a dead top caused by budworm. Mortality means are the percentage of all stems (live and dead combined) that were killed by budworm defoliation. Means were computed using the Douglas-fir and white fir sample trees only (other hosts were excluded). Error bars are the standard error of the stratified mean estimate.

Budworm Impacts By Aspect

Budworm impacts were summarized for 4 aspects (fig. 54; aspect refers to the direction in which a slope faces): north (40% of the remeasured plots had a north-facing exposure), east (22% of the remeasured plots), south (17% of the remeasured plots), and west (22% of the remeasured plots).

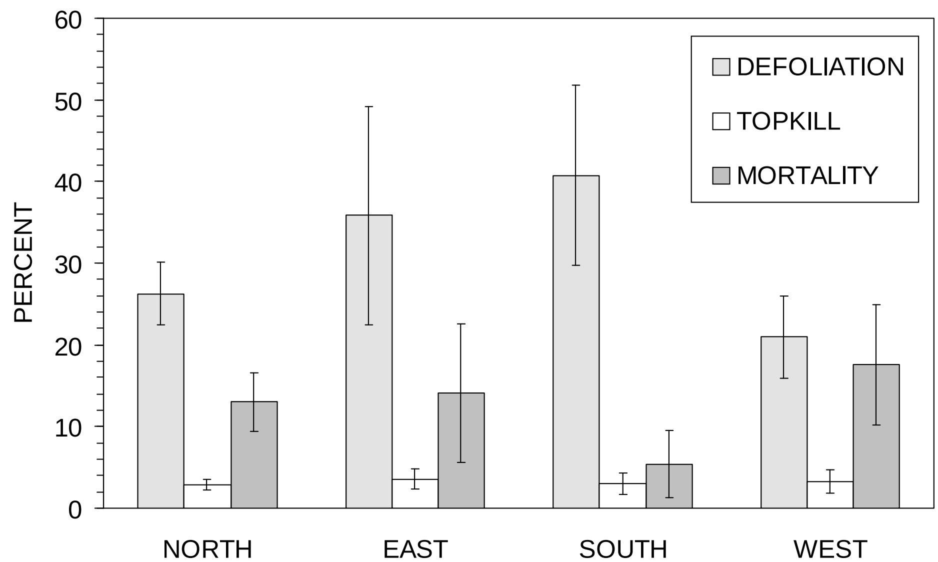


Figure 54—Budworm impacts by aspect. Defoliation was greatest on south- or east-facing exposures, whereas topkill percentages had little variation with aspect. Budworm-caused mortality was greatest on westerly slopes. It is possible that mortality was lowest on southerly exposures because those plots tended to have lower stand densities, which means that sample trees would have been under less competition-related stress than trees on crowded north-facing aspects.

It has been suggested that budworm impacts are most severe on warm, dry sites, which were defined to be those with south and west exposures (Carlson and Wulf 1989). Some of these results seem to support that assertion. In the Pacific Northwest, however, east aspects may be drier than west-facing slopes in some situations, primarily because west-facing slopes receive the full impact of prevailing maritime storms moving eastward from the Pacific ocean.

Defoliation means are the percentage of a tree's foliage that was missing as a result of budworm feeding. Topkill means are the percentage of a tree's height that consisted of a dead top caused by budworm. Mortality means are the percentage of all stems (live and dead combined) that were killed by budworm defoliation. Means were computed using the Douglas-fir and white fir sample trees only (other hosts were excluded). Error bars are the standard error of the stratified mean estimate.

Budworm Impacts By Physiographic Position

Budworm impacts were summarized for 3 physiographic classes (fig. 55): ridges (14% of the remeasured plots occurred on ridges), mountain slopes (58% of the remeasured plots), and low, sheltered positions (mid-slope benches, and bottoms or draws; 27% of the remeasured plots).

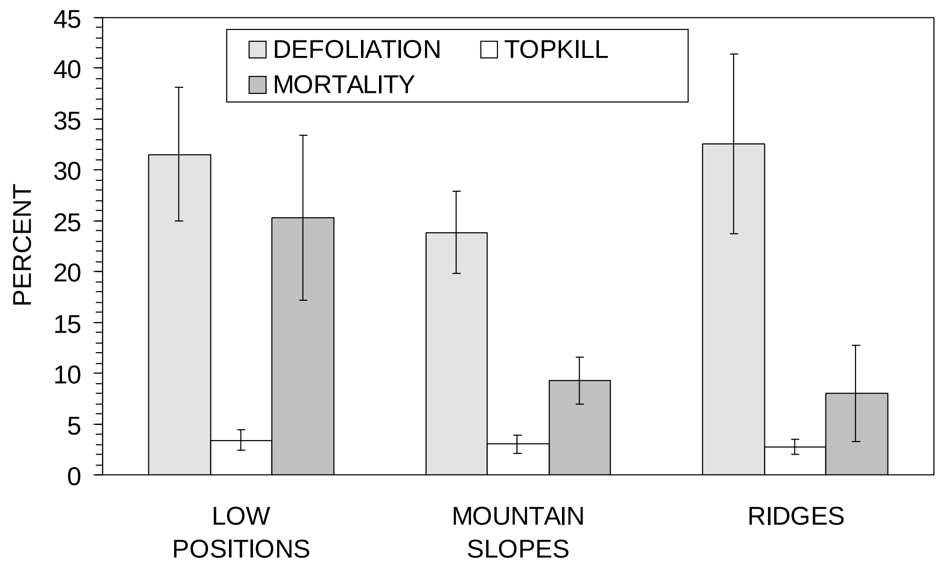


Figure 55—Budworm impacts by physiographic position. Defoliation was highest on ridges or low, sheltered positions, but really did not vary much with changes in physiographic position. Topkill exhibited very little change with physiography. Budworm-induced mortality was significantly greater on low, sheltered positions when compared to the other two categories. These results for the low, sheltered physiographic position category are similar to those for high site productivity (the 60 + category; see fig. 51), indicating that highly productive sites often occupied low, moist, sheltered slope positions.

Defoliation means are the percentage of a tree's foliage that was missing as a result of budworm feeding. Topkill means are the percentage of a tree's height that consisted of a dead top caused by budworm. Mortality means are the percentage of all stems (live and dead combined) that were killed by budworm defoliation. Means were computed using the Douglas-fir and white fir sample trees only (other hosts were excluded). Error bars are the standard error of the stratified mean estimate.

Budworm Impacts By Plant Association

Budworm impacts were summarized for 5 groups of plant associations (fig. 56): Douglas-fir (DF)/sodgrass associations (PSME/CAGE and PSME/CARU; 16% of the remeasured plots had those associations); Douglas-fir (DF)/shrub associations (PSME/CELE, PSME/COST, PSME/SYAL, and PSME/SYOR; 17% of the remeasured plots); white fir (WF)/sodgrass associations (ABGR/ARCO, ABGR/BRVU, ABGR/CAGE, and ABGR/CARU; 41% of the remeasured plots); white fir (WF)/shrub associations (ABGR/SPBE, ABGR/VAME, and ABGR/VASC; 17% of the remeasured plots); and white fir (WF)/forb associations (ABGR/CLUN and ABGR/LIBO2; 8% of the remeasured plots). Two of the remeasured plots had subalpine fir associations and were ignored for this analysis. During field sampling, species codes (using Powell 1989) and canopy coverage values were recorded for every vascular plant species on each sample point. Plant associations were eventually determined after a revised vegetation classification was produced for the Blue Mountains (Johnson and Clausnitzer 1992).

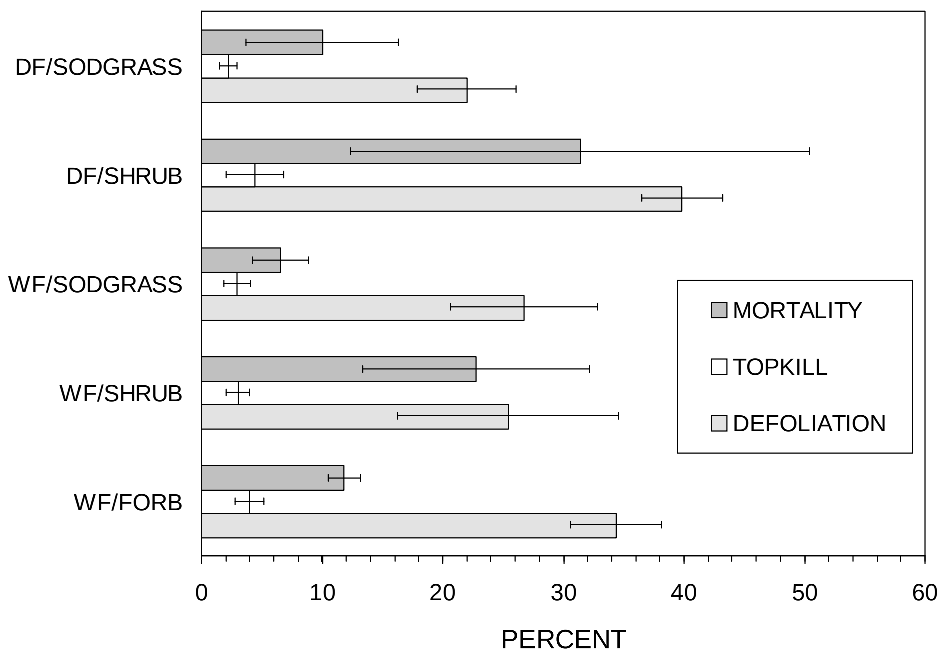


Figure 56—Budworm impacts by plant association. Defoliation was greatest on the Douglas-fir/shrub and white fir/forb groups, which include some of the moistest, most productive plant associations within those plant series. Topkill amounts were low and showed little variation with changes in plant association. Mortality was highest in the shrub-dominated plant associations, regardless of whether they occurred in the Douglas-fir or white fir series. It has been suggested that budworm does best on drier plant associations (Carlson and Wulf 1989). These results seldom support that assertion because moister groups had substantial budworm impacts. Defoliation means are the percentage of a tree's foliage that was missing as a result of budworm feeding. Topkill means are the percentage of a tree's height that consisted of a dead top caused by budworm. Mortality means are the percentage of all stems (live and dead combined) killed by budworm defoliation. Means were computed using the Douglas-firs and white firs only (other hosts were excluded). Error bars are the standard error of the stratified mean estimate.

Budworm Impacts By Budworm-Host Percentage

Budworm impacts were summarized for 3 classes of budworm-host percentage (fig. 57): 0–60 percent host trees (22% of the remeasured plots had a budworm host percentage in that range), 61–80 percent host trees (18% of the remeasured plots), and 81–100 percent (59% of the remeasured plots). The percentage of budworm host trees was calculated using all trees that were alive in 1980, including those which subsequently died from any cause, and trees that became established between the 1980 and 1989 measurements (ingrowth).

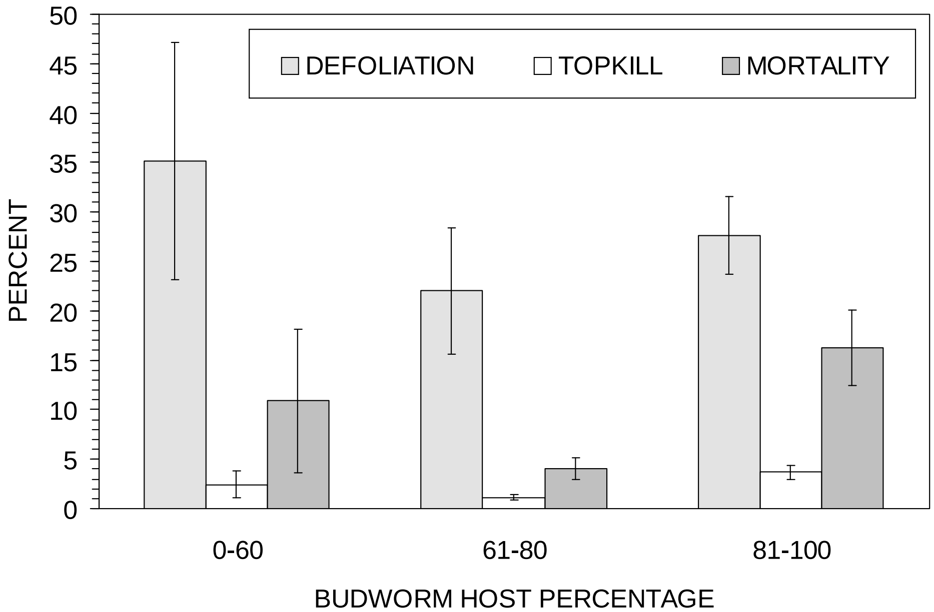


Figure 57—Budworm impacts by budworm host percentage. Defoliation was greatest for plots with the lowest percentage of budworm host species (0–60%), whereas topkill and mortality were highest on plots comprised almost exclusively of host trees (81–100%). It has been suggested that susceptibility to budworm damage increases as the proportion of host trees increases (Carlson and Wulf 1989, Campbell 1993), and some of the results shown here seem to support that contention.

Defoliation means are the percentage of a tree's foliage that was missing as a result of budworm feeding. Topkill means are the percentage of a tree's height that consisted of a dead top caused by budworm. Mortality means are the percentage of all stems (live and dead combined) that were killed by budworm defoliation. Means were computed using the Douglas-fir and white fir sample trees only (other hosts were excluded). Error bars are the standard error of the stratified mean estimate.

Budworm Impacts By Defoliation History

Budworm impacts were analyzed for 2 groups of defoliation history (fig. 58): plots which had 0–4 years of mapped defoliation (45% of the remeasured plots), and plots which had 5–8 years of mapped defoliation (55% of the remeasured plots). Aerial sketch maps, which are prepared annually by the Pacific Northwest Region, were used to estimate the number of years that each plot had been defoliated between 1981 and 1989. During analysis of this factor and the next one (defoliation severity), sketch-map information for the year in which a plot was visited (1988 or 1989) was not used unless the plot had been measured on August 15th or later. Measurements collected before August 15th are not considered to be representative of defoliation conditions as they existed when that year's sketch map was prepared.

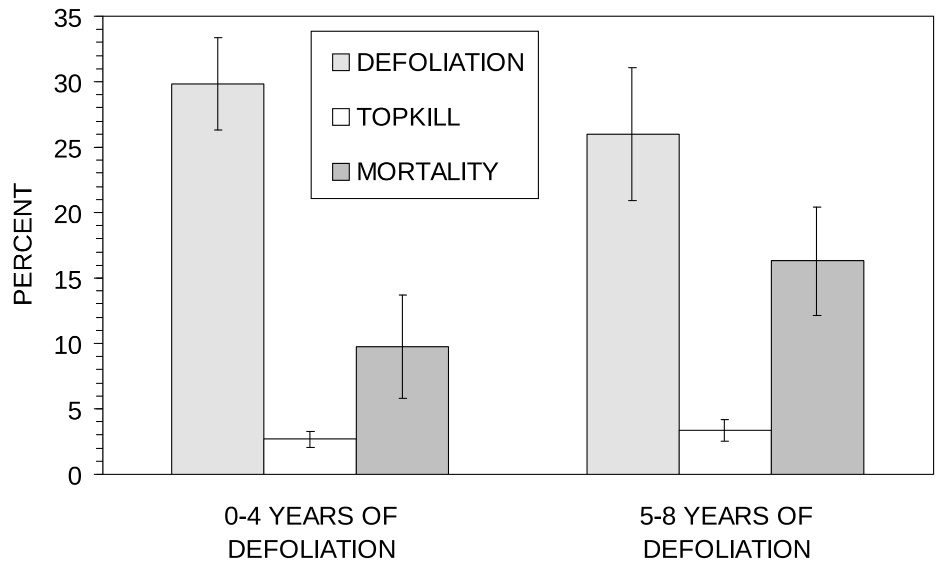


Figure 58—Budworm impacts by defoliation history. Surprisingly, defoliation was higher on plots that had been defoliated for 0–4 years than on plots with 5 to 8 years of defoliation, although the difference was minor and not statistically significant. It is certainly possible that defoliation was more intense (severe) on the plots that had been defoliated for 0–4 years, even though it was not sustained for as long as it was on the plots with 5–8 years of budworm feeding. It is also possible that trees on plots with 5–8 years of defoliation sustained their heaviest losses early in the outbreak, and were then able to replace some foliage before the field data was collected in 1988–1989. Topkill was highest on plots defoliated for 5–8 years, although the difference was minor. Mortality was appreciably greater on plots with 5–8 years of defoliation, although the difference between those plots and the ones with 0–4 years of defoliation was not statistically significant.

Defoliation means are the percentage of a tree's foliage that was missing as a result of budworm feeding. Topkill means are the percentage of tree height that consisted of a dead top caused by budworm. Mortality means are the percentage of all stems (live and dead combined) killed by budworm defoliation. Means were computed using Douglas-firs/white firs only (other hosts were excluded). Error bars are the standard error of the stratified mean estimate.

Budworm Impacts By Defoliation Severity (1986–1989)

Beginning with the 1986 aerial sketch map, budworm defoliation was recorded using four severity classes, ranging from barely-visible damage (severity of 1) to severe defoliation (severity of 4). Budworm impacts were summarized for 3 categories of defoliation severity (fig. 59): very low (average defoliation severity of less than 1; 52% of the remeasured plots); low (average defoliation severity of 1 to 1.9; 32% of the remeasured plots); and moderate/high (average defoliation severity of 2 or greater; 16% of the remeasured plots). A defoliation severity rating was calculated for each plot by averaging the mapped severity values from 1986 to the year in which it was remeasured (1988 or 1989). Years in that range in which the plot was not shown as being defoliated were assigned a value of zero and used in the severity calculations.

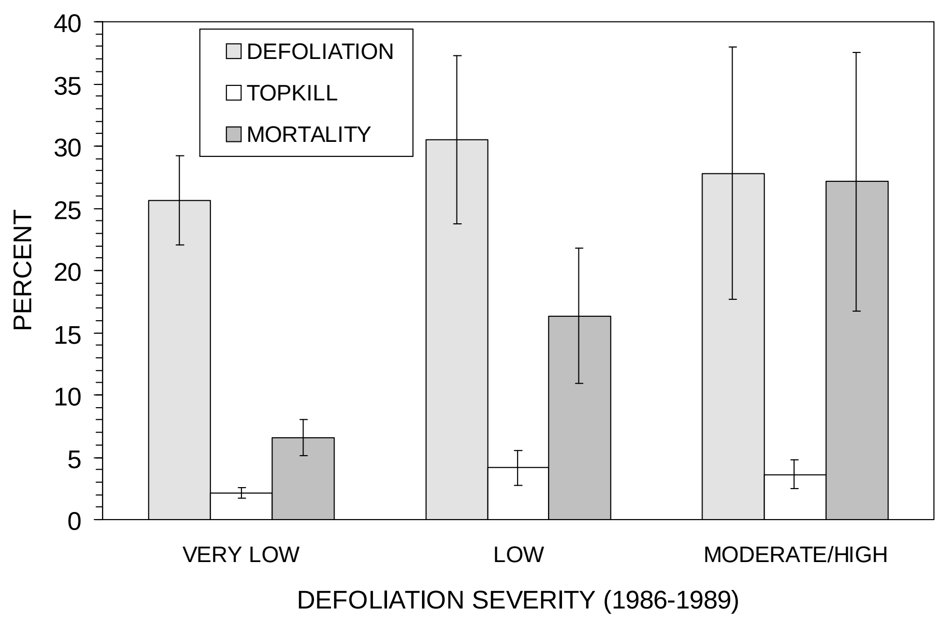


Figure 59—Budworm impacts by defoliation severity (1986–1989). Defoliation and topkill did not exhibit much variation with changes in defoliation severity. Budworm-induced mortality increased steadily as defoliation severity increased. The mortality means for the moderate/high and low severity ratings were not statistically different because the moderate/high value had a large standard error, which reflected the low sample size associated with that category.

Defoliation means are the percentage of a tree's foliage that was missing as a result of budworm feeding. Topkill means are the percentage of a tree's height that consisted of a dead top caused by budworm. Mortality means are the percentage of all stems (live and dead combined) that were killed by budworm defoliation. Means were computed using the Douglas-fir and white fir sample trees only (other hosts were excluded). Error bars are the standard error of the stratified mean estimate.

Budworm Impacts By Insecticide Treatment History

During the 1980s spruce budworm outbreak, portions of the Malheur NF were sprayed four times with a chemical or biological insecticide to suppress budworm populations (see figs. 67 and 69, and Table 4). Budworm impacts were summarized for 3 treatment categories (fig. 60): untreated (54% of the remeasured plots); borderline (7% of the remeasured plots); and treated (39% of the remeasured plots). The borderline category includes those plots which fell within a quarter-mile of a spray project boundary, whether inside or outside. They were included in a separate category because treatment maps do not have enough resolution to indicate whether plots near the project-area boundaries were actually treated.

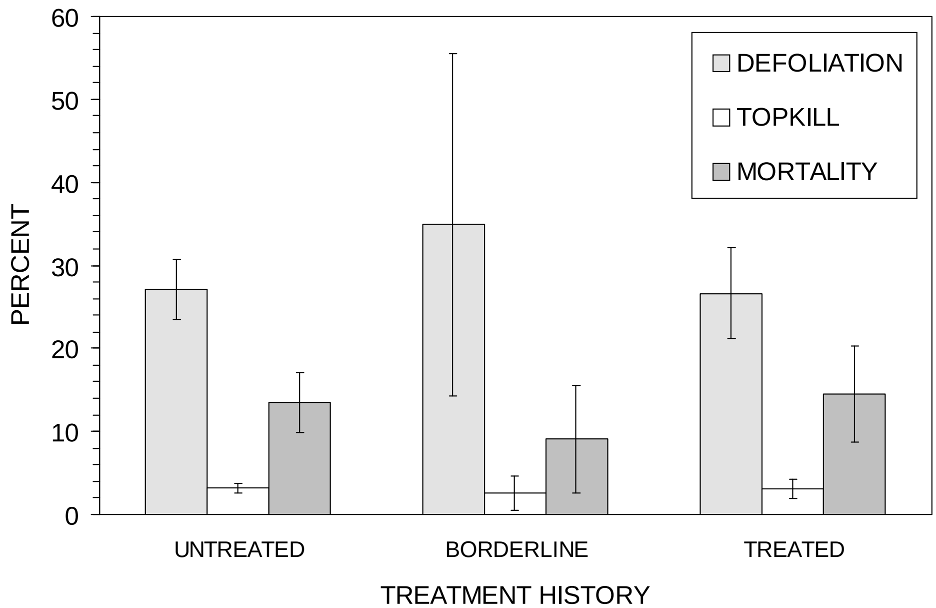


Figure 60—Budworm impacts by insecticide treatment. This chart indicates that there were no statistically significant differences in budworm-caused defoliation, topkill, or mortality between treated and untreated plots. Does that mean that the treatments were ineffective? Possibly, but it could also indicate that treated areas had high defoliation levels before treatment, which could have been one reason for their inclusion in an analysis area. It could also indicate that budworm populations recovered completely within a few years of treatment, or that more than one insecticide application would have been required for long-term suppression of western spruce budworm populations. None of the remeasured inventory plots were treated with an insecticide more than once during the 1980s budworm outbreak. (However, there were areas on the Malheur NF that were treated more than once during the 1980s budworm outbreak; see fig. 69.)

Defoliation means are the percentage of a tree's foliage that was missing as a result of budworm feeding. Topkill means are the percentage of a tree's height that consisted of a dead top caused by budworm. Mortality means are the percentage of all stems (live and dead combined) that were killed by budworm defoliation. Means were computed using the Douglas-fir and white fir sample trees only (other hosts were excluded). Error bars are the standard error of the stratified mean estimate.

Future Timber Yields

An objective of the special project was to determine if future timber yields will be affected by budworm damages sustained from 1980 to 1989. That objective was accomplished by using these processes:

Inventory plots assigned to the same Forest Plan model component were grouped together as a stratum. Eight of the 130 remeasured plots had been harvested between the 1980 and 1988–1989 measurements and were not included in the computer modeling process.

Computer Modeling Information

Two data sets were then created—one containing the 1980 measurements to provide an estimate of pre-outbreak conditions, and a second one with the 1988–1989 information that portrayed conditions as they existed late in the outbreak. The following model components, and the number of tree records available for each, were used for the modeling:

101: ponderosa pine type, regeneration recommended (126 records for 1980; 135 records for 1988-1989).
201: ponderosa pine type, commercial thinning recommended (165 records for 1980; 182 records for 1988-1989).
102: mixed-conifer type, regeneration recommended (318 records for 1980; 380 records for 1988-1989).
202: mixed-conifer type, commercial thinning recommended (371 records for 1980; 438 records for 1988-1989).
502: mixed-conifer type, overstory removal recommended (428 records for 1980; 427 records for 1988-1989).
602: mixed-conifer type, no treatment recommended (237 records for 1980; 243 records for 1988-1989).

An insufficient number of tree records were available for model components 501 and 601 (ponderosa pine types) and all of the lodgepole pine components (103, 203, 503, and 603); therefore, they were not included in the computer modeling process.

Height Growth Modified For Topkill

For the 1988–1989 data, older, taller trees with serious topkill had their heights truncated so that no further height growth would occur. Host trees with less serious topkill had their heights reduced to account for the dead tops, but future height growth was allowed to occur.

Small Douglas-firs and white firs (trees 3 inches or less in diameter) had their height growth reduced using formulas that correlate defoliation amounts with the proportion of expected height growth (Crookston 1991). Small trees had their height growth constrained until the year 2000, after which it was assumed that they would have regained their pre-outbreak growth rates.

Management Scenarios

Three management scenarios were then simulated using the Blue Mountain variant of the Stand Prognosis Model (Johnson 1990): an unmanaged “base” run spanning as much as 150 years (to the year

2130); a low-density silvicultural regime involving an overstory removal and concurrent precommercial thinning to a relatively low residual density, followed by one or more commercial thinnings; and a high-density regime involving an overstory removal and concurrent precommercial thinning to a relatively high residual density, followed by one or more commercial thinnings.

Modeling Results

Results of the computerized modeling are provided in figures 61 to 65. Those figures describe the volume reductions resulting from budworm impacts sustained between 1980 and 1989. The board-foot reductions described in figures 61–65 are conservative and may represent the minimum reduction that occurred, for these reasons:

- When budworm populations "crashed" in 1987 (see fig. 6), it was believed that the outbreak was ending and that further defoliation would cease in a year or two. That eventuality did not occur, and budworm defoliation began increasing again in 1990. Field sampling to measure budworm-related damage occurred in 1988 and 1989, and no additional sampling was completed to determine the effects of subsequent defoliation in 1990 or 1991. However, 32% of the remeasured plots were visited again in 1992 by crews from the Tri-Forest Inventory Group (headquartered in Pendleton, OR). Although they did not record defoliation and topkill in a manner similar to that used in 1988–89, they did assess mortality using comparable methods. The mortality increase between 1988–89 and 1992 was substantial but, surprisingly, the percentage of the mortality attributable to budworm defoliation actually declined during that period (fig. 66).

- Computerized modeling was designed to analyze the effects of this outbreak (1980-1989) only; no future outbreaks of either western spruce budworm or Douglas-fir tussock moth were simulated. Why was that assumption made? It would be difficult to determine the volume reductions associated with the 1980s epidemic if the model had been allowed to confound the situation by simulating further outbreaks, whether by budworm or tussock moth. But formulating computer simulations spanning 150 years that do not include future budworm and tussock-moth outbreaks is not a reasonable representation of "real life" for mixed-conifer forests of the Blue Mountains. For example, recent surveys indicate that tussock-moth populations are rising again, and several small outbreaks occurred on the Malheur NF in 1992 and 1993 (Willhite 1993).

- When the mixed-conifer inventory plots were remeasured in 1988 and 1989, the severity of a wide range of biotic and abiotic agents was recorded for each sample tree (dwarf mistletoe ratings, etc.). For that reason, the effects on tree growth from insects other than budworm and from diseases such as dwarf mistletoe and root rots, and the effects of abiotic factors like drought and suppression, are in-directly incorporated in the modeling results. If those non-budworm factors remain relatively constant, the modeling has probably incorporated their effects adequately. But if they suddenly become worse, such as accelerated impacts from annosus root disease in mixed-conifer stands that have been partially cut, or a severe drought with less rainfall than occurred during the late 1980s, it is likely that the modeling does not reflect the total amount of potential reduction.

Consistency With Forest Plan

The situations described above explain why the volume losses portrayed in figures 61–65 may be conservative. But users of that information should also realize that nothing was done in the modeling to intentionally mitigate the effects of budworm. Each management scenario was modeled using the same silvicultural assumptions that were used to prepare managed-stand yield tables for the Forest's Land and Resource Management Plan (USDA Forest Service 1990).

Forest Plan Yield Assumptions

The Plan's yield tables assumed that existing understories would be managed after the overstory had been removed, even though many of those understories consist of white fir, Douglas-fir, and other species susceptible to budworm impacts. Therefore, it's possible that the volume losses described in figures 61–65 would not have occurred if the existing understories, many of which were affected by budworm-caused defoliation between 1980 and 1989, had been destroyed and replaced with healthy trees—particularly if the replacement trees were ponderosa pines and other seral species that aren't hosts of budworm.

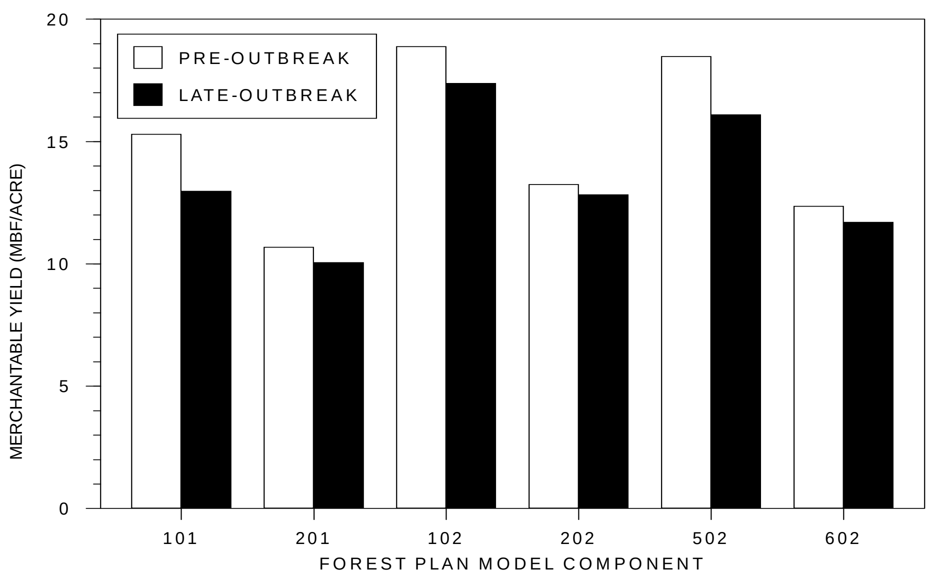


Figure 61—Projected yields in 1990 for pre-outbreak and late-outbreak conditions. The pre-outbreak volumes were derived by growing the unaffected (1980) trees forward to 1990; late-outbreak values are the result of growing the affected (1988–1989) trees forward to 1990. Volume reductions from budworm varied, ranging from lows of 3.2% for model component 202 and 5.3% for component 602, to highs of 12.9% for component 502 and 15.2% for component 101. Model components 201 and 102 had intermediate reductions, which were 5.8% and 7.9%, respectively.

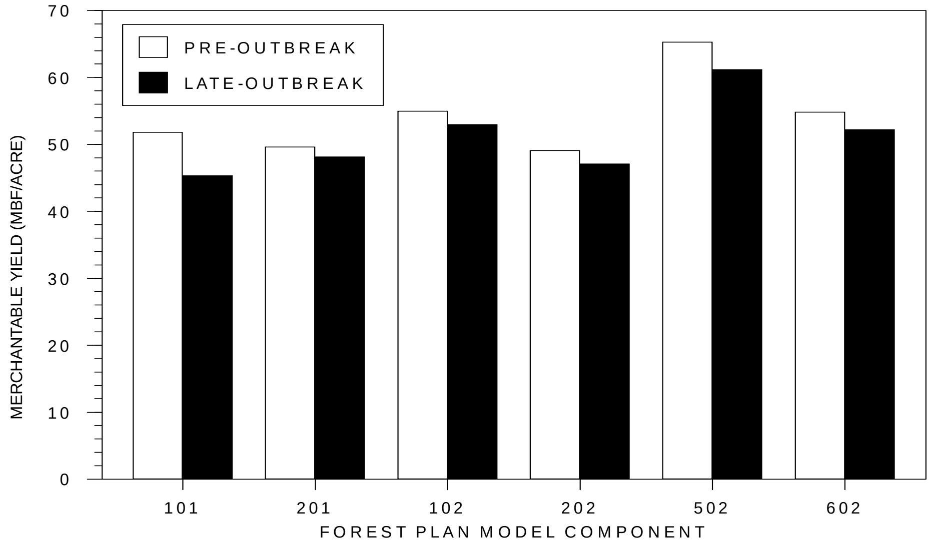


Figure 62—Projected yields in 2130 for pre-outbreak and late-outbreak conditions. Figure 61 shows how budworm damage affected yields in 1990; this figure compares yields about 150 years after the outbreak began in 1980. Even though the volume difference between unaffected (pre-outbreak) and affected (late-outbreak) conditions is greater for every component, in absolute terms, than it was in 1990, reductions by 2130 actually declined on a percentage basis. Four of the six components had reductions of less than 5% (201: 3.1%; 102: 3.7%; 202: 4.1%; 602: 4.8%), and only one component (101) still had a substantial reduction (12.5%). Component 502, the largest one on the Forest with over a half million acres, had a loss of 6.3% in 2130.

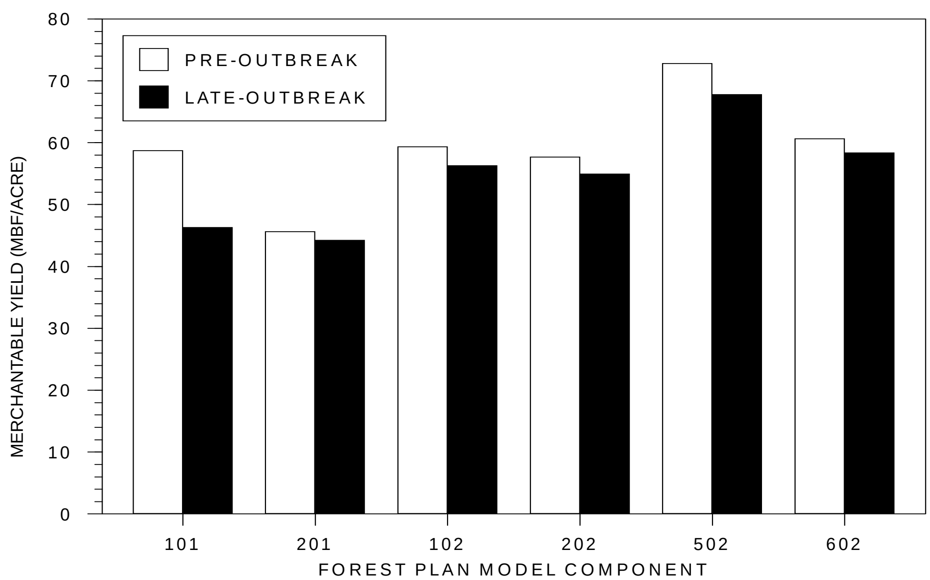


Figure 63—Projected timber yields for pre-outbreak and late-outbreak conditions under a low-density silvicultural regime. Total yield (standing volume in 2130 plus harvest volumes from periodic overstory removals and commercial thinnings) is always higher for a low-density regime than it was for the unmanaged scenario (fig. 62), but the volume reductions associated with late-outbreak conditions varied widely. Five of the six components had relatively minor reductions, ranging from 3% for component 201 to 6.9% for component 502. Component 101 had a substantial reduction; volumes for the late-outbreak condition were 21.2% less than yields from the pre-outbreak plots.

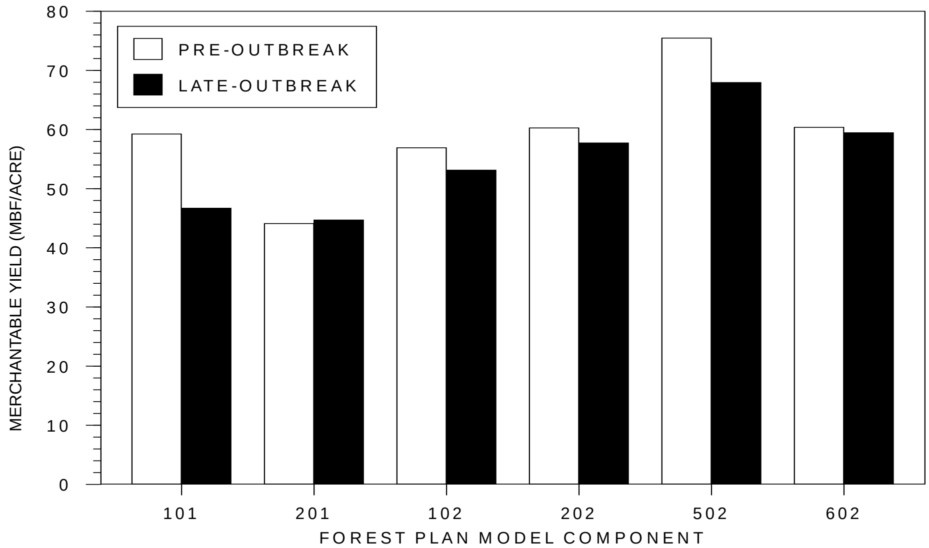


Figure 64—Projected timber yields for pre-outbreak and late-outbreak conditions under a high-density silvicultural regime. Total yield (standing volume in 2130 plus harvest volumes from periodic overstory removals and commercial thinnings) is generally higher for a high-density regime than it was for either the unmanaged or low-density scenarios (figs. 62–63). The volume reductions attributable to late-outbreak budworm impacts (as of 1988–1989) varied widely, ranging from none for model component 201 and an insignificant 1.5% for component 602, to more substantial declines of 9.9% for component 502 and 21.2% for component 101.

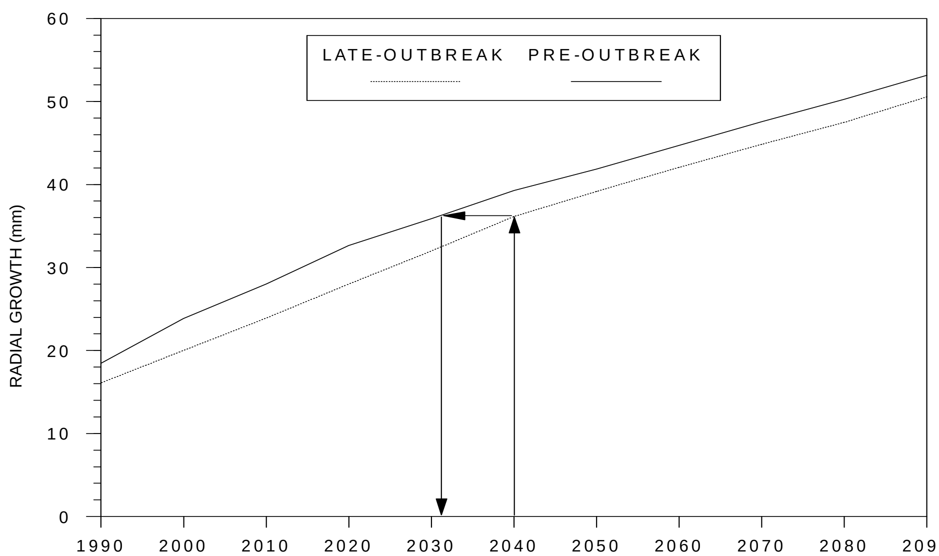


Figure 65—Projected timber yields associated with pre-outbreak and late-outbreak conditions for model component 502. This figure shows cumulative (standing) board-foot volumes for model component 502 only (unmanaged). It demonstrates that volume reduction from budworm impacts tended to remain rela-tively constant through time—the percentage reduction in 1990 is similar (but not identical) to the percentage at each succeeding 10-year interval. It also shows that the 1980s budworm outbreak caused a loss of almost exactly 10 years of growth; the volume of affected (late-outbreak) trees in 2040 is virtually identical to the volume attained by unaffected (pre-outbreak) trees 10 years earlier (see arrows in the chart).

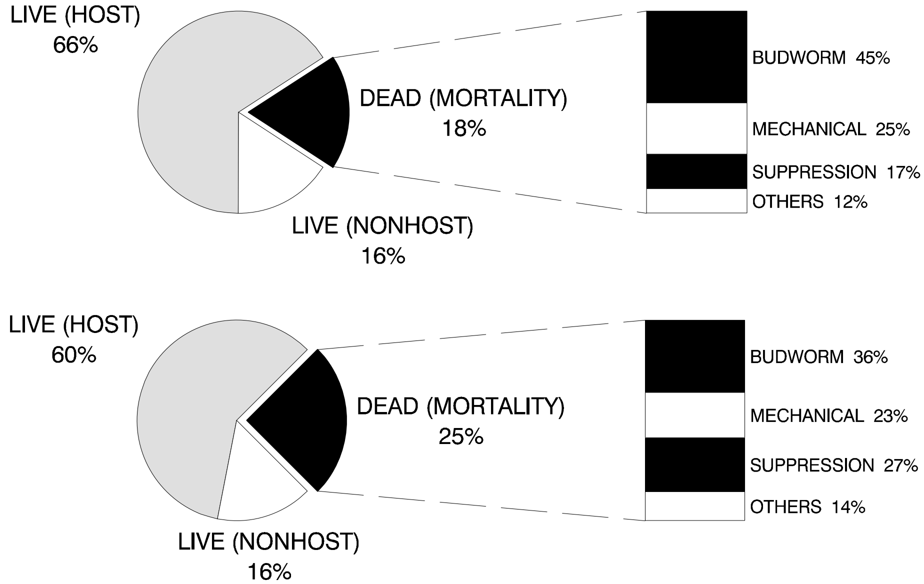


Figure 66—1992 mortality update. In 1992, 42 of the 130 inventory plots used for this study were revisited by an inventory crew. Although defoliation and topkill were not estimated in the same way as they were in 1988–89 (which means that changes cannot be compared for those budworm impacts), the crew did assess tree mortality in a similar manner.

The top half of this chart summarizes tree composition and mortality causes in 1988–1989 for the 42 remeasured plots; the bottom half summarizes the same information for 1992. In the 3–4 year interval represented in the chart, mortality increased substantially. However, the proportion of trees killed by budworm actually declined in 1992, even though total mortality increased. It is unclear whether the reduction in budworm-caused mortality is a real change, or whether it occurred because the surveys were completed by different individuals. It is possible that the change reflects differing interpretations about the causes of mortality in the 1988–1989 and 1992 surveys.

Managing Budworm and Its Impacts

Although this report was designed to describe recent impacts from budworm defoliation, it was difficult to do so without discussing how those impacts could have been mitigated or avoided. This section of the report provides that discussion.

Budworm Management Approaches

Managing budworm populations typically involves four approaches, used independently or in concert. The approaches are described below.

- Taking no direct action; letting the outbreak run its natural course.
- Suppressing budworm populations by applying an insecticide.
- Reducing budworm impacts by improving tree and stand vigor.
- Avoiding budworm impacts by modifying the insect's habitat with silvicultural practices.

No Action Approach

A no-action approach is appropriate when budworm damage is not expected to prevent accomplishment of the management objectives for an area, such as attainment of its desired future condition. Land managers have been considering a no-action approach more often than they used to, especially as more information becomes available about the important role that budworm and other insects play in the ecosystem. But during the recent outbreak, many managers chose to implement the direct suppression approach because the severity and extent of budworm impacts was greater than they could accept.

Direct Suppression Approach

During the 1944–1958 budworm outbreak in the Blue Mountains, almost 4.7 million acres were sprayed with an insecticide called DDT (Dolph 1980). DDT became popular after two early successes—it was used to control Douglas-fir tussock moth outbreaks in northern Idaho (Carlson and others 1983) and the northern Blue Mountains (Wickman and others 1973) in 1947, and for experimental suppression of spruce budworm populations on part of the Heppner Ranger District (Umatilla NF) and adjacent industrial lands (Kinzua) in 1948 (Eaton and others 1949). Several large DDT spray projects were completed on the Malheur NF, including 233,764 acres in 1955 (Whiteside and others 1956) and 409,000 acres in 1958 (fig. 67).

Early Use of DDT for Budworm Control

DDT, a powerful chemical applied in a fuel oil diluent, could affect many organisms besides budworm (Hunter 1990). Even though DDT was commonly applied during the 1944–1958 outbreak in the Blue Mountains (fig. 68), land managers eventually realized that it did not provide any long-term budworm control because its use did not address the underlying cause—proliferation of budworm habitat throughout the western United States (Carolin and Coulter 1971, Fellin 1983). Because of its environmental persistence and the broad spectrum of organisms affected by it, DDT was eventually banned for all uses in 1972.

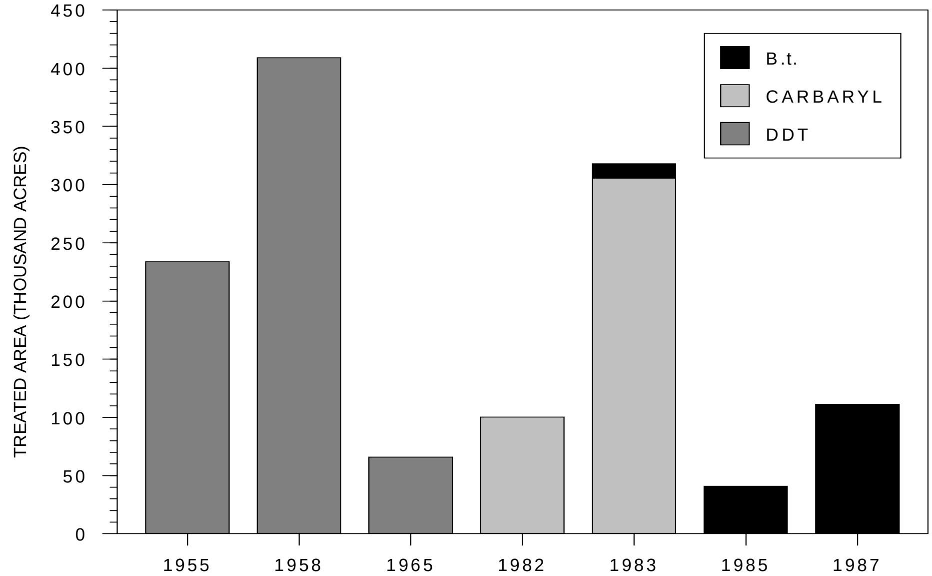


Figure 67—Summary of defoliator suppression projects on the Malheur NF. Several large projects using the insecticide DDT were completed against budworm in 1955 and 1958. The 1965 DDT application was used to help control an outbreak of the Douglas-fir tussock moth. When budworm reached outbreak levels once again in the early 1980s, carbaryl was the primary insecticide used to suppress budworm populations. In 1983, one relatively small area was treated with mexacarbate, a chemical insecticide, and another with B.t., a bacterial insecticide. By the mid 1980s, a bacterium called *Bacillus thuringiensis* (B.t.) was being used for all of the national forest treatment projects.

Figure 68—Trailing plumes of insecticide, an airplane applies DDT and a diesel oil diluent to defoliated stands in the northern Blue Mountains in June of 1951. On the Malheur NF, DDT was used as a budworm insecticide in 1955 and 1958, when more than 640,000 acres were treated.

1980s Budworm Suppression Projects

During the 1980s budworm outbreak direct suppression projects were completed in 1982, 1983, 1985, and 1987. Those projects involved application of a chemical or biological insecticide, on areas with varying sizes, to suppress budworm populations (fig. 69 and Table 4).

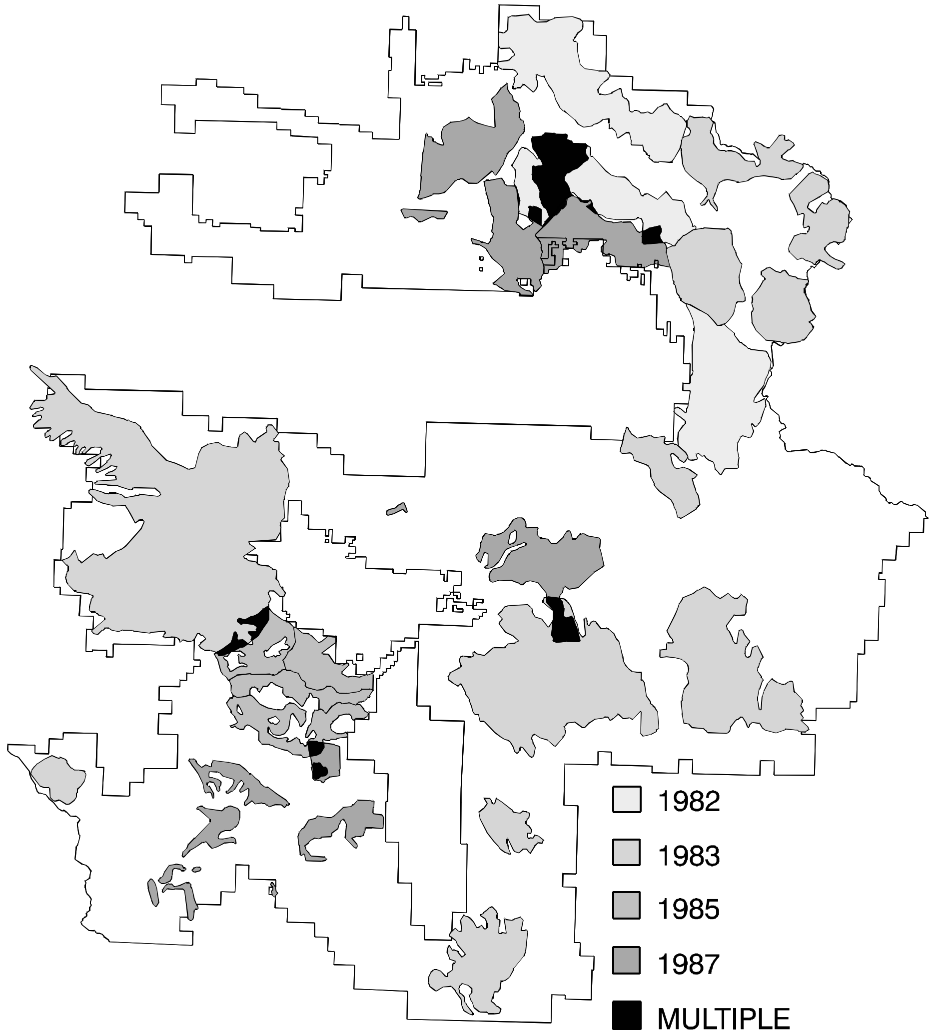


Figure 69—Budworm suppression projects completed during the 1980s on the Malheur NF. During the 1980s outbreak, four different projects were completed to suppress budworm populations, and three different insecticides were used (Table 4). The "multiple" areas are those that were treated during two different years.

Suppression Project Objectives

The objective of the 1980s suppression projects was to reduce budworm populations to non-damaging levels for the remainder of the outbreak (USDA Forest Service 1982, 1983, 1985, and 1987b). For a variety of reasons, that objective was not achieved. One possible reason is that insecticides were not applied to all of the area with visible defoliation, so that budworms in untreated areas could reinvade the treated units. Another reason is that an insecticide application does not eradicate budworm or its impacts—it typically suppresses populations and associated tree impacts for a period of three or four years at best.

Table 4—Treatment information for budworm suppression projects completed on the Malheur NF, 1982–1987.

Year	**Treatment Unit**	**Acres Treated**	**Insecticide**	**Dosage Per Acre***	**Diluent**	**Volume Per Acre**
1982	Baldy	32,798	carbaryl	1 lb. AI	diesel oil	64
	Middle Fork	67,584	carbaryl	1 lb. AI	diesel oil	64
	Total (1982)	100,382				
1983	Aldrich	127,748	carbaryl	1 lb. AI	diesel oil	64
	Logan North	10,520	carbaryl	1 lb. AI	diesel oil	64
	Logan South 1	62,741	carbaryl	1 lb. AI	diesel oil	64
	Logan South 2	39,897	carbaryl	1 lb. AI	diesel oil	64
	Snow	5,536	carbaryl	1 lb. AI	diesel oil	64
	Butte	6,743	carbaryl	1 lb. AI	diesel oil	64
	King	18,850	carbaryl	1 lb. AI	diesel oil	64
	Pogue Point 1	15,291	carbaryl	1 lb. AI	diesel oil	64
	Pogue Point 2	11,663	mexacarbate	.1 lb. AI	diesel oil	128
	Pogue Point 3	12,309	B.t.	12 BIU	water	96
	P.A.	18,231	carbaryl	1 lb. AI	diesel oil	64
	Total (1983)	329,529				
1985	Rail	9,598	B.t.	12 BIU	undiluted	24
	Scotty	10,070	B.t.	12 BIU	undiluted	32
	Burnt Cabin	7,815	B.t.	12 BIU	water	48
	Crooked	12,685	B.t.	12 BIU	water	96
	Lost Cabin	565	B.t.	15 BIU	water	64
	Total (1985)	40,733				
1987	Dixie	18,445	B.t.	12 BIU	water	96
	Flat	46,223	B.t.	12 BIU	water	96
	Lost Cabin	23,774	B.t.	12 BIU	water	96
	Canyon	22,537	B.t.	12 BIU	water	96
	Starr	393	B.t.	12 BIU	water	96
	Total (1987)	111,372				
	Total (1982–87)	582,016				

* AI is active ingredient; BIU is Billion International Units.

Source: Unpublished project records provided by the Forest Insects and Diseases Group of the Natural Resources Staff, located at the Regional Office for the Pacific Northwest Region of the U.S. Forest Service in Portland, Oregon.

Using Chemical Insecticides

During the 1982 and 1983 treatments, chemical insecticides were applied in a diesel oil diluent. Diesel oil was used to improve the chemical's adherence to foliage, and to minimize the risk of insecticide being washed away by a rainstorm shortly after application (based on the principle that oil and water don't mix). A chemical called carbaryl was applied in most of the general-forest situations; another chemical called mexacarbate was used in one area having special environmental sensitivity. Beginning with an experimental application in 1983, the insecticide used for all subsequent projects on the Malheur NF (the 1985 and 1987 treatments) was a natural bacterium called *Bacillus thuringiensis* (B.t.). B.t. was always applied in a water base, rather than the diesel oil used with the predominant chemical insecticide—carbaryl.

B.t. Becomes Primary Insecticide

By the mid 1980s, B.t. was the insecticide of choice because of its low risk to the environment and human health. It directly affects a narrow range of organisms—only butterflies and moths in the Lepidoptera insect order are killed. B.t. is similar to the toxins contained in some spider and snake venoms in that it is cytolytic—after ingestion, it causes cells in the guts of susceptible insects to rupture and disintegrate (Ware 1989). Following the success of B.t. and other natural insecticides, scientists are evaluating derivatives from marigolds and other asters, soil microorganisms, the neem tree, and other natural sources in their efforts to develop new insecticides for forestry applications (Helson 1992). The need to develop biologically based pest management strategies is widely recognized (USDA Forest Service 1993).

B.t. Offers Environmental Benefits

Adoption of B.t. in the mid 1980s did not occur because the previous insecticides (carbaryl, acephate, and mexacarbate) had been banned, as was the case when DDT was abandoned in the early 1970s. A switch to B.t. reflected an increasing awareness that chemical insecticides and their diesel oil diluent may have had adverse environmental consequences. For example, using B.t. allowed land managers to maintain more of the pretreatment arthropod diversity than was probable with carbaryl, acephate, or mexacarbate. Some of that pretreatment diversity included thatch ants, carpenter ants, jumping spiders, yellowjackets, and other natural enemies of spruce budworm (see fig. 91).

Short-Term Stand Vigor Approaches

In some situations, converting susceptible mixed-conifer stands to resistant tree species, or adopting another long-term budworm approach, will not meet the short-term objectives for an area. In the past, land managers reacted to those situations by implementing the direct suppression approach (i.e., applying an insecticide). They now have several other treatments to consider if adequate time (3 to 5 years) is available before budworm defoliation reaches high levels. The objective of short-term treatments is to increase the vigor of host trees to the point where most of them can survive a persistent budworm outbreak.

Tree Thinning

One stand-vigor approach is thinning (fig. 70), where some trees are removed so that those which remain have access to additional growing space, nutrients, and sunlight. Trees respond to a thinning by producing more foliage; full-crowned trees typically experience less defoliation damage (on a proportional basis) than short-crowned trees (see fig. 48).

Thinning From Below

Thinned, vigorous trees usually develop a higher level of root reserves, which improves their ability to recover from prolonged defoliation. Thinning from below is particularly beneficial because it creates the open, single-storied stand structure that promotes mortality of dispersing budworm larvae (Carlson and Wulf 1989). Thinning also offers an opportunity to remove some host trees and thereby favor nonhosts.

Thinning Can Favor Budworm

Budworm research conducted in western Montana showed beneficial effects from thinning (Carlson and Wulf 1989), but thinned stands in the Blue Mountains have seldom shown a similar response (Boyd Wickman, *personal communication*; Wickman and others 1992).

Studies in the Blue Mountains found that thinning can actually favor budworm. It allows more sun into the canopy, thereby creating warmer budworm microhabitats. Warmer conditions allow budworm to develop faster, eat more, and to possibly escape more natural predation while in the larval stage (Boyd Wickman, *personal communication*).

Figure 70—Tree thinning. Thinning can offer at least three benefits for budworm management—vigor of the residual trees is increased, thereby increasing budworm resistance; a single-storied stand can be created by thinning from below, which increases the mortality of dispersing larvae; and thinning provides an opportunity to remove host trees and thereby favor nonhosts.

Forest Fertilization

Another promising stand-vigor approach is fertilization (fig. 71), a treatment that allows host trees to produce more foliage than budworm larvae can consume. In a study near King Mountain on Burns Ranger District of the Malheur NF, fertilized trees had high foliage production, rapid recovery from budworm-induced top damage, and dramatically increased rates of diameter growth, as compared to the unfertilized controls (Wickman and others 1992).

Figure 71—Fertilization of mixed-conifer stands. Recent research (Wickman and others 1992) showed that fertilizer may help reduce budworm damage if applied early in an outbreak. A study near Mt. Emily in the northern Blue Mountains indicates that fertilization may not be effective if budworm populations were high before treatment (photo courtesy of Art Tiedemann).

Fertilization and Budworm Resistance

A recent study showed that budworm resistance may be related to the nutritional qualities of foliage, and that susceptible trees had lower levels of foliar nitrogen and sugars than resistant trees (Clancy and others 1993). Fertilization may provide opportunities to modify foliar chemistry and thereby improve a tree's resistance to budworm defoliation. Fertilization would be particularly effective if it increased foliar sucrose (sugar) without commensurate increases in the levels of foliar nitrogen and other minerals (Clancy 1992).

Timing of Fertilization

A recent study in the northern Blue Mountains near Mt. Emily indicates that fertilization may not be as effective when budworm populations are very high (Boyd Wickman, *personal communication*). To achieve satisfactory results, fertilizer should apparently be applied early in an outbreak or, if possible, just before its onset. In areas with high susceptibility to budworm damage, it now appears that fertilization may be a viable alternative to repetitive insecticide applications (Waring and others 1992).

Other Benefits of Fertilization

Fertilization may provide other benefits as related to insect and disease management. It may help reduce stem decay for grand firs that have been wounded during logging or by other agents (Filip and others 1992). By changing root chemistry, fertilization with nitrogen and potassium apparently has beneficial effects on a tree's resistance to Armillaria root disease (Moore and others 1993).

Long-Term Silvicultural Approaches

Many silvicultural practices can reduce stand and forest susceptibility to budworm, primarily by reducing the proportion of host trees in future stands; by capitalizing on budworm-resistant genotypes; by regulating stand density to optimize future vigor and associated budworm resistance; and by improving conditions for birds, ants, and other enemies of budworm (Carlson and Wulf 1989). There is a pressing need to evaluate how alternative silvicultural systems could address budworm outbreaks and other forest health concerns (USDA Forest Service 1993). Some common silvicultural practices, and their effects on budworm susceptibility, are described below.

Stand Clearcutting

Stand clearcutting (fig. 72) removes most of the trees from an area in a single entry, with the objective of establishing a new, even-aged stand. It can be an effective way to regenerate ponderosa pine, lodgepole pine, western larch, and western white pine, all of which require open, sunny environments for optimum regeneration and growth. Since those species are not budworm hosts, stand clearcutting can reduce budworm susceptibility for the forests of the future. Stand clearcutting with reserve trees (fig. 72) would be less effective at reducing budworm susceptibility if host trees are selected as the reserves.

Patch and Strip Clearcuts

Small-patch and strip clearcuts (figs. 73 and 74) result in smaller harvest areas than with stand clearcutting. Although they are more visually attractive than stand clearcuts, patch or strip clearcuts have greater potential to create the shady post-harvest conditions conducive to regeneration of budworm-host trees. But in areas with visual sensitivity, both patch and strip clearcuts can provide regeneration opportunities for nonhost species and still meet some aesthetic objectives.

Seed-Tree Cutting

Seed-tree cutting (fig. 75) is similar to clearcutting except that 6 or more seed producing trees are left on each acre to promote natural regeneration. When using this method, silviculturists can affect future budworm resistance by their choice of seed trees, and by their decision about whether to plant the harvest units. If future budworm resistance is an objective, then retention of larches, pines, and other nonhost trees should be considered when selecting the seed trees, unless harvested areas will be planted to control their future species composition.

Shelterwood Cutting

Shelterwood cutting (fig 76) differs from the seed-tree method in that the number of residual trees is great enough to influence environmental conditions over a large area, rather than next to each seed tree. A shelterwood seed cut retains at least 12 or more well-distributed trees on each acre. If future budworm resistance is an objective, and the harvest area is not planted with nonhost species, then it would be important to retain larches, pines, and other nonhost trees in the seed cut.

Figure 72—Stand clearcutting. Stand clearcutting can create single-storied, even-aged stands with low budworm susceptibility, especially if nonhost species like ponderosa pine and western larch are regenerated. In the past, stand clearcutting resulted in all of the trees being removed from an area; now, both dead trees (snags) and live reserve trees are retained. Although clear-cutting can effectively create some of the environmental conditions conducive to regeneration of seral, nonhost tree species, it is unlikely to be applied much in the future because of public concern about its short-term impact on aesthetics and other values. In response to those concerns, the U.S. Forest Service issued direction to reduce clearcutting on the national forests by 70% or more from fiscal year 1988 levels (USDA Forest Service 1992).

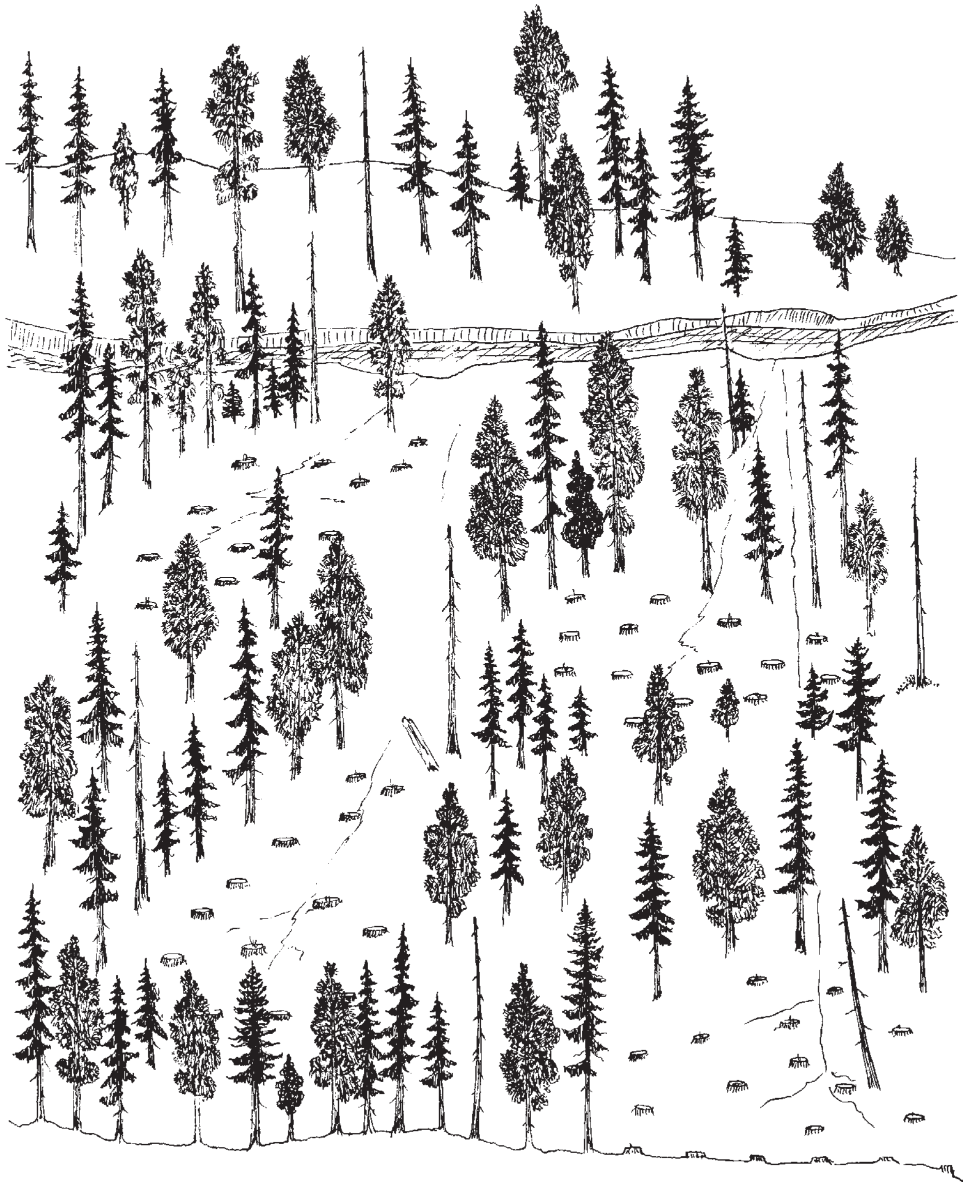


Figure 73—Patch clearcutting. Small-patch clearcuts are effective at reducing budworm susceptibility, although creation of small openings could result in post-harvest conditions that are shady enough to favor regeneration of budworm host trees. Although clearcutting can effectively create some of the environmental conditions conducive to regeneration of seral, nonhost tree species, it is unlikely to be applied much in the future because of public concern about its short-term impact on aesthetics and other values. In response to those concerns, the U.S. Forest Service issued direction to reduce clearcutting on the national forests by 70% or more from fiscal year 1988 levels (USDA Forest Service 1992).

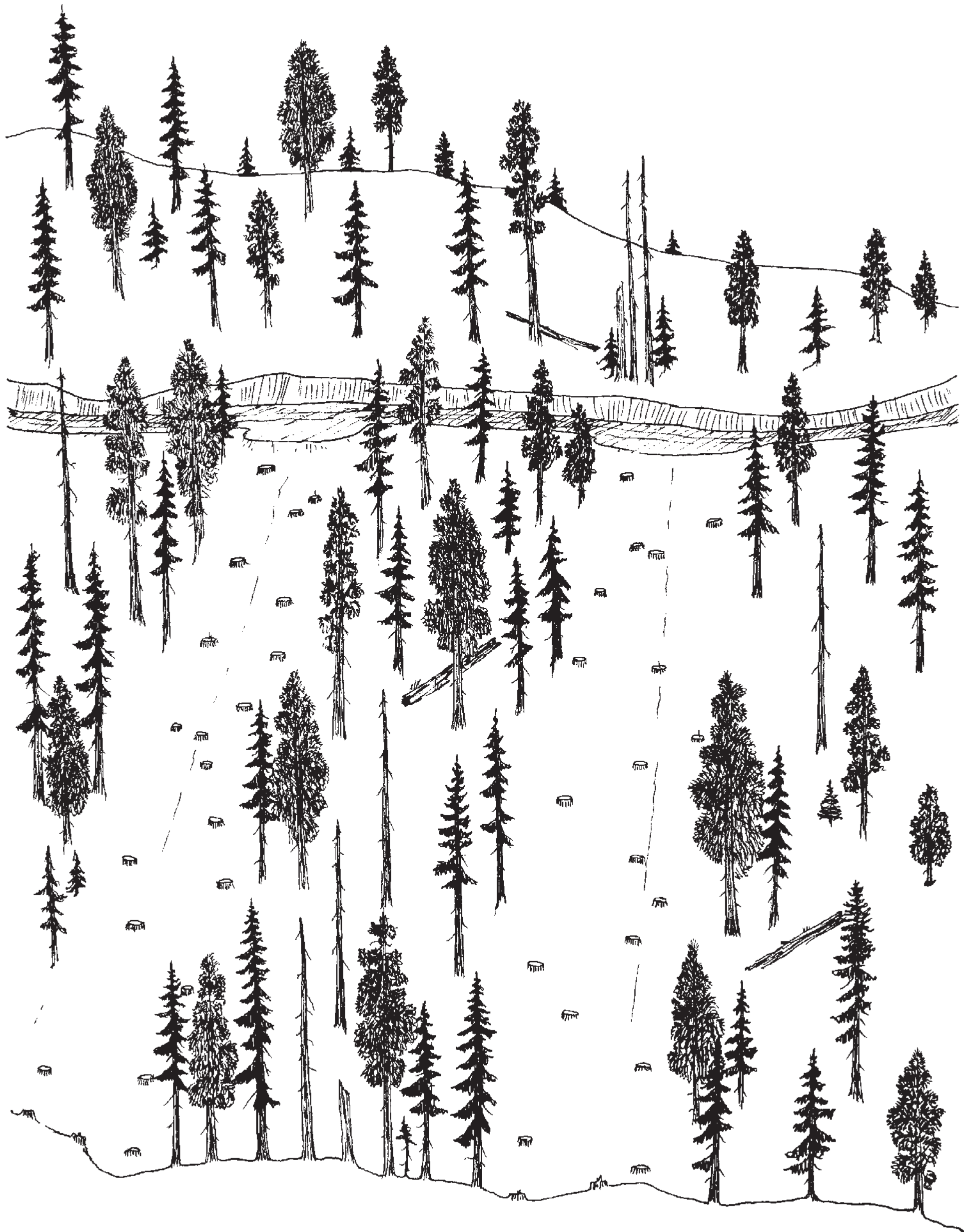


Figure 74—Strip clearcutting. Strip clearcuts are effective at reducing budworm susceptibility, although creation of narrow openings could result in post-harvest conditions that are shady enough to favor regeneration of budworm host trees. Although clearcutting can effectively create some of the environmental conditions conducive to regeneration of seral, nonhost tree species, it is unlikely to be applied much in the future because of public concern about its short-term impact on aesthetics and other values. In response to those concerns, the U.S. Forest Service issued direction to reduce clearcutting on the national forests by 70% or more from fiscal year 1988 levels (USDA Forest Service 1992).

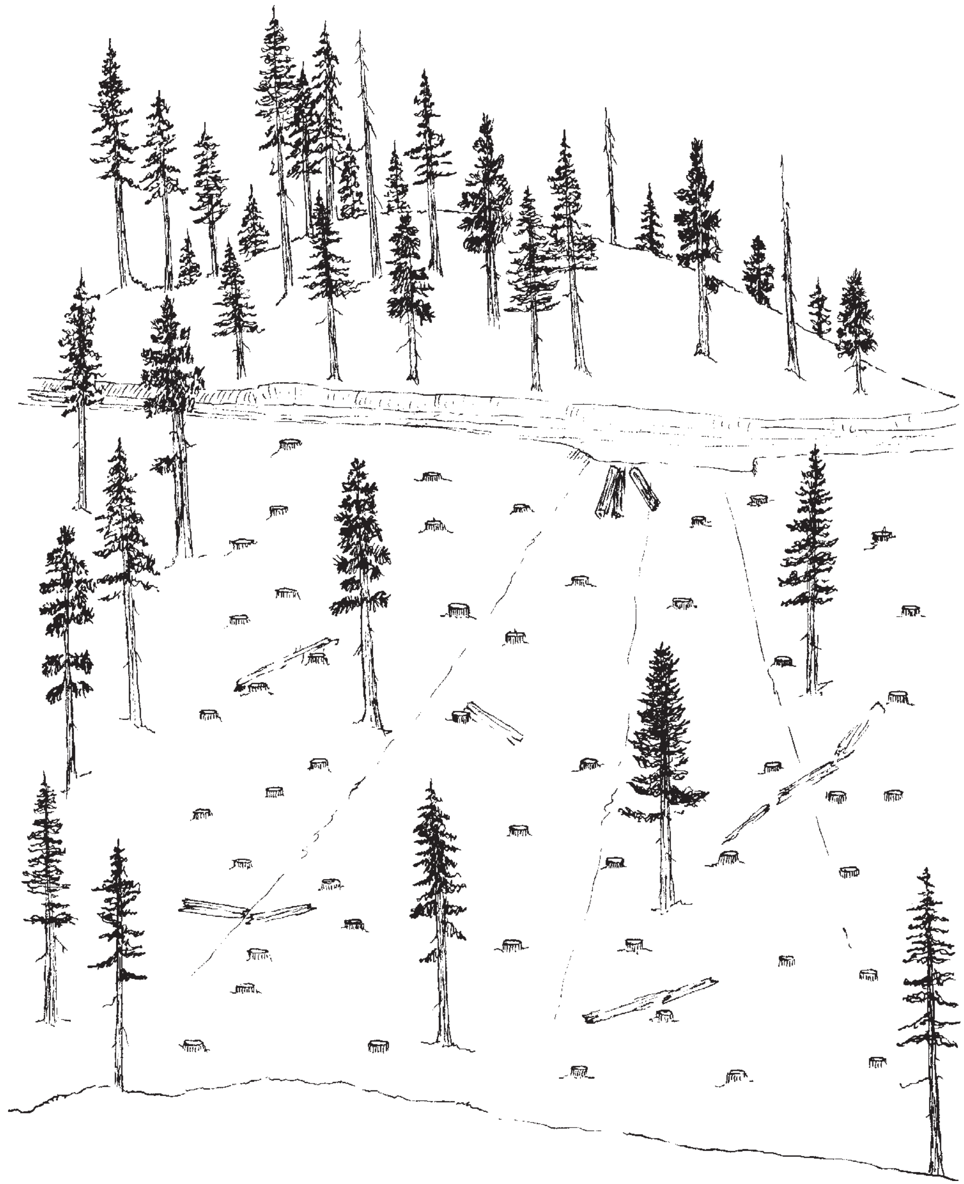


Figure 75—Seed-tree cutting. Seed-tree cutting can reduce budworm susceptibility if host trees are removed in the seed cut, thereby favoring regeneration of non-host species. For both clearcutting and seed-tree cutting, planting of the harvest units can help improve the proportion of nonhost species in the future stand. Since it is likely that the seed trees will be retained for long periods in the future (or never removed), so that they can serve as biological legacies or to provide replacement snags for cavity-nesting birds, it is important to choose nonhost species as the seed trees.

Figure 76—Shelterwood cutting. Shelterwood cutting can reduce budworm susceptibility if the host trees are removed in the seed cut. Since shelterwood cutting results in more site shading than either clearcutting or seed-tree cutting, it can promote regeneration of host species. Planting the shelterwood units can help improve the proportion of nonhost species in the future forest.

Group Selection

Group selection (fig. 77) is an uneven-aged cutting method where trees are removed in small groups. The distance across an individual group is usually no more than one or two times the height of the surrounding trees, up to a maximum size of 2 acres. These openings permit more sunlight to reach the forest floor than with single-tree selection; regeneration of some shade-intolerant trees is possible. However, the amount of exposed ground is less than that produced by clearcutting, seed-tree cutting, or other even-aged methods. If uneven-aged management is desired for an area with high budworm susceptibility, then group selection cutting offers the most promise for regenerating some nonhost species.

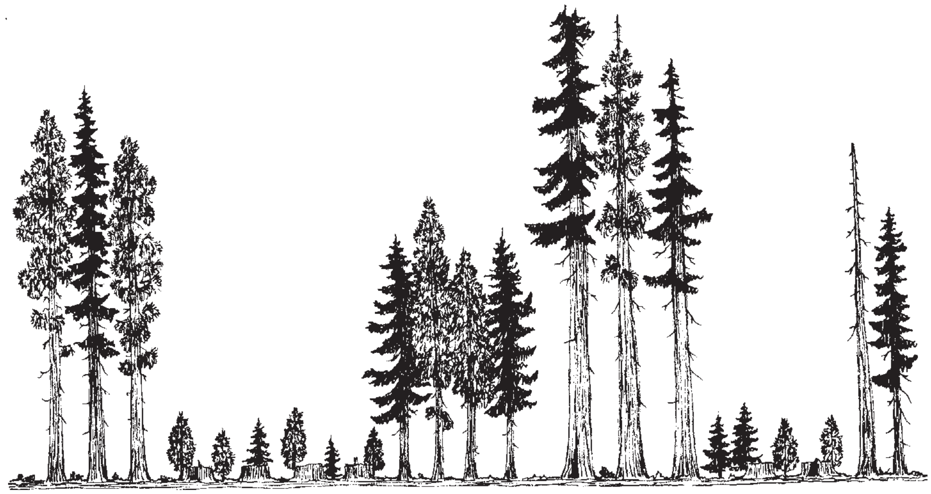


Figure 77—Group selection. Group selection cutting creates a series of small openings in a stand. It offers some opportunities to provide suitable conditions for regeneration of nonhost species. Since side shading from the uncut stand is great in the small openings, group selection often promotes regeneration of shade-tolerant host species.

Single-Tree Selection

Single-tree selection (fig. 78) is an uneven-aged cutting method where individual trees are removed from certain size or age classes over an entire treatment area. Removing single trees creates small openings similar to those resulting from natural mortality. For that reason, single-tree selection favors regeneration of species that can tolerate shade (Powell 1987). In the mixed-conifer forests of the Blue Mountains, this method is least acceptable for reducing budworm susceptibility, primarily because it favors regeneration of shade-tolerant host trees, and it perpetuates a feeding ladder for budworm larvae (see fig. 20).

Figure 78—Single-tree selection. Single-tree selection is generally the least acceptable cutting method for mixed-conifer forests of the Blue Mountains, particularly if reducing budworm susceptibility is an important objective. This cutting method can create ideal conditions for regeneration of white fir, Douglas-fir, Engelmann spruce, and subalpine fir, all of which are hosts of western spruce budworm.

Uneven-Aged Management in Mixed-Conifer Forests

The effect of uneven-aged management depends on the successional status of the species being managed. On dryer sites where ponderosa pine is the climax species, it can be regenerated and sustained using selection cutting. On slightly moister sites where Douglas-fir is climax, it is possible to maintain a reasonable proportion of ponderosa pine or western larch with uneven-aged management. On moist areas where white fir or subalpine fir are the climax species, it is very difficult to maintain an acceptable component of seral, nonhost trees when using either single-tree or group selection cuttings. Uneven-aged management can be expected to promote the multi-layered stand structure that is particularly susceptible to budworm damage (fig. 79).

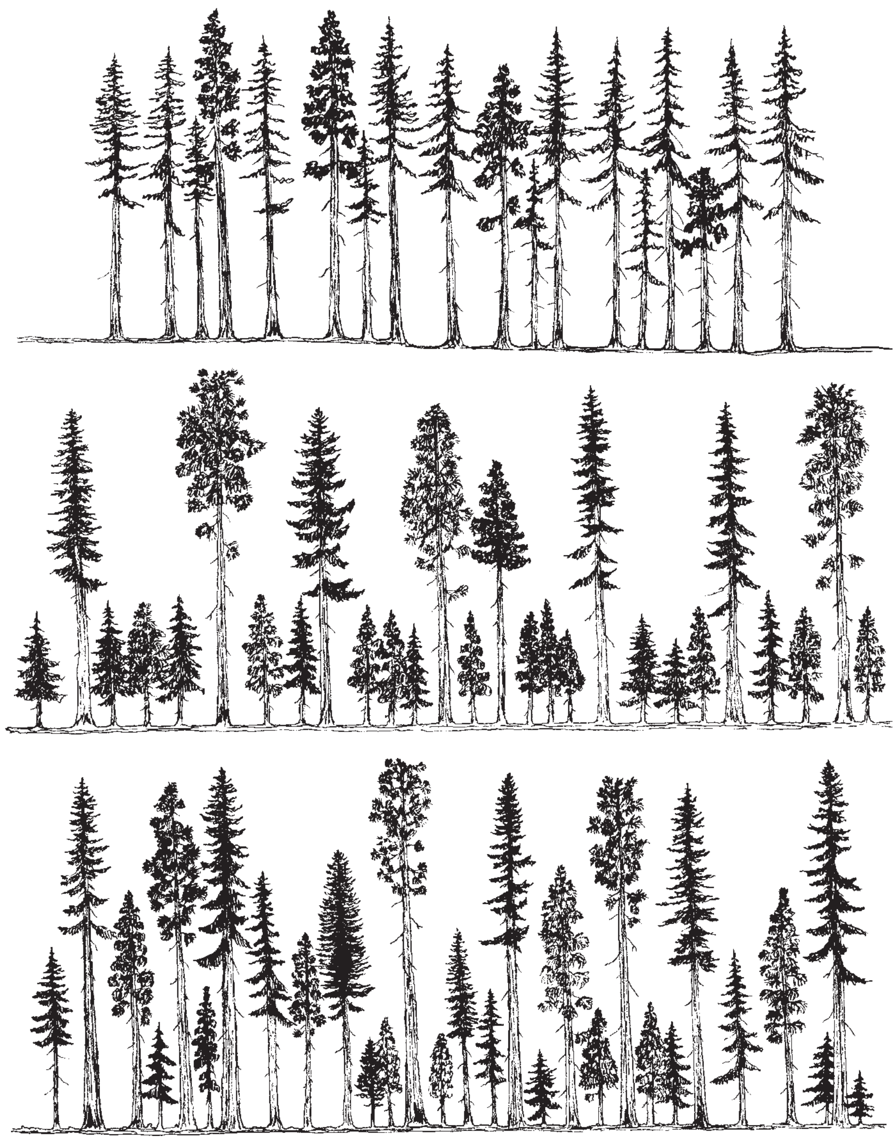


Figure 79—Three common stand structures. Single-storied stands (top third of figure) are generally more resistant to budworm damage than other stand structures. Two-storied stands (middle third) may have high budworm susceptibility because of the feeding ladder effect (see fig. 20). Uneven-aged stands (lower third) have high budworm susceptibility because of the feeding ladder effect, and because they promote establishment of shade-tolerant host species.

Overstory Removals

Overstory removals (fig. 80) are used in multi-storied stands with an understory of healthy trees. On the Malheur NF, overstory removals were originally intended to be used more than any other silvicultural method when the Forest's Land and Resource Management Plan was developed (USDA Forest Service 1990). They were designed to take advantage of the two-storied stands resulting from 80 or more years of fire suppression. It was a strategy that seemed to make good sense—it avoided the costly expense of tree planting and site preparation; it avoided the undesirable appearance associated with clearcutting; it maintained the semblance of a green, forested setting; and it capitalized on at least 60 years of growth on the understory trees.

Figure 80—Overstory removals. Overstory removals are used in multi-storied stands with healthy understory trees. In the past, all of the overstory trees were typically removed; in the future, some of the overstory trees will be retained as biological legacies, snag replacements, or for other purposes (as shown in this figure). In areas with high budworm susceptibility, few of the reserve trees should be host species to avoid creating a budworm feeding ladder.

Overstory Removals and Budworm

Unfortunately, the potential benefits of overstory removals could not be realized because many of the understory trees are hosts of spruce budworm. As budworm larvae rained down from the overstory trees in what is referred to as a feeding ladder (see fig. 20), the understory trees were damaged or killed. Research has shown that either all or none of the overstory trees should be removed when using overstory removals—leaving half of the overstory trees resulted in the greatest understory mortality from budworm defoliation (Carlson and Schmidt 1989).

On the Malheur NF, it was also found that many of the understory trees were affected by other insects and pathogens such as root diseases promoted by previous partial cuttings, or latent infections of Indian paint fungus. Many of the severely affected understories were destroyed, and the sites planted back to pines and other ecologically sustainable species.

Understory Removals

Understory removals (fig. 81) are used in multi-storied stands with an overstory of nonhost trees, and an understory of host species. The objective is to remove a high proportion of the understory host trees. Their removal not only reduces overall budworm susceptibility, but also improves overstory vigor by reducing competition from the understory. When the overstory trees are overmature ponderosa pines and western larches, this treatment can be particularly effective for ensuring their continued survival.

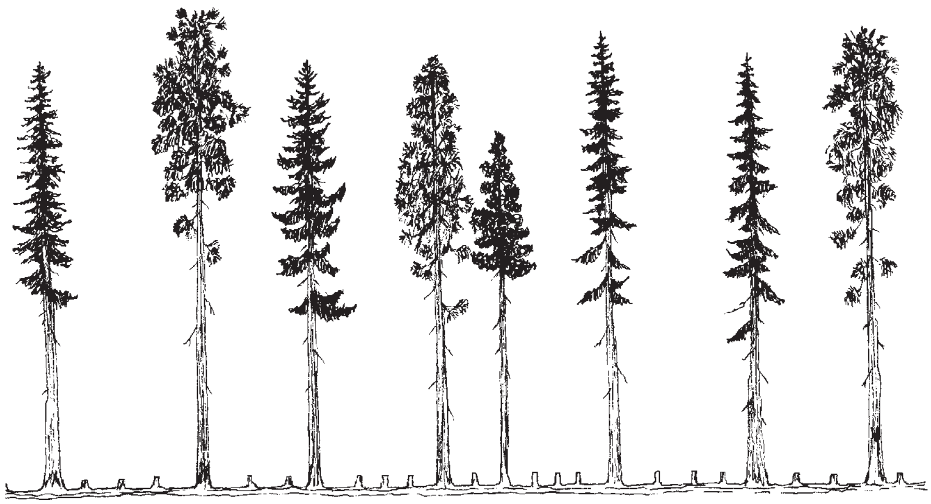


Figure 81—Understory removals. Understory removals are used in multi-storied stands with an overstory of nonhost trees, and an understory of host species. Since many of the overstory trees are overmature ponderosa pines and western larches, this treatment can contribute to their continued survival.

Applying Understory Removals

Understory removals are implemented in at least two ways: on an area basis, or around individual trees. In the first method, understory trees are removed on large areas having a relatively uniform stand composition and structure. Area-wide understory removals can be especially useful before initiating an underburning program. In areas lacking uniform conditions, the understory is removed from around individual overstory trees, primarily to prolong their survival by decreasing inter-tree competition and increasing their vigor.

Overstory and Understory Removals Compared

The ecological differences between understory and overstory removals are striking. Overstory removals harvest the mature pines and larches that were historically maintained by fire, while favoring the small Douglas-firs and white firs that invaded after fires were suppressed. Understory removals harvest the small, shade-tolerant invaders, thereby facilitating reintroduction of fire for the benefit of pines and larches. In one instance (understory removals), the treatment is designed to mimic an important ecosystem process; in the other (overstory removals), ecological conditions are moved even further away from the historical range of variation.

Tree Planting

Planting (fig. 82) is a powerful tool for influencing the future composition of a forest. In areas with substantial budworm damage, planting can help reestablish a high proportion (60–70%) of nonhost trees. At lower elevations, Douglas-fir is the climax species and the choice of nonhost species is limited, with ponderosa pine and western juniper being the most obvious ones. At higher elevations and on cooler sites, white fir or subalpine fir are climax and the selection of nonhost species is wider—lodgepole pine, western larch, ponderosa pine, western white pine, or quaking aspen could be used depending on the ecological conditions of the planting site.

Figure 82—Tree planting. Planting is a powerful way to influence the future composition of a forest. In areas with substantial budworm damage, planting can be used to establish a high proportion (60–70%) of nonhost trees.

Tree Pruning

Pruning (fig. 83) is typically used to produce clear, knot-free wood, but it could also play a role in the management of budworm-susceptible forests. In areas where budworm-host trees will continue to be a stand component, pruning could provide several benefits. The first and most obvious benefit is that by removing the lower crown portion of host trees, pruning results in less food for the survival and growth of budworm larvae.

Pruning for Fire Resistance

After pruning host trees that are large enough to have developed a fire-resistant bark (fig. 84), it would be possible to underburn mixed stands without “torching” the budworm hosts. Host trees with short, pruned crowns would be less likely to serve as ladder fuels, thereby minimizing the risk of an underburn turning into a crown fire. Pruning host trees must be carefully coordinated with the onset of an underburning program; if trees were pruned too soon, epicormic sprouts could occur on the stem and increase a tree’s risk of torching in an underburn.

Figure 83—Tree pruning. Pruning could reduce budworm impacts by removing the lower crown portion of host trees, which results in less substrate (food) being available for budworm larvae. Pruning can also be used to increase the fire resistance of host trees (see fig. 84).

Prescribed Burning

Prescribed burning (fig. 85) is a common practice that has been used to reduce natural fuel loading, to treat logging residues, and to prepare a site for planting or natural regeneration. In the future, it may play a much greater role in the management of Blue Mountains ecosystems (Mutch and others 1993), but only if smoke management concerns do not unduly constrain its use. An example of how prescribed burning could be used is described next.

Prescribed Burning for Silviculture

A common silvicultural prescription for mixed-conifer forests is to regenerate them using the seed-tree or shelterwood systems. Ponderosa pine, western larch, and western white pine (if available) are retained in the seed cut. After harvest, the slash may be piled and burned, particularly on sites with high fuel loads, or treated by lopping it into small pieces and scattering them across the site. At that point, a prescribed fire may be used to cycle nutrients, reduce wildfire hazard, and expose mineral soil for establishment of seral, nonhost species or to create planting spots. Stimulation of perennial bunchgrasses, forbs, and a variety of shrubs can also result from the burn.

Burning On A Regular Cycle

After a new forest has gotten established, a regular cycle of prescribed burning could then begin. Once the ponderosa pines and larches are 10 to 12 feet tall, the first burn could be completed, although a low-intensity fire would leave most of the 6- to 8-foot trees undamaged as well (Wright 1978). From that point on, ground fires could be run through the stand on a regular cycle, usually at intervals of 10 to 15 years. Regular underburns would remove many of the budworm host trees that had regenerated since the last burn, and could also provide an irregular thinning of the pines and larches.

Figure 84—Bark and lower-stem branching characteristics of a mature white fir. White fir has thin bark, a long crown, and other traits that result in low fire resistance. However, those traits are most prominent when the trees are small. As white firs mature, their bark thickens considerably, and when growing in dense stands, their crowns become shorter as they self prune from areas of deep shade upward. The main difference between the fire resistance of true firs and ponderosa pine or western larch is that pine and larch develop a thick bark and short crown much more quickly than the firs. Since underburns occurred frequently in many presettlement ecosystems (on an average of every 8–20 years at low elevations), it was difficult for firs to escape fire long enough to develop the thick bark and short crown that ensured their survival.

Fall Burns Are Ecologically Preferable

Fall burns are preferable from an ecological standpoint because they replicate the natural fire regime. Fall burning also results in fewer losses of overmature pines to fire-induced stress or western pine beetle attacks (Swezy and Agee 1991). Fire may not be beneficial on all mixed-conifer sites (fig. 86); on moist areas, burns could favor dominance by bracken fern, western coneflower, and other allelopathic plants that inhibit conifer regeneration (Adams and Ferguson 1990, Ferguson 1991, Ferguson and Boyd 1988).

Figure 85—Prescribed burning. This common practice has been used to reduce natural fuel loading, to treat logging residue, and to prepare a site for planting or for regeneration of seral, nonhost species.

Figure 86—Mixed-conifer stand with an undergrowth dominated by bracken fern. Some mixed-conifer stands have an undergrowth featuring bracken fern or western coneflower, both of which can inhibit conifer regeneration by producing chemicals that kill newly-germinated trees (Ferguson and Boyd 1988, Ferguson 1991). Both bracken and coneflower sprout from rhizomes and can spread vigorously after fire. Heavy cutting or use of prescribed fire should be carefully considered before treating sites where bracken is present.

Burning to Favor Nitrogen-Fixing Plants

Periodic burning can also be used to increase the nutrient capital of a site by maintaining sparse stands of snowbrush ceanothus, tailcup lupine, peavines, vetch, and other nitrogen-fixing plants (fig. 87). Numerous studies have documented the slow decomposition rates associated with large, woody material in the interior West (Brock and Brock 1993, Gary and Currie 1977, Gruell 1980, Gruell 1983, Gruell and others 1982). Forests of the interior West may have depended more on nitrogen-fixing plants to replenish soil nutrients than on the decomposition of woody debris. Providing adequate levels of site nutrition is important for maintaining tree resistance to budworm and other insects and pathogens (see fertilization discussion earlier in this section).

Figure 87—Nitrogen-fixing plants. Periodic burning was an important ecological process for maintaining snowbrush ceanothus, tailcup lupine, peavines, vetch, and other nitrogen-fixing plants. Forests of the interior West may have depended more on nitrogen-fixing plants to replenish soil nutrients than on the decomposition of woody debris. The site shown here has a mixture of snowbrush ceanothus and planted ponderosa pines.

Salvage Logging of Budworm-Caused Tree Mortality

In areas with substantial mortality from budworm defoliation (fig. 88), some of the dead trees are usually salvaged. As is often the case with land management practices, salvage logging can have both positive and negative effects. Some important benefits of salvage are to harvest and utilize wood fiber while it is still merchantable, to remove enough dead trees to promote regeneration of sun-loving seral species, and to reduce fuel loadings to the point where wildfire risk is acceptable and a prescribed burning program could be initiated.

Retaining Some Dead Trees

But in order to avoid exacerbating an already unfortunate situation, salvage logging should be done carefully. Enough dead trees should be left to provide adequate habitat for cavity-dependent birds. Retaining dead trees also provides habitat for ants and other invertebrates that prey on budworm larvae. And standing dead trees eventually fall to the ground, where they contribute to nutrient cycling, maintain long-term site productivity, and provide mycorrhizal habitat.

Figure 88—A mixed-conifer stand killed by budworm defoliation. Stands with the amount of mortality shown here are often logged to salvage some of the dead trees. Without their removal, it may be difficult to create the open, sunny conditions that are required for establishment of ponderosa pine, western larch, and other seral species. Note the abundance of thistle in the undergrowth of this stand. Typically, thistle invades following a hot prescribed burn. But in situations like the one shown here, thistle can dominate in unlogged, unburned stands because cattle grazing had created an ideal seed-bed for its establishment.

Retaining Some Live Host Trees

Managers can affect the future structure and composition of the forest by how they handle the surviving host trees. The objective of salvage is not to eradicate the budworm-host trees from an area. It makes good sense to retain some of the host trees that survive an outbreak, especially if they demonstrate natural resistance to defoliation (fig. 89).

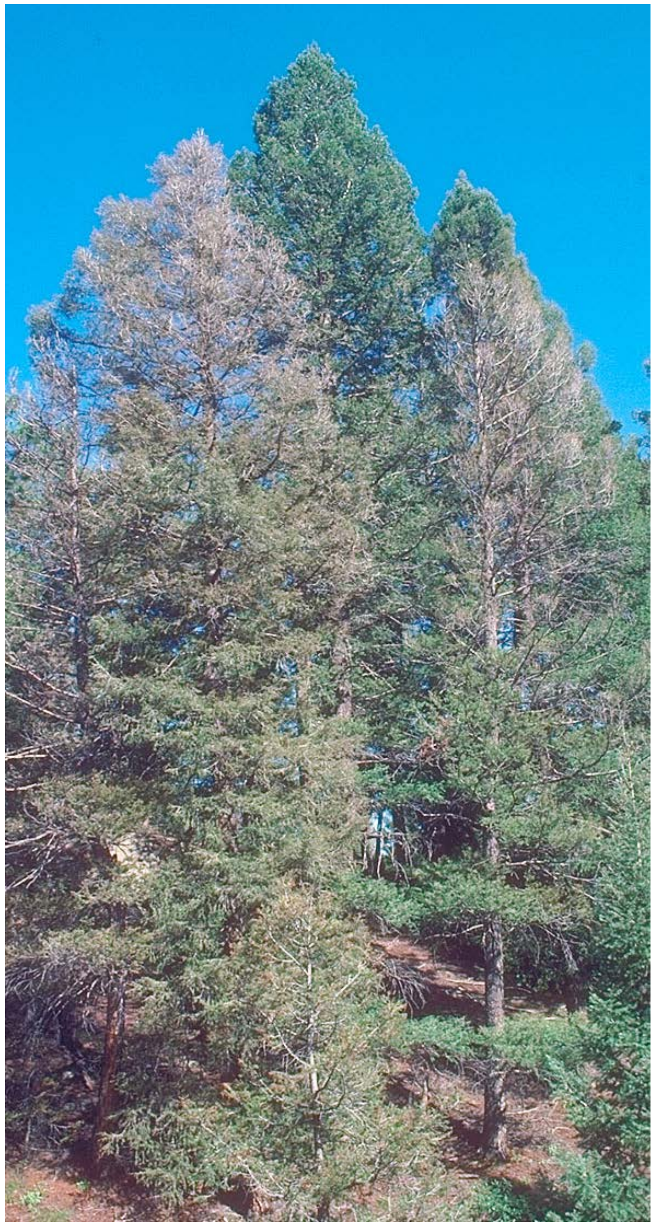


Figure 89—Natural resistance to budworm defoliation. This photograph shows a dry-site, mixed-conifer stand dominated by Douglas-fir. Note that the tree in the center has sustained much less defoliation than those just in front of it, even though the crowns of the three trees are touching or intertwined. The center tree seems to have some natural resistance to budworm feeding. Recent research found that foliage from defoliated Douglas-firs had lower amounts of terpenes (a defensive chemical) than nondefoliated trees, and that severely-defoliated trees broke bud 7 to 10 days earlier than nondefoliated trees (Muzika and others 1993). Both of those characteristics could have application in a genetics program to breed budworm-resistant trees.

Biological Legacies

Some of the surviving white firs and Douglas-firs could be ideal trees to retain as biological legacies (fig. 90). Legacy trees can serve as a biological bridge between one generation of trees and the next. Some of the legacies provided by remnant trees could include Indian paint fungus, mycorrhizae and associated soil flora and fauna, root diseases, cavity-nesting bird habitat, black bear den sites, and many others.

Whether those legacies are "good" or "bad" depends on one's perspective, and whether the legacy affects a manager's capability to achieve the goals and objectives (desired future condition) for an area. For example, overstory trees infected with Indian paint fungus may be a desirable legacy from a wildlife standpoint because they provide cavity-nesting bird habitat and black bear dens, but they may be undesirable from a timber standpoint because of their reduced merchantability.

Figure 90—A "cull" white fir. In the past, large white firs such as the one shown here would have been removed from a timber sale area and sold as fiber (chips), or felled and left on site. It is infected with Indian paint fungus, and has a lot of internal decay (see fig. 11). Now, these trees are often retained as biological legacies, particularly for pileated woodpeckers and other cavity-nesting birds that require large-diameter trees with internal rot.

Maintaining Tree Species Diversity

An important objective is to assure that salvage operations will not interfere with the ultimate goal of providing biologically diverse forests, both now and in the future. To reach that goal, it will be important for forest managers to promote mixed species stands. Even so, the proportion of budworm-host species should not be allowed to exceed 30 or 40 percent, at least for areas where a defoliator outbreak would jeopardize being able to meet future objectives (desired future conditions).

Natural Enemies of Budworm

Land managers may be able to influence the extent of future outbreaks by how they affect the natural enemies of budworm and tussock moth (fig. 91). Ants, birds, yellowjackets, and other budworm predators can be affected by insecticide applications, prescribed fire, silvicultural practices, insect and disease treatments, and logging methods.

Birds As Budworm Enemies

Birds are important enemies of budworm (fig. 91). Budworm-feeding birds can be promoted by using the following management practices (Langelier and Garton 1986): provide stands with horizontal and vertical diversity; avoid large clearcuts; provide edges; avoid high-grading; avoid homogeneous, plantation-like stands; leave some slash; reduce herbicide use; control livestock grazing; provide habitat for cavity-nesting birds; provide salt; and provide water.

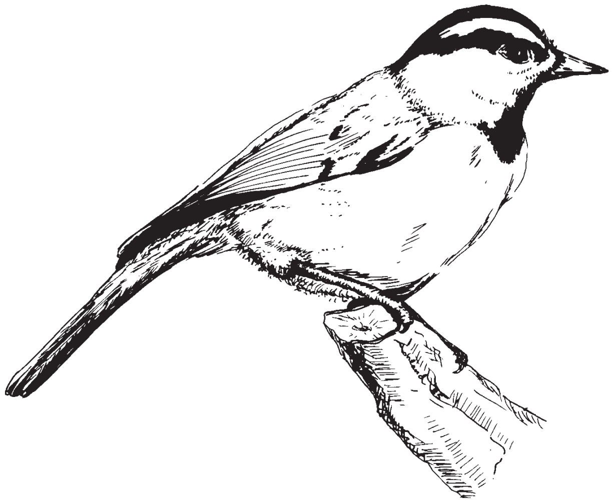
Birds and Dwarf Mistletoe

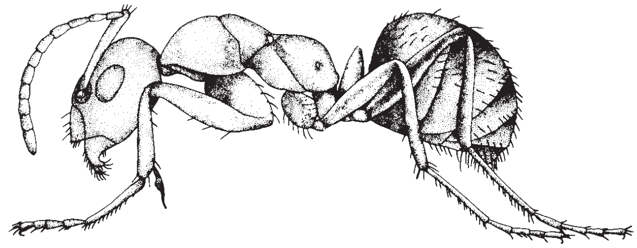
Managers can also affect bird populations by how they handle insects or pathogens other than budworm. For example, a recent study found bird diversity and abundance to be greater in forests infected with dwarf mistletoe (fig. 92). In fact, the number of bird species increased as the dwarf mistletoe infection level increased. The study also found that dwarf mistletoe was not being used as food—its berries are small and hard—but the “witches brooms” it caused provided nesting and roosting sites, and served as habitat for butterflies, moths, and some of the other insects that birds feed on (Mlot 1991).

Protecting Arthropods During Management

Ants and ground-dwelling spiders can be affected by site preparation activities, fuel or residue treatments, insecticide applications, and logging practices. Retaining down woody material, particularly large logs and standing dead trees (snags), is important for sustaining carpenter ants and other forest-floor arthropods. Recent recommendations for retention of logs and snags for pileated woodpeckers and other vertebrates, long-term site productivity, fungi and bryophytes, nutrient cycling, and for other purposes, would probably be adequate to meet the needs of ants and forest-floor spiders.

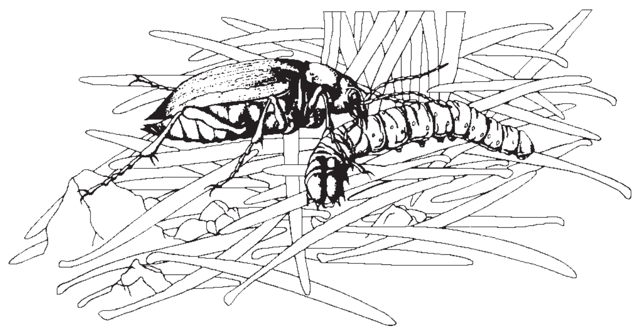
During logging operations and other activities involving heavy equipment, thatch-ant nests should be avoided. Even if thatch ants are not protected in recognition of their intrinsic value to the ecosystem, the nests should be avoided because ants are important predators of spruce budworm larvae (fig. 93).



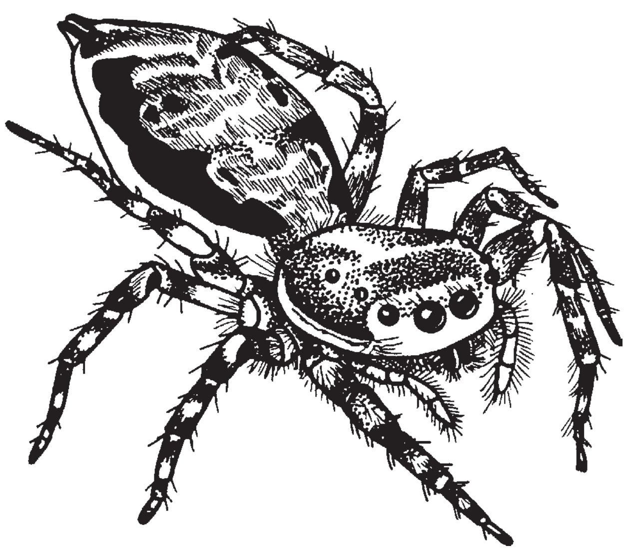


Ants are important predators of budworm. Thatch ants, such as the one shown here, and carpenter ants are effective at preying on budworm larvae that have fallen to the forest floor. Some ants are arboreal foragers; they can be very important by feeding on budworm larvae that fall onto seedling- and sapling-sized host trees.

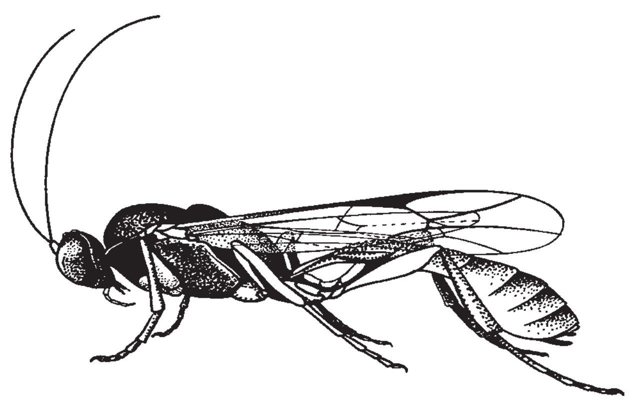
Birds are important budworm predators. At least 26 birds have been documented as budworm predators (Garton 1987), but it's likely that more species than that may play such a role. The mountain chickadee, shown here, and red-breasted nuthatches are particularly important budworm predators. Both of those birds require dead wood (standing snags or tall stumps) in which to nest.



Beetles and the true bugs (stink bugs, etc.) are just two examples of insect groups which feed on budworm larvae that fall to the forest floor. Little information is available about the importance of these insects as budworm predators. A carabid beetle feeding on a budworm larva is shown here.



Spiders outnumber all other arthropods on the foliage of Douglas-fir and true firs. In the Blue Mountains, hunting spiders are much more plentiful than the web spinners (Mason 1992), although both types prey on budworm. An especially effective budworm predator is the jumping spider shown here.



Many species of wasps and flies are known to parasitize insect larvae. Parasitic insects find budworm larvae, pupae, or eggs, where they then lay their own eggs. After their eggs hatch, the developing parasite feeds on the budworm host, eventually killing it. The wasp shown here is a common Blue Mountains species (*Hyposoter masoni* Torgersen).

Figure 91—Some natural enemies of western spruce budworm.

Figure 92—Douglas-fir infected with dwarf mistletoe. The Douglas-fir in this photograph has several areas with dense, bunched branches ("witches brooms") caused by dwarf mistletoe. A recent study found bird diversity and abundance to be greater in forests infected with dwarf mistletoe (Mlot 1991). The study showed that dwarf mistletoe was not being used as food—its berries are small and hard—but the "witches brooms" it caused provided nesting and roosting sites, and served as habitat for butterflies, moths, and some of the other insects that birds feed on. Since birds are important budworm predators, it may not be prudent to remove all of the mistletoe-infected trees on areas with a high proportion of budworm host species.

Figure 93—Large thatch ant nest on a mixed-conifer site. Ants, spiders, and other forest-dwelling arthropods can be affected by timber harvest, site preparation activities, fuel or residue treatments, insecticide applications, and other management practices. During timber harvest operations and other activities involving heavy equipment, thatch-ant nests should be avoided because ants are important predators of spruce budworm larvae (photo courtesy of Torolf Torgersen). And perhaps not unsurprisingly, these nests also function as hotspots for nutrient cycling because the ants' shredding treatment of organic nest materials aids decomposition processes and nutrient release.

This report described an important reason for extensive budworm defoliation during the 1980s—suppression of wildfires since about 1900, especially natural underburns (see "Effects of Fire Suppression on Budworm Habitat," page 9). Land managers who prefer to administer forests with low budworm susceptibility are ready, willing, and eager to expand the use of prescribed fire in their management of Blue Mountain ecosystems. More use of prescribed fire could help reestablish vegetation conditions similar to those of presettlement times, including a higher proportion of ponderosa pine, western larch, and other budworm-resistant species.

Fire Effects and Project Planning

Project planning requires that fuels specialists, silviculturists, wildlife biologists, and other members of an interdisciplinary team be able to predict how plant species will respond to fire. Without that information, it is difficult to evaluate the effect of alternative fire regimes on vegetation. The information in Table 5 was compiled to help meet the need for fire effects information—it provides ratings of fire resistance and post-fire response, and comments about regeneration characteristics affecting a plant's reaction to fire, for more than 70 species. Plants included in Table 5 were the most common species on 130 mixed-conifer inventory plots that were remeasured in 1988 and 1989.

Fire Resistance Ratings

Plants have varying degrees of fire resistance. A plant's response to fire depends on many factors, including the moisture content of soil and duff at the time of burning, the physiological stage of the plant (immature, mature, etc.), and the fire's severity, particularly with regard to the amount of heat that permeates the litter, duff, and upper soil layers (Crane and Fischer 1986). An important factor affecting a plant's fire resistance is whether it regenerates vegetatively (survivor plants) or from off-site or buried seed (colonizer plants). Fire resistance ratings ("Resistance" in Table 5) have the following interpretation (Volland and Dell 1981):

- High—Greater than 65 percent chance that 50 percent of the species population will survive or immediately reestablish after passage of a fire with an average flame length of 12 inches.

- Medium—35 to 64 percent chance that 50 percent of the species population will survive or immediately reestablish after passage of a fire with an average flame length of 12 inches.

- Low—Less than 35 percent chance that 50 percent of the species population will survive or immediately reestablish after passage of a fire with an average flame length of 12 inches.

Post-fire Response Ratings

Post-fire response ratings ("Response" in Table 5) are an estimate of how quickly a plant species will regain its prefire population level. They have the following interpretation (Volland and Dell 1981):

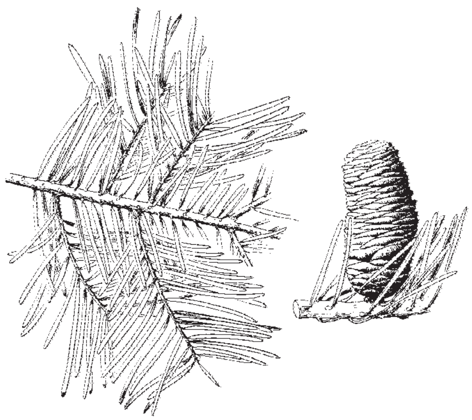
- High—The species population will regain its preburn frequency or cover in 5 years or less.

- Medium—The species will regain its preburn frequency or cover in 5 to 10 years.

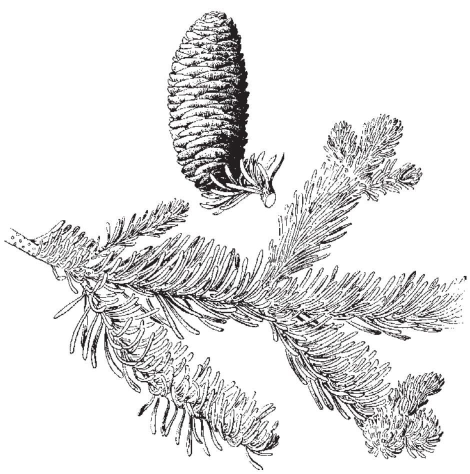
- Low—The species will regain its preburn frequency or cover in more than 10 years.

Site Type Ratings

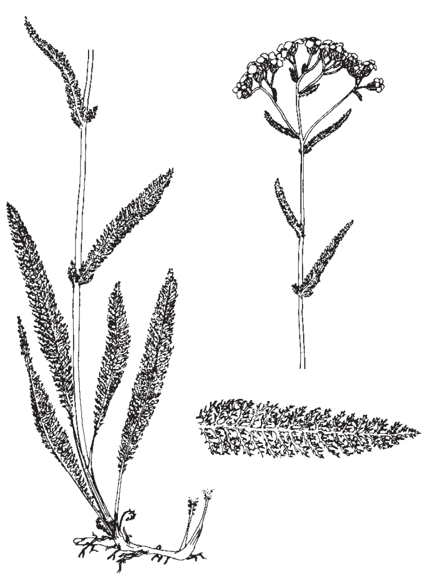
The site type ratings are somewhat subjective and were included in Table 5 to describe the temperature and moisture relationships for sites on which the species is abundant and widely distributed.



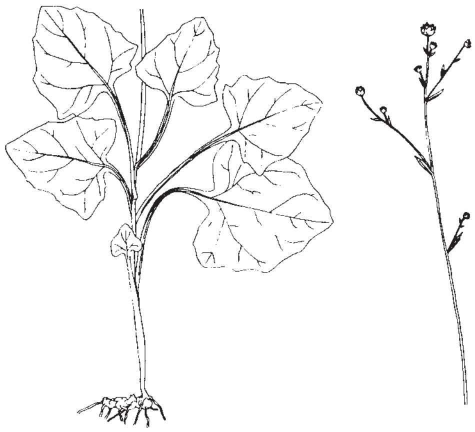
Name: White/Grand Fir (*Abies concolor/grandis).* **Code**: ABCO.
Resistance: Medium. **Response**: Low. **Site Type**: Cool, Mesic.
Comments: White fir, or a natural hybrid with characteristics intermediate between those of white fir and grand fir, is the most common fir at lower elevations. White fir's dense, low branching habit and its flammable foliage, resinous bark, and high stand density result in a moderate or high susceptibility to fire-induced mortality. The thick bark of mature trees adds to their fire resistance (fig. 84). Fire often causes high mortality on moist sites where the trees have developed shallow lateral roots. Decay often enters through, or is initiated by, fire scars. Because small white firs are very sensitive to fire, low-intensity prescribed burns can be used to intentionally kill them. White fir, the favorite food of spruce budworm, has flourished in the fir stands that have encroached on ponderosa pine sites over the last 80 years.



Name: Subalpine Fir (*Abies lasiocarpa).* **Code**: ABLA2.
Resistance: Low. **Response**: Low. **Site Type**: Cold, Mesic.
Comments: Subalpine fir grows at high elevations where its slender, spire-like crown sheds the heavy snowfalls of subalpine winters. Those snows often bend its lower branches to the ground, where they root and eventually form independent trees in a process called layering. This handsome tree produces inch-long needles from all sides of the twig. It has thin, gray, smooth bark covered with resin blisters; often, a single bark blister may hold up to half a teaspoon of aromatic, sticky balsam. Purplish cones are produced upright on branch tops high in the crown. It has very low fire resistance because of its thin bark; the presence of resin blisters on the bark; a low, dense branching habit; a shallow root system; and a tendency to occur in dense stands where neighboring trees are touching. Entire stands of this high-elevation species are easily killed by fire.

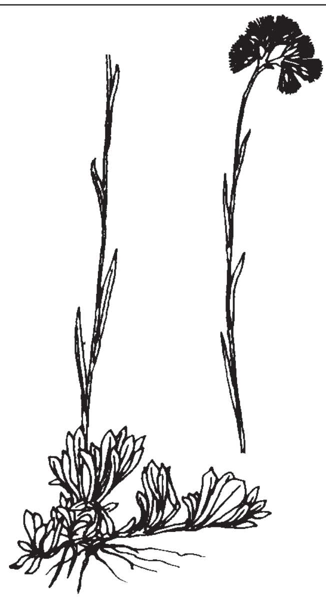


Name: Western Yarrow (*Achillea millefolium).* **Code***:* ACMI.
Resistance: Medium. **Response**: High. **Site Type**: Disturbed Areas.
Comments: Western yarrow is a strongly aromatic forb with grayish, finely-divided leaves and flat-topped clusters of small, white flowers. It is a weedy, widely-distributed plant that regenerates from short, shallow rhizomes, and from seed. Yarrow may decline after severe fires, although reestablishment from off-site seed usually occurs rapidly.



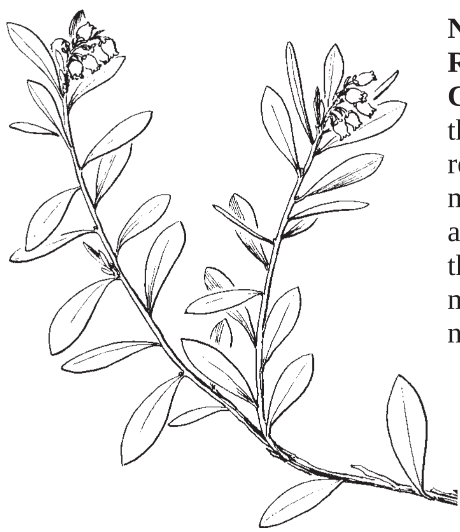
Name: Trailplant (*Adenocaulon bicolor).* **Code**: ADBI.
Resistance: Low. **Response**: Low. **Site Type**: Cool, Moist.
Comments: Trailplant is a low or mid-height forb with triangular, bi-colored leaves that are green above, and white beneath. It grows on shaded, highly-productive sites and regenerates from short surface rhizomes and seed, generally surviving cool fires that don't consume all of the litter and duff layers or cause excessive soil heating. The post-fire recovery of trail plant is usually slow.

Name: Serviceberry (*Amelanchier alnifolia).* **Code**: AMAL.
Resistance: Medium. **Response**: High. **Site Type**: Cool, Mesic.
Comments: Serviceberry is a mid-height shrub that has dull-green leaves with toothed tips, and attractive clusters of white, fragrant flowers. It provides excellent big-game browse. This widespread plant sprouts from the root crown, its stem bases, and from a large rhizome, and usually survives severe fires if the soil is fairly moist at the time of burning. Serviceberry sprouts immediately after fire and often regains preburn levels within 2 or 3 years. Good fruit production occurs every 3–5 years; its seeds are spread by birds and bears that feed on the fruits.



Name: Rose Pussytoes (*Antennaria rosea).* **Code**: ANRO.
Resistance: Low. **Response**: Medium. **Site Type**: Cool, Dry.
Comments: Rose pussytoes is a low, mat-forming forb with small, pink, ball-shaped flowers produced on slender stalks. This diminutive plant reproduces by using trailing stolons, and from wind-blown seed. It prefers sites with the light shading of a partial forest canopy. Although fire effects information is scarce for rose pussytoes, it is apt to increase slightly or remain unchanged following a low- or moderate-intensity burn.

Name: Red Columbine (*Aquilegia formosa).* **Code**: AQFO.
Resistance: Medium. **Response**: Medium. **Site Type**: Cool, Moist.
Comments: Red columbine is a slender, perennial forb with attractive, red-and-yellow flowers. This plant is commonly found on moist, shaded sites, where it regenerates mostly from seed. Although fire effects information is scarce for this species, it is likely that moderate or hot fires which consume most of the litter and duff layers are apt to have a detrimental effect on red columbine.



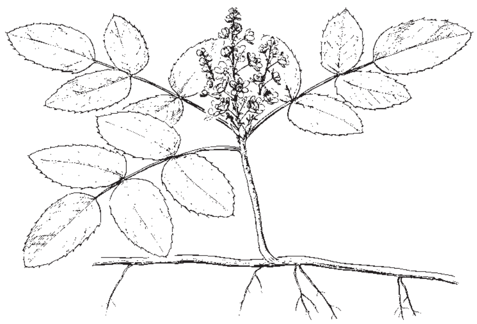
Name: Manzanita (*Arctostaphylos nevadensis).* **Code**: ARNE.
Resistance: Low. **Response**: Medium. **Site Type**: Cool, Dry.
Comments: Pinemat manzanita is a creeping shrub with small, thick, leathery leaves and white or pink, urn-shaped flowers. It regenerates from the root crown, runners (stolons) or, most commonly, from seed. The seed is produced in bright red berries that are a favorite food of birds and other wildlife. It survives cool fires if the litter and duff layers were not completely consumed. Pinemat manzanita often invades burned areas from unburned patches nearby.

Name: Bigleaf Sandwort (*Arenaria macrophylla).* **Code**: ARMA3.
Resistance: Low. **Response**: Medium. **Site Type**: Cool, Mesic.
Comments: Bigleaf sandwort, a very common plant of the mixed-conifer forest type, is a low forb with opposite, lance-shaped leaves and small, white flowers borne on slender stalks. It regenerates from shallow rhizomes and seed, and decreases slightly or remains unchanged after fire, depending upon how much of the litter and duff was consumed and how much soil heating occurred.

Name: Heartleaf Arnica (*Arnica cordifolia).* **Code**: ARCO.
Resistance: Low. **Response**: High. **Site Type**: Cool, Mesic.
Comments: Heartleaf arnica is a shade-loving, early-blooming forb with broad, heart-shaped, opposite leaves that have prominent veins and are hairy and rough. Generally, each plant produces a single large, showy, yellow flower. It often declines in clearcuts or other openings. This species sprouts from surviving rhizomes, but is easily killed by all except mild fires. However, heartleaf arnica readily invades burned areas using windborne seed.

Name: Showy Aster (*Aster conspicuus).* **Code**: ASCO.
Resistance: Medium. **Response**: High. **Site Type**: Cool, Mesic.
Comments: Showy aster is a moderately shade-tolerant forb with alternate, sharply-toothed leaves that clasp the stem, and terminal flowers with bluish or purplish rays. It regenerates by sprouting from surviving rhizomes, and from seed. This plant typically survives cool or moderate fires that don't cause excessive soil heating. Occasionally, showy aster increases rapidly after burning because its windborne seed disperses over long distances.

Name: Balsamroot (*Balsamorhiza sagittata).* **Code**: BASA.
Resistance: High. **Response**: High. **Site Type**: Warm, Dry.
Comments: Arrowleaf balsamroot, a common forb of dry, open sites, has large, hairy, triangular leaves arising from a basal clump, and attractive yellow flowers that look like small sunflowers. It regenerates from a stout caudex (root crown) and from animal-disseminated seed, and generally survives even the severest fires—plant densities are often greater than pre-burn levels by the second growing season after burning. After trees get reestablished and site shading increases, arrowleaf balsamroot populations can be expected to decline dramatically.

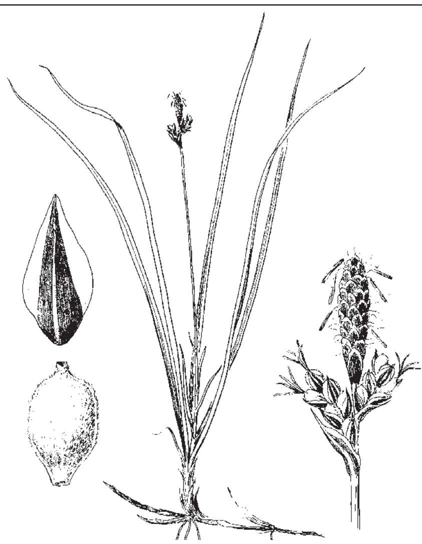


Name: Creeping Hollygrape (*Berberis repens).* **Code**: BERE.
Resistance: Medium. **Response**: Medium. **Site Type**: Cool, Dry.
Comments: Creeping hollygrape is a low, prickly shrub with compound, evergreen leaves. Each leaflet has wavy or shallowly-lobed margins and spine-tipped teeth. Clusters of yellow flowers appear early in spring and are followed by attractive, blue berries. This plant sprouts from surviving rhizomes after fire. It survives all but severe burns that cause high soil heating. Populations decrease slightly or remain unchanged following low- or moderate-intensity burns. Rarely does regeneration occur from the seeds contained in its bright, blue berries.

Name: California Brome (*Bromus carinatus).* **Code**: BRCA.
Resistance: Medium. **Response**: Medium. **Site Type**: Warm, Dry.
Comments: California brome is a tall grass with narrow, upright panicles of awned flowers. It regenerates from the root crown, and from seed. Since it is a coarse-stemmed species with relatively sparse foliage, California brome is more fire-resistant than fine, leafy bunchgrasses. This plant is most susceptible to fire damage when actively growing in spring and early summer.

Name: Columbia Brome (*Bromus vulgaris).* **Code**: BRVU.
Resistance: Medium. **Response**: Medium. **Site Type**: Cool, Moist.
Comments: Columbia brome is a medium or tall, non-rhizomatous grass with open, drooping panicles of awned flowers. It regenerates from seed, some of which may be stored in the soil. This species declines following severe fires, although the moist sites on which it grows are seldom easy to burn. Although Columbia brome persists under a dense tree canopy, it often increases in the open environments provided by timber harvest and other disturbances.

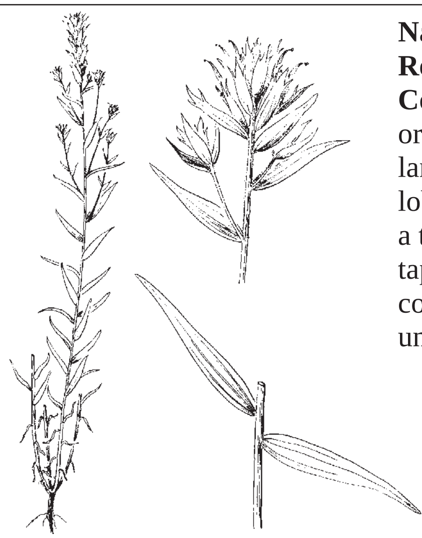
Name: Pinegrass (*Calamagrostis rubescens).* **Code**: CARU.
Resistance: Medium. **Response**: Medium. **Site Type**: Warm, Mesic.
Comments: Pinegrass, a creeping species, is one of the most common plants of mixed-conifer forests. It often increases in disturbed areas or natural openings, especially on moist sites. Pinegrass seldom flowers in the shade of a dense forest canopy, although abundant seed is often produced during the year following a fire. It regenerates from rhizomes and seed, and survives all but severe fires that completely remove the litter and duff layers. Pinegrass can be a formidable competitor with planted seedlings, especially if they are not well established within 3 years of timber harvest. This plant is not a preferred forage species for cattle, especially after it matures in late summer (Hedrick and others 1968).



Name: Northwestern Sedge (*Carex concinnoides).* **Code**: CACO.
Resistance: Medium. **Response**: Medium. **Site Type**: Cool, Moist.
Comments: Northwestern sedge is a moist-site species with flat, wide, shiny leaves and brownish leaf sheaths. It sprouts from rhizomes located in the duff, or between the duff and mineral soil. Those rhizomes allow this plant to form sparse, loose mats on mesic, mixed-conifer sites. Since its creeping rhizomes are very shallow, there is high risk that fires which consume most of the litter and duff layer will have an adverse impact on this species.

Name: Elk Sedge (*Carex geyeri).* **Code**: CAGE.
Resistance: High. **Response**: High. **Site Type**: Warm, Mesic.
Comments: Elk sedge is a moderately shade-tolerant plant with flat, leathery, rough-margined leaves and tight, narrow flower spikes. It may be common in the undergrowth of mixed-conifer stands, especially those on dryer sites. Following fire, it sprouts from surviving rhizomes. Even though it decreases immediately after burning, elk sedge then increases within a few years to form dense stands. Although it is seldom abundant on mixed-conifer sites, elk sedge is a preferred forage species for cattle (Hedrick and others 1968).

Name: Ross Sedge (*Carex rossii).* **Code**: CARO.
Resistance: High. **Response**: Medium. **Site Type**: Cool, Dry.
Comments: Ross sedge is a low-growing plant with thin, narrow leaves and short spikes of small, brown flowers. Some of the flowers are produced on stems longer than the foliage, while others occur near the base of the plant and are hidden among the leaves. The leaf bases usually have an obvious reddish color. It regenerates from surviving rhizomes, and from seed stored in the duff and upper soil. This species often increases after fires which don't consume all of the litter and duff layers or cause excessive soil heating. On dryer sites, Ross sedge often becomes abundant after clearcutting and scarification activities.



Name: Scarlet Paintbrush (*Castilleja miniata).* **Code**: CAMI2.
Resistance: Medium. **Response**: Medium. **Site Type**: Warm, Mesic.
Comments: Scarlet paintbrush is a mid-height forb with red or dark-orange bracts and unbranched stems up to two feet tall. Its leaves are lance-shaped and have entire margins. The reddish bracts are usually lobed, although some are entire and have a sharp tip. This plant has a tough, woody base. It regenerates from the crown of a deep taproot, and from off-site seed. Its reestablishment in the post-fire community is somewhat slow; usually, it does not even reappear until the second or third year after burning.

Name: Snowbrush Ceanothus (*Ceanothus velutinus).* **Code**: CEVE.
Resistance: High. **Response**: High. **Site Type**: Warm, Mesic.
Comments: Snowbrush ceanothus is a clumpy, mid-height shrub that can form dense stands after burning. If mature plants are present before a fire, they resprout from their root crown. But most often, it regenerates prolifically on sites where ceanothus plants weren't even present before the fire—they arise from seeds buried in the soil, seeds that can remain viable for hundreds of years. Ceanothus is a nitrogen-fixing shrub that grows best on south and west exposures. An intense fall burn is more likely to produce a dense stand of ceanothus than a cooler spring fire. Using spring burns to intentionally produce a moderate stand of ceanothus, so it could then provide nitrogen fixation, wildlife browse, vegetation diversity, and other benefits, would not create a situation where the shrubs compete seriously with tree regeneration.

Name: Mountain Mahogany (*Cercocarpus ledifolius)*. **Code**: CELE.
Resistance: Low. **Response**: Low. **Site Type**: Warm, Dry.
Comments: Mountain mahogany is an important wildlife species with thick, leathery, in-rolled leaves, and distinctive fruits bearing long, slightly-twisted plumes. It sprouts weakly after low-intensity fires. Unfortunately, it is seriously damaged by all but the coolest of burns. Following moderate or severe fires, this tall shrub must reestablish from off-site, wind-dispersed seed. Because of its low tolerance for fire, mountain mahogany is similar to bitterbrush in that it has probably benefitted from the fire suppression programs initiated in the early 1900s.

Name: Pipsissewa (*Chimaphila umbellata).* **Code**: CHUM.
Resistance: Low. **Response**: Medium. **Site Type**: Cool, Mesic.
Comments: Pipsissewa is a short, semi-woody forb with dark-green, stiff, glossy leaves having toothed margins, and a single flower stalk supporting a dozen or more round, pink blossoms. It sprouts from shallow rhizomes following a fire, and usually survives cool or moderate burns that don't consume all of the litter and duff layers. Pipsissewa is found on cool, moderately-moist, mixed-conifer sites that often feature an abundance of mosses and lichens.

Name: Bull Thistle (*Cirsium vulgare).* **Code**: CIVU.
Resistance: Medium. **Response**: Medium. **Site Type**: Disturbances.
Comments: Bull thistle is a tall, biennial forb that regenerates from root sprouts and seed. It often increases dramatically in clearcuts after burning. Bull thistle is a moderate competitor with tree seedlings; competition is not intense during the first-year rosette stage, but was found to inhibit ponderosa pine seedling growth during the second-year adult stage (Randall and Rejmanek 1993). It has a short, fleshy taproot, and weakly-developed lateral roots. In stands with a high amount of budworm-caused mortality and active cattle grazing, bull thistle can still dominate even if the dead trees are not salvaged and no burning has occurred because cattle create good thistle seedbeds (see fig. 88).

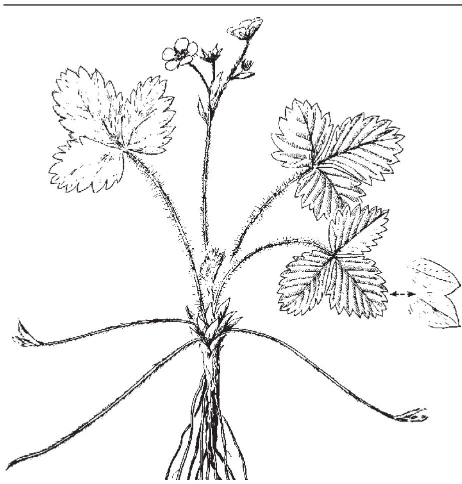
Name: Queencup Beadlily (*Clintonia uniflora*). **Code**: CLUN.
Resistance: Low. **Response**: Low. **Site Type**: Cool, Moist.
Comments: Queencup beadlily is a low, succulent forb with 2 or 3 basal, oblong leaves, and attractive white flowers. The flowers are followed by shiny, blue berries. This species regenerates from widely-spreading rhizomes, and from seed. Queencup beadlily generally declines after fire, although the moist, shaded sites on which it grows are seldom easy to burn.

Name: Blue Wildrye (*Elymus glaucus*). **Code**: ELGL.
Resistance: Medium. **Response**: Medium. **Site Type**: Warm, Mesic.
Comments: Blue wildrye is a tall bunchgrass with flat, rough leaves less than a foot long and a dense, narrow spike of greenish flowers. The flowers have an awn up to three-quarters of an inch long. This grass regenerates from the root crown, rootstock sprouts, and from seed. It is well adapted to sites disturbed by fire, overgrazing, or logging. Most of its post-fire regeneration arises from seed that is capable of surviving the surface temperatures associated with a moderate-intensity burn. In fact, fire often creates an ideal seedbed for the germination and establishment of this species. Blue wildrye is a preferred forage species for cattle (Hedrick and others 1968).

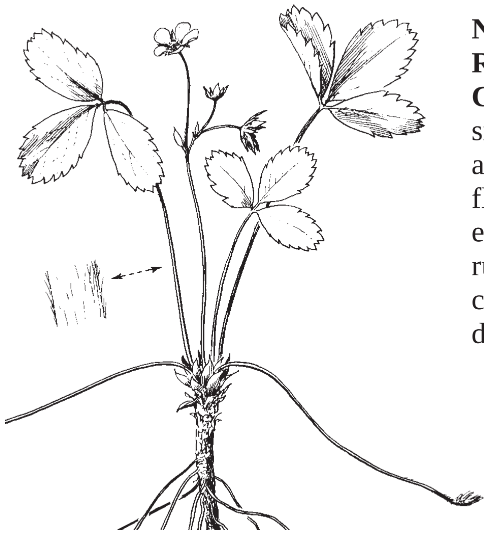
Name: Longleaf Fleabane (*Erigeron corymbosus*). **Code**: ERCO3.
Resistance: Low. **Response**: Medium. **Site Type**: Cool, Dry.
Comments: Longleaf fleabane is a mid-height forb with hairy, strap-shaped leaves and purplish stem bases. The flowers contain deep-blue or pinkish rays. It is typically found in dryer parts of the Big Cow burn and on other areas with a fairly open tree canopy. Since this species lacks rhizomes or stolons, it regenerates using off-site seed or by sprouting from a moderately well-developed root-crown. Although fire effects information is scarce for longleaf fleabane, it is apt to decrease slightly or remain unchanged following a low- or moderate-intensity burn.

Name: Idaho Fescue (*Festuca idahoensis).* **Code**: FEID.
Resistance: Low. **Response**: Medium. **Site Type**: Warm, Dry.
Comments: Idaho fescue is a tough bunchgrass with narrow, bluish, inrolled leaves and a narrow panicle of short-awned flowers. This species regenerates from the surviving root crown, and from seed. It can be badly harmed by hot summer fires, but resists spring or fall burns fairly well. Since it grows as a dense, fine-leaved tuft, Idaho fescue can be damaged by a smouldering fire long after the main flame front has passed.

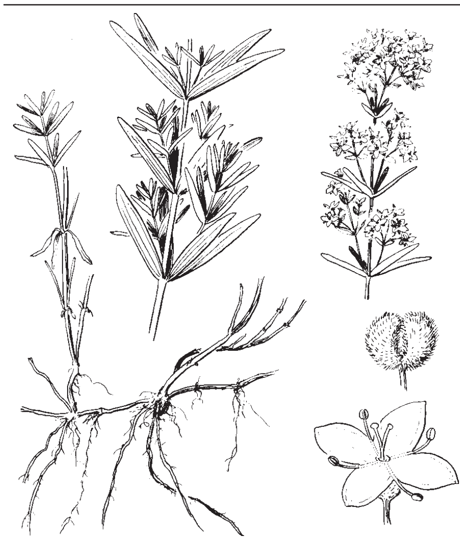
Name: Western Fescue (*Festuca occidentalis).* **Code**: FEOC.
Resistance: Low. **Response**: Low. **Site Type**: Cool, Mesic.
Comments: Western fescue is a short bunchgrass with basal tufts of soft, inrolled leaves and an open panicle of awned flowers. This species regenerates from the surviving root crown, and from off-site seed. It almost always declines following fire, although the moist sites on which it grows are seldom easy to burn. Western fescue germinates well on bare, shaded soil. Unlike many other fescues that prefer open, dry environments, this plant is found in the understory of moist, mixed-conifer stands.



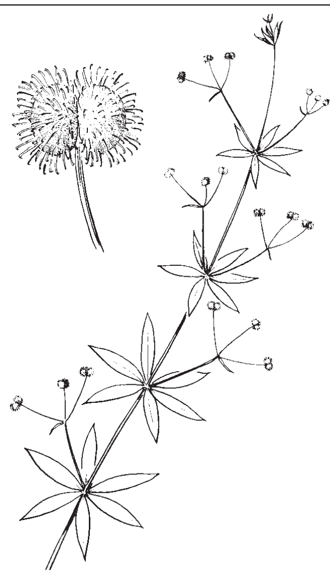
Name: Woods Strawberry (*Fragaria vesca).* **Code**: FRVE.
Resistance: Medium. **Response**: Medium. **Site Type**: Cool, Mesic.
Comments: Woods strawberry is a low, creeping forb with greenish-yellow, hairy leaflets that have deep, prominent veins. The easily recognized fruits have seeds attached on the outside, rather than in deep pits. Also, its terminal leaflet tooth is not smaller than the others and does not form a "gun sight" (see blueleaf strawberry narrative). This common plant is generally found on moister sites than its close relative—blueleaf strawberry. It regenerates from root crown sprouts and runners (stolons), and from some seed stored in the upper soil. Woods strawberry survives cool fires that don't consume all of the litter and duff layers.



Name: Blueleaf Strawberry (*Fragaria virginiana).* **Code**: FRVI. **Resistance**: Medium. **Response**: High. **Site Type**: Cool, Mesic. **Comments**: Blueleaf strawberry is a low, creeping forb with smooth, blue-green leaves that have a distinctive "gun sight" notch at the tip of their terminal leaflet. The small, 5-petalled, white flowers are followed by the familiar sweet, red fruits with seeds embedded in deep pits. It regenerates using root crown sprouts and runners (stolons). Blueleaf strawberry survives cool fires that don't consume all of the litter and duff layers. It is generally found on dryer sites than its close relative—woods strawberry.

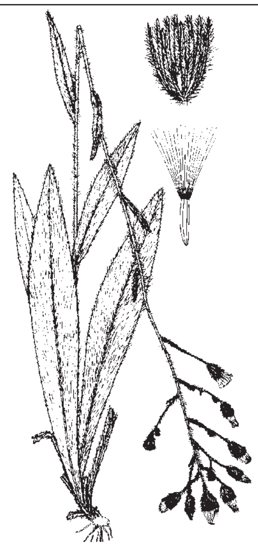


Name: Northern Bedstraw (*Galium boreale).* **Code**: GABO. **Resistance**: Medium. **Response**: Medium. **Site Type**: Cool, Mesic. **Comments**: Northern bedstraw is a low forb with whorled leaves (four, three-veined leaves at each node) and a square (four-sided) stem. The small, white flowers are fragrant and occur in bunched clusters on the upper third of the plant. It regenerates from creeping, underground stems called rhizomes, and from sticky seed. Northern bedstraw is generally resistant to light underburns, but may decline significantly following severe fires.



Name: Sweetscented Bedstraw (*Galium triflorum).* **Code**: GATR. **Resistance**: Low. **Response**: Medium. **Site Type**: Cool, Moist. **Comments**: Sweetscented bedstraw is a sprawling forb with whorled leaves (six at each node) and small, inconspicuous, greenish flowers that occur in groups of three. It regenerates using rhizomes and seed. Sweetscented bedstraw decreases dramatically after severe fires, but can increase following cool burns completed in spring or late fall. Since this plant is typically found near streams, springs, seeps, and on moist toeslopes and benches or other well-watered landforms, the sites on which it grows are seldom easy to burn.

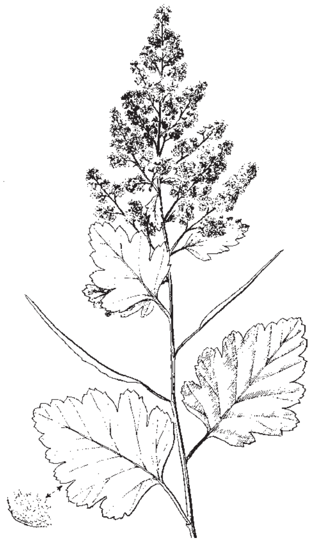
Name: Rattlesnake Plantain (*Goodyera oblongifolia).***Code**: GOOB. **Resistance**: Low. **Response**: Low. **Site Type**: Cool, Mesic. **Comments**: Rattlesnake plantain is a common orchid that typically grows as a small cluster of two or three, white-striped leaves on the forest floor. Occasionally, it produces a single, straight stalk bearing small, white flowers. It is found on cool, moderately-moist, mixed-conifer sites that often feature an abundance of mosses and lichens. This unobtrusive forb regenerates using rhizomes and seed. Rattlesnake plantain is easily killed by fire because its shallow rhizomes are very sensitive to heat. Fires which consume most of the litter and duff layers are likely to have a detrimental impact on this plant.



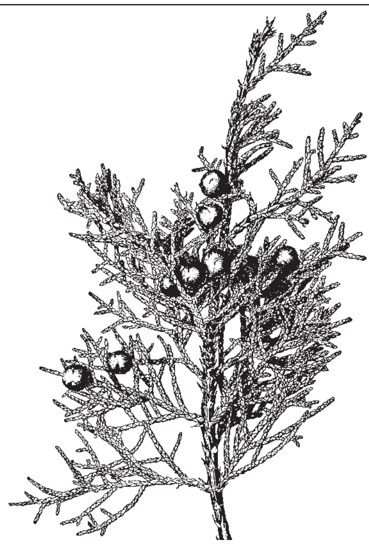
Name: Western Hawkweed (*Hieracium albertinum).* **Code**: HIAL2. **Resistance**: Low. **Response**: Medium. **Site Type**: Cool, Dry. **Comments**: Western hawkweed is a hairy, upright forb with long, woolly, strap-like leaves and yellow flowers. Flower color is a good way to tell it apart from its close relative—white hawkweed. It lacks rhizomes or another means of vegetative reproduction, but readily invades burned areas using windborne seed. Since western hawkweed occurs on dry sites, it is most common in the undergrowth of mixed-conifer forests established at lower elevations.

Name: White Hawkweed (*Hieracium albiflorum).* **Code**: HIAL. **Resistance**: Low. **Response**: Medium. **Site Type**: Cool, Mesic. **Comments**: White hawkweed is one of the most common plants of the mixed-conifer forest type. This mid-height, white-flowered forb has elliptic, wavy-edged leaves. It lacks rhizomes or another means of vegetative reproduction, but readily invades burned areas using windborne seed. White hawkweed grows on moister sites than the closely-related western hawkweed and is found throughout the mixed-conifer vegetation zone.

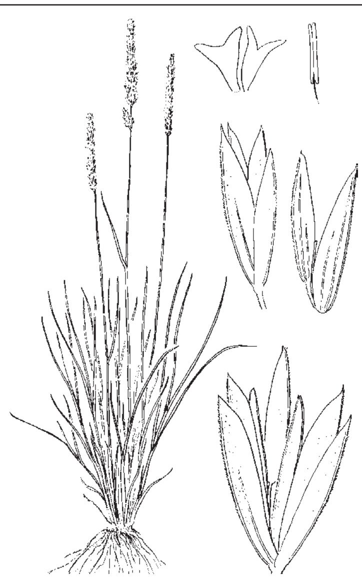
Table 5–Fire Effects Information for Plants of Mixed-Conifer Forests (Continued)



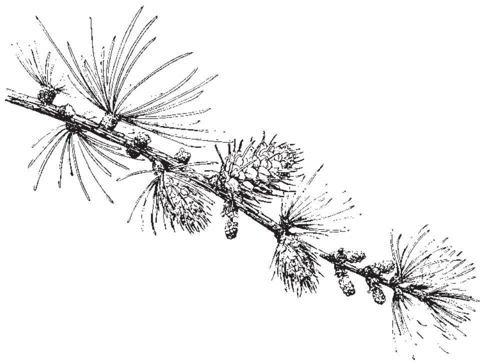
Name: Ocean Spray (*Holodiscus discolor).* **Code**: HODI.
Resistance: Medium. **Response**: High. **Site Type**: Warm, Dry.
Comments: Ocean spray is a mid-height shrub with lobed, toothed leaves that are triangular in outline, and dense plumes of small, creamy flowers. This plant regenerates from the surviving root crown, and from seed stored in the soil. It may be enhanced by fire because seedlings establish easily on the freshly-exposed mineral soil created by burns that remove most of the litter and duff layers.



Name: Western Juniper (*Juniperus occidentalis).* **Code**: JUOC.
Resistance: Medium. **Response**: Low. **Site Type**: Warm, Dry.
Comments: Western juniper is a small tree found on dry, mixed-conifer sites supporting mixed stands of ponderosa pine and Douglas-fir. It does not reproduce vegetatively, so all post-fire establishment occurs from seed, much of which is dispersed by animals (rabbits, squirrels, etc.). Since small trees have thin bark and long crowns, they are easily killed by fire. However, older stems are moderately resistant to all but severe burns. Because of its low tolerance for fire, western juniper is similar to bitterbrush in that it has probably benefitted from the fire suppression programs initiated in the early 1900s. This plant has had many cultural and ethnic uses—Native Americans made beads from the seeds, and the berries were used more recently to furnish the flavor compounds that give gin (an alcoholic beveridge) its distinctive taste.



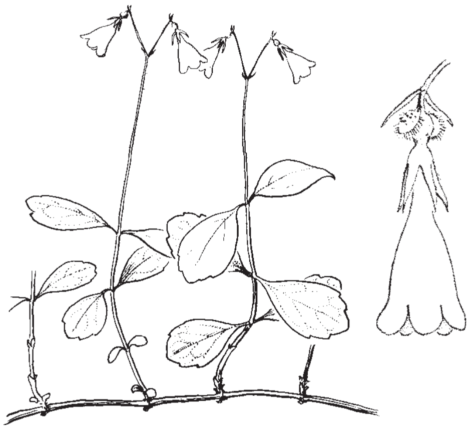
Name: Prairie Junegrass (*Koeleria cristata).* **Code**: KOCR.
Resistance: Medium. **Response**: Medium. **Site Type**: Warm, Dry.
Comments: Prairie junegrass is a cool-season, perennial bunchgrass with basal leaves and a narrow seedhead up to five inches long. The leaves are somewhat similar to those of bluegrasses because they have boat-shaped tips. Its panicle may be relatively wide when flowering in early spring; after seed is set, it becomes narrow and tight. This common species regenerates from seed, and not from rootstocks or rhizomes. It is susceptible to mortality from late-spring burns, although its small clump size and coarse-textured foliage make this plant one of our more fire-resistant bunchgrasses.



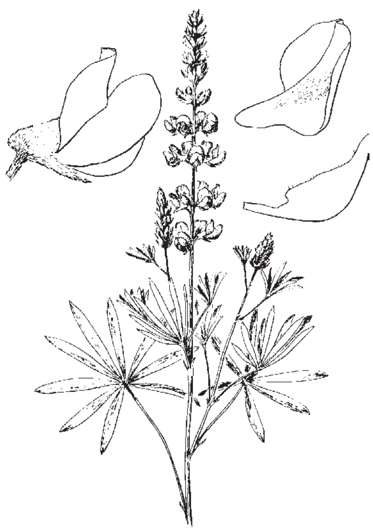
Name: Western Larch (*Larix occidentalis).* **Code**: LAOC.
Resistance: High. **Response**: High. **Site Type**: Cool, Mesic.
Comments: Western larch is plentiful in forests of the lower Columbia River basin, an area encompassing western Montana, northern and central Idaho, eastern Washington, and northeastern Oregon. It has short, soft, tufted needles that are shed each fall after turning a bright, lemon-yellow color, and small cones with short bracts protruding out from between the cone scales. Western larch is our most fire-resistant conifer because of its thick bark, short crown length, and high tolerance to foliage loss. As a seral species, it is well-adapted to colonization of mesic sites that have been disturbed by fire or logging. Larch seedlings establish easily on mineral soil seedbeds, and its diameter growth often increases after prescribed fire. This important tree species can withstand a high proportion of crown scorch.

Name: Thickleaf Peavine (*Lathyrus lanzwertii).* **Code**: LALA2.
Resistance: Medium. **Response**: High. **Site Type**: Warm, Dry.
Comments: Thickleaf peavine is a perennial legume with pinnately-compound leaves bearing thick, narrow leaftlets, and clusters of lavender or pinkish, pea-like flowers. It regenerates from rhizome sprouts and seed. Although fire effects information is scarce for this species, it apparently increases slightly or remains unchanged after burning. Peavines are similar to other legumes in that they are nitrogen fixers, which means they can help improve the nutrient capital of a site.

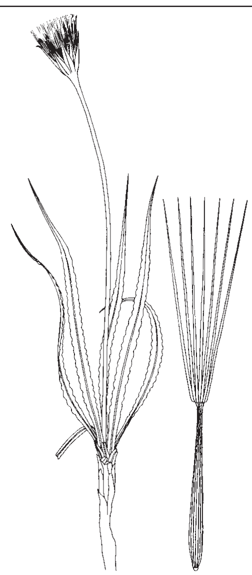
Name: Cusick's Peavine (*Lathyrus nevadensis).* **Code**: LANE.
Resistance: Medium. **Response**: High. **Site Type**: Warm, Mesic.
Comments: Cusick's peavine is a shade-loving forb with pinnately-compound leaves bearing 2–4 pairs of oval leaflets, and white or pinkish flowers. This plant often declines in clearcuts or other openings. It sprouts from surviving rhizomes, and generally increases slightly or remains unchanged after fire. Peavines are similar to other legumes in that they are nitrogen fixers; they can help improve the nutrient capital of a site. Peavines, preferred forage species for cattle, help improve livestock utilization of pinegrass when the two species occur together (Hedrick and others 1968).



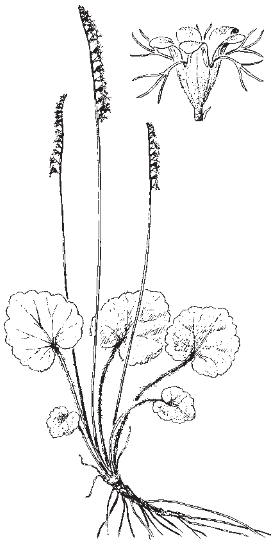
Name: American Twinflower (*Linnaea borealis).* **Code**: LIBO2. **Resistance**: Low. **Response**: Medium. **Site Type**: Cool, Moist. **Comments**: American twinflower is a creeping sub-shrub that produces short, leafless, forked flower stalks bearing twin pink blossoms shaped like narrow bells. Its oval leaves are an inch or less in length and have shallowly-toothed edges. This plant regenerates from surviving root crowns and runners (stolons), and from seed. It survives cool fires if the duff and litter layers were damp and not totally consumed. Twinflower declines following fire, although the moist sites on which it grows are seldom easy to burn. Often, its runners quickly invade burned areas from adjacent, unburned patches.



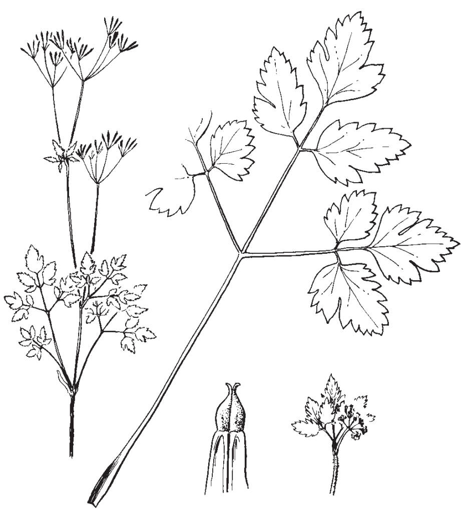
Name: Tailcup Lupine (*Lupinus caudatus).* **Code**: LUCA. **Resistance**: High. **Response**: Medium. **Site Type**: Cool, Mesic. **Comments**: Tailcup lupine is a common, mid-height forb with hairy, silvery leaves and blue or violet flowers. This plant regenerates from the crown of a deep taproot, and from heavy seed. It produces seed during the first year after a fire and then spreads quickly. Since the seed can survive for long periods in the lower duff and upper soil layers, it is not uncommon for this species to dominate on sites where it was not plentiful before burning or logging. In those situations, tailcup lupine may become more abundant than another of the common colonizers, such as thistle, mullein, or cheatgrass. Lupines are nitrogen fixers that can help improve the nutrient capital of a site.



Name: False-Agoseris (*Microseris troximoides).* **Code**: MITR. **Resistance**: Medium. **Response**: High. **Site Type**: Warm, Dry. **Comments**: False-agoseris is a short, yellow-flowered forb with long, narrow leaves that have shallowly-scalloped edges. This plant regenerates from the crown of a deep taproot. It is typically found on dry, mixed-conifer sites supporting mixed stands of ponderosa pine and Douglas-fir. False agoseris increases or remains unchanged after fires which don't consume all of the litter and duff layers.



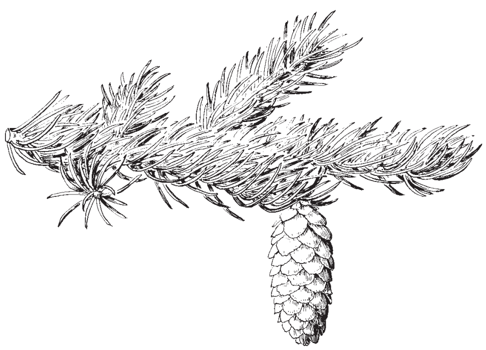
Name: Sideflowered Mitella (*Mitella stauropetala).* **Code**: MIST2. **Resistance**: Medium. **Response**: High. **Site Type**: Cool, Mesic. **Comments**: Sideflowered mitella is a shade-loving forb with heart-shaped, scallop-edged leaves and small, greenish-white flowers in a one-sided raceme. This plant regenerates from the root crown, and from seed. It is found on cool, moderately-moist, mixed-conifer sites that often feature an abundance of mosses and lichens. Fires which consume most of the litter and duff layers are apt to have a detrimental impact on sideflowered mitella.



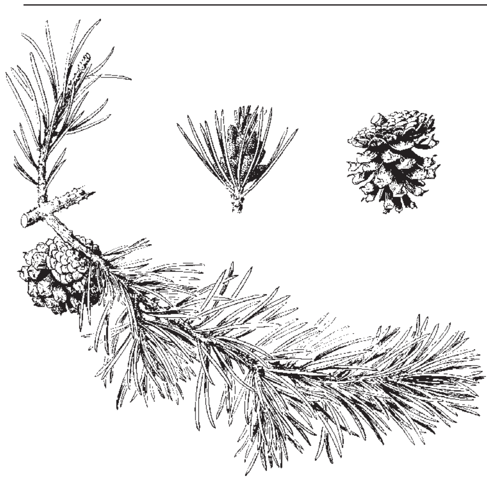
Name: Mountain Sweetroot (*Osmorhiza chilensis).* **Code**: OSCH. **Resistance**: Medium. **Response**: Medium. **Site Type**: Cool, Moist. **Comments**: Mountain sweetroot is a mid-height forb with compound, toothed leaves, tiny, inconspicuous flowers, and short, flat fruits. This moist-site plant regenerates from a taproot or caudex (root crown), and from seeds. Its barbed seeds are often disseminated by animals. Flowering usually increases after the tree canopy has been opened by harvest or fire. Generally, mountain sweetroot is unchanged or increases slightly after burning, although the moist sites on which it grows are often difficult to burn.

Name: Myrtle Pachistima (*Pachistima myrsinites).* **Code**: PAMY. **Resistance**: Medium. **Response**: Medium. **Site Type**: Cool, Mesic. **Comments**: Myrtle pachistima, a creeping, low-growing shrub, is relished by elk and may be suppressed by big-game browsing in areas with high elk populations. It has small, thick, oval leaves with slightly-toothed edges and small, red flowers that appear in early spring and are inconspicuous by being hidden in the foliage. This plant regenerates from the crown of a deep taproot, or from stem bud sprouts or stored seed. It may increase after cool or moderate burns that don't consume all of the litter and duff layers or cause excessive soil heating.

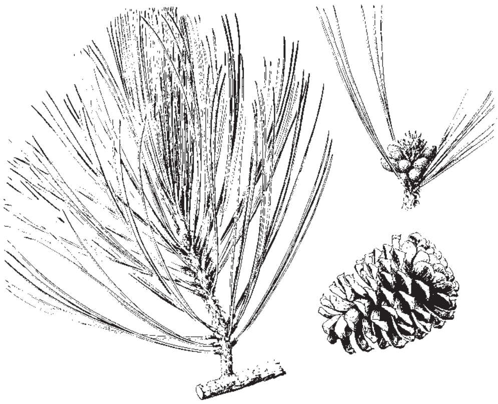
Name: Common Timothy (*Phleum pratense).* **Code**: PHPR. **Resistance**: Medium. **Response**: High. **Site Type**: Disturbances. **Comments**: Common timothy is a medium to tall bunchgrass with slender, bristly seedheads. Its smooth, flat, or slightly-folded leaves are prominently veined. It regenerates from the surviving root crown or, more commonly, from seed that blows in from adjacent roadsides and forest openings. Often, timothy seed arrives from closed roads, skid trails, and other sites that have been seeded with a mix of non-native grasses to prevent or control soil erosion.



Name: Engelmann Spruce (*Picea engelmannii).* **Code**: PIEN. **Resistance**: Low. **Response**: Low. **Site Type**: Cold, Moist. **Comments**: Engelmann spruce has sharp, inch-long needles that are square in cross section; thin, scaly, orange or brown-colored bark; and papery cones that hang or droop from the branch tips. The young branches and leaf bases are hairy (pubescent). It is easily killed by fire because of its long, full crown, thin bark, and a shallow root system. In the central and southern Blue Mountains, Engelmann spruce tends to be a riparian species growing on sites that may be difficult to burn. Despite its high damage risk, this species is favored more by fire than a frequent associate on the high-elevation sites where it commonly grows—subalpine fir.



Name: Lodgepole Pine (*Pinus contorta).* **Code**: PICO. **Resistance**: Medium. **Response**: High. **Site Type**: Cool, Mesic. **Comments**: Lodgepole pine is a slender tree with one- to two-inch long needles occurring in bundles of two or three; thin, scaly, reddish or gray bark, and small, knobby cones. This widespread tree can survive cool fires because of its fairly short, open crown. Its thin bark results in low resistance to medium or hot burns. Lodgepole pine often regenerates after stand-replacing wildfires, when it forms dense, even-aged thickets. It has good post-fire response, especially in stands where some of the trees have stored their seed in tightly-closed cones (serotinous cones). The closed cones are not universal; their presence varies from area to area. As a seral species that is well adapted to colonization of disturbed sites, frost pockets, and other harsh environments, its seedlings establish easily on mineral soil seedbeds.



Name: Ponderosa Pine (*Pinus ponderosa).* **Code**: PIPO.
Resistance: High. **Response**: High. **Site Type**: Warm, Mesic.
Comments: The thick bark, short crown lengths, and wide tree spacing typically associated with ponderosa pine stands result in high fire resistance for this species. At a diameter of about 2 inches, ponderosa pine begins to develop fire-resistant bark with a dead outer layer that insulates the sensitive cambium tissues from heat damage. It also appears that decomposing ponderosa pine needles produce a substance that inhibits pine growth; periodic burning would prevent that substance from accumulating by periodically removing the litter layer (Hall 1991). Seedling establishment is favored by fires that expose mineral soil seedbeds. Ponderosa pine experiences reduced diameter growth after high levels of crown scorch. By controlling underburns, land managers were inadvertently swapping ponderosa pines for white firs and Douglas-firs.

Name: Wheeler Bluegrass (*Poa nervosa).* **Code**: PONE.
Resistance: Medium. **Response**: High. **Site Type**: Warm, Mesic.
Comments: Wheeler bluegrass is a creeping, mid-height grass with narrow, sometimes-folded leaves and a sparse, open panicle of hairy, unawned flowers. The flowers and stem bases tend to be a purplish color. It regenerates from surviving rhizomes and seed. Like many other rhizomatous grasses, Wheeler bluegrass is seldom damaged by fire unless the litter and duff layers are consumed and excessive soil heating has occurred.

Name: Kentucky Bluegrass (*Poa pratensis).* **Code**: POPR.
Resistance: High. **Response**: High. **Site Type**: Warm, Mesic.
Comments: Kentucky bluegrass is a creeping, sod-forming, mid-height grass with stems from one to three feet tall and leaves that are dark-green, flat or folded, and boat-shaped at their tip. Flowers are produced in a loose, pyramidal panicle up to six inches long. This aggressive, weedy species regenerates from basal stem buds and slender rhizomes, and from seed. Kentucky bluegrass is seldom damaged by fire, although population declines occasionally occur following hot, spring burns.

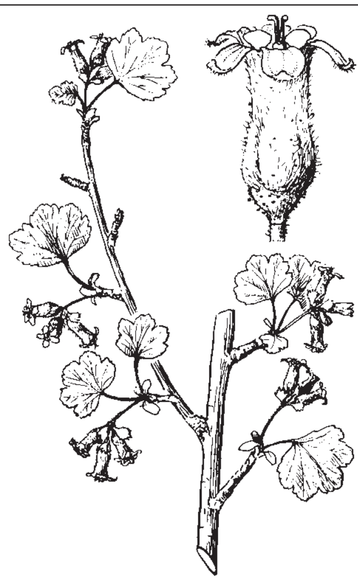
Name: Polemonium (*Polemonium pulcherrimum).* **Code**: POPU.
Resistance: Low. **Response**: Medium. **Site Type**: Cold, Moist.
Comments: Showy polemonium is a low, clumpy forb with compound leaves having two-ranked leaflets suggestive of a ladder. It has dainty, wide-open, sky-blue flowers, and foliage that smells “skunk-like” when crushed. This plant regenerates from the semi-woody crown of a large taproot, and from seed. Showy polemonium usually declines following fire, although the cold, high-elevation sites on which it grows are seldom easy to burn.

Name: Common Chokecherry (*Prunus virginiana).* **Code**: PRVI.
Resistance: Medium. **Response**: High. **Site Type**: Warm, Mesic.
Comments: Common chokecherry has reddish-brown bark, shiny, toothed leaves, and attractive clusters of fragrant, white flowers. After a fire, this medium to tall shrub sprouts prolifically from its root crown. It decreases immediately after fire, but usually regains preburn levels within 5 years. Occasionally, new chokecherry plants are established after robins, waxwings and other birds, bears, and mule deer spread the seeds by feeding on the fruit.

Name: Douglas-fir (*Pseudotsuga menziesii).* **Code**: PSME.
Resistance: High. **Response**: Medium. **Site Type**: Warm, Mesic.
Comments: Douglas-fir has short needles supported on small stalks; long, pointed, shiny, brown buds; and hanging cones with unique, three-pointed or “rat-tail” bracts protruding out from between their scales. Its rough bark is gray when young, and thick, reddish-brown and furrowed on older trees. Mature trees are fire resistant due to their thick bark, but thin-barked poles and saplings are easily damaged by burning. A long, dense crown and moderate stand densities also add to Douglas-fir’s fire susceptibility in some instances. Because Douglas-fir saplings and poles are sensitive to fire, low-intensity prescribed burns can be used to intentionally kill them. Douglas-fir has become much more common over the last 80 years as a result of fire suppression. By controlling natural underburns, land managers were inadvertently swapping ponderosa pines and western larches for white firs and Douglas-firs.

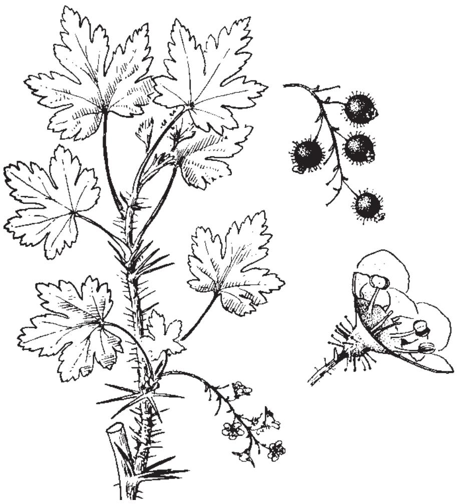
Name: Bracken Fern (*Pteridium aquilinum).* **Code**: PTAQ.
Resistance: High. **Response**: High. **Site Type**: Cool, Moist.
Comments: Bracken is a large, stout fern with triangular fronds up to four feet tall. It is commonly found on moist toe-slopes or similar topographic positions. Recent research found that bracken inhibits conifer regeneration by producing chemicals that kill newly-germinated trees, a situation known as allelopathy (Ferguson and Boyd 1988). It may be a serious tree competitor on moist sites. Bracken fern sprouts from surviving rhizomes and spreads vigorously after fire. Native Americans used fire on Puget Sound's Whidbey Island as a tool to maintain bracken (and camas) fields (Robbins and Wolf 1994).

Name: Sidebells Pyrola (*Pyrola secunda).* **Code**: PYSE.
Resistance: Low. **Response**: Low. **Site Type**: Cool, Mesic.
Comments: Sidebells pyrola is a low-growing forb with ovate leaves and nodding, white or greenish flowers arranged along a curved, four- to eight-inch stalk. The flowers all point in the same direction, which accounts for another of its common names: one-sided wintergreen. Although its leaves are evergreen, they do not have the aromatic qualities of true wintergreens (*Gaultheria*). This plant of shaded sites sprouts from rhizomes creeping along in the lower duff, or established at the soil surface. Sidebells pyrola commonly decreases after fire, but will survive when duff moisture is high and excessive soil heating hasn't occurred.

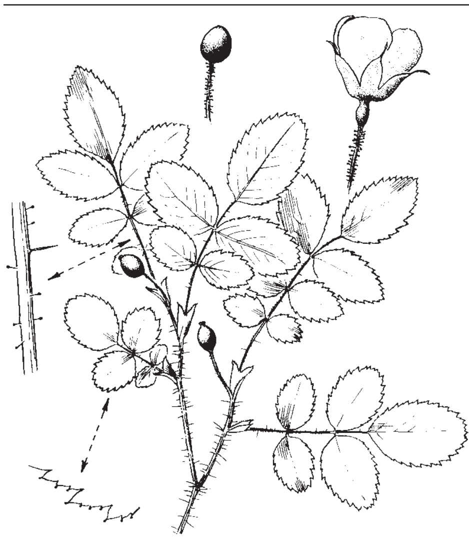


Name: Wax Currant (*Ribes cereum).* **Code**: RICE.
Resistance: Medium. **Response**: High. **Site Type**: Warm, Dry.
Comments: Wax currant is a spineless, mid-height shrub with maple-like leaves having 3 or 5 shallow lobes, and bright red or orange berries. The leaves are somewhat sticky and tend to have a waxy upper surface. This plant regenerates from seed stored in the litter and duff layers, and from basal stem sprouts. It often increases after clearcutting on dryer sites, especially if the harvest units are burned to reduce fuel accumulations or to prepare the site for planting or natural regeneration. Wax currant is susceptible to fire-induced mortality, especially after severe burns. However, regeneration of wax currant is often favored by short-duration, low-intensity fires.

TABLE 5–FIRE EFFECTS INFORMATION FOR PLANTS OF MIXED-CONIFER FORESTS (CONTINUED)



Name: Prickly Currant (*Ribes lacustre).* **Code**: RILA.
Resistance: High. **Response**: High. **Site Type**: Cool, Moist.
Comments: Prickly currant is a prickly, mid-height shrub with divided, maple-like leaves, and greenish or pinkish, saucer-shaped flowers produced in drooping racemes. It grows near streams and on other moist sites, where regeneration occurs from the root crown and from seed. This plant, which harbors one of the life stages of white pine blister rust, usually increases after burning, even if the fire was a severe one. Cool or moderate-intensity fires favor establishment of prickly currant seedlings.



Name: Baldhip Rose (*Rosa gymnocarpa).* **Code**: ROGY.
Resistance: Medium. **Response**: Medium. **Site Type**: Cool, Mesic.
Comments: Baldhip rose is a prickly, mid-height shrub with compound leaves bearing 5 to 7 oval, toothed leaflets, and small, pink flowers produced singly, rather than in clusters. This common plant regenerates from the root crown, stem bases, and from seed. It responds vigorously to cool or moderate fires. New rose plants are occasionally established after mice, coyotes, and birds spread the seeds by feeding on the fruits (rose hips).

Name: Scouler Willow (*Salix scouleriana).* **Code**: SASC.
Resistance: High. **Response**: High. **Site Type**: Cool, Mesic.
Comments: Scouler willow, a tall shrub, differs from most other willows because it is found on upland forest sites instead of along streams or in other riparian habitats. Its hairy leaves are widest above their middle (oblanceolate), which is another characteristic that differs from most other willows. It regenerates by sprouting from the root crown, or by using small, windborne seed produced in small capsules that follow the showy catkins of early spring. In many areas of the northern Rocky Mountains, Scouler willow increases dramatically following a variety of burn intensities, especially on relatively moist sites.

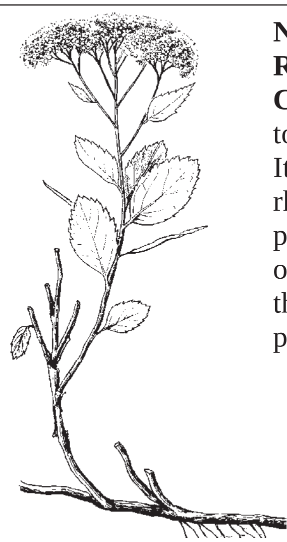
Name: Woolly Groundsel (*Senecio integerrimus).* **Code**: SEIN.
Resistance: Low. **Response**: Medium. **Site Type**: Cool, Dry.
Comments: Woolly groundsel is an early-blooming forb with hairy, lance-shaped leaves and an open cluster of small, yellow flowers. The central flower is always older and shorter than others in the cluster. It grows on dryer mixed-conifer sites. This hairy plant lacks rhizomes, stolons, or a stout, persistent rootcrown, so regeneration occurs mainly from off-site seed. Although fire effects information is scarce for woolly groundsel, it is apt to decrease slightly or remain unchanged following a low- or moderate-intensity burn.

Name: Bottlebrush Squirreltail (*Sitanion hystrix).* **Code**: SIHY.
Resistance: Medium. **Response**: High. **Site Type**: Warm, Dry.
Comments: Bottlebrush squirreltail is a low bunchgrass with distinctive, bristly seedheads closely resembling a "bottlebrush." Its stems may reach two feet in height, but are most often a foot or so tall. This weedy grass regenerates from the root crown, and from seed. It has coarse, loosely-clustered stems and a minimum of leaf matter, which means it burns quickly and that little heat is transferred downward to the underground tissues. Since it "cures" early, bottlebrush squirreltail survives summer fires better than spring ones.

Name: Feather Solomonplume (*Smilacina racemosa).***Code**: SMRA.
Resistance: Medium. **Response**: Medium. **Site Type**: Cool, Mesic.
Comments: Feather solomonplume is a mid-height forb with large, oval leaves arranged alternately along the stem, and a 4- to 6-inch long cluster of small, white flowers produced at the end of the stem. The flowers are followed by lightly-striped, greenish to tan berries. This common plant grows on moderately moist sites with heavy shading. It regenerates from stout, creeping rhizomes, and is fairly resistant to fire damage. Feather solomonplume usually maintains its prefire frequency after burning, although it may be detrimentally affected by fires that consume most of the litter and duff layers and cause excessive heating of the upper soil.

TABLE 5–FIRE EFFECTS INFORMATION FOR PLANTS OF MIXED-CONIFER FORESTS (CONTINUED)

Name: Starry Solomonplume (*Smilacina stellata).* **Code**: SMST.
Resistance: Medium. **Response**: Medium. **Site Type**: Cool, Mesic.
Comments: Starry solomonplume is a low to medium forb with long, narrow leaves; small, white flowers produced in a sparse, open cluster; and yellowish-green berries. This common species sprouts from creeping rhizomes. Starry solomonplume likes shade as much as feather solomonplume does, although it typically occurs on slightly drier sites than its close relative. It often decreases after fire, especially severe burns that consume most of the litter and duff layers and cause excessive heating of the upper soil.



Name: White Spiraea (*Spiraea betulifolia).* **Code**: SPBE.
Resistance: High. **Response**: High. **Site Type**: Cool, Mesic.
Comments: White spiraea is a low, spreading shrub with oval, toothed leaves and dense, rounded clusters of small, white flowers. It regenerates by sprouting from the root crown, and by use of deep rhizomes located 2–5 inches beneath the soil surface. This common plant usually increases after burning, even if the fire was a severe one. White spiraea often flowers the year following a burn, although the resultant seed has low viability and is probably unimportant for post-fire recovery.

Name: Western Needlegrass (*Stipa occidentalis).* **Code**: STOC.
Resistance: Low. **Response**: Low. **Site Type**: Warm, Dry.
Comments: Western needlegrass is a mid-height bunchgrass with narrow leaves less than a foot long, and a loose spike of small, hairy flowers tipped with twisted awns up to an inch and a half long. This high-elevation species regenerates from surviving root crowns, and from seed. It is damaged most severely by early spring and late summer fires. As a group, perennial needlegrasses are reported to have some of the lowest fire resistance of the bunchgrasses.

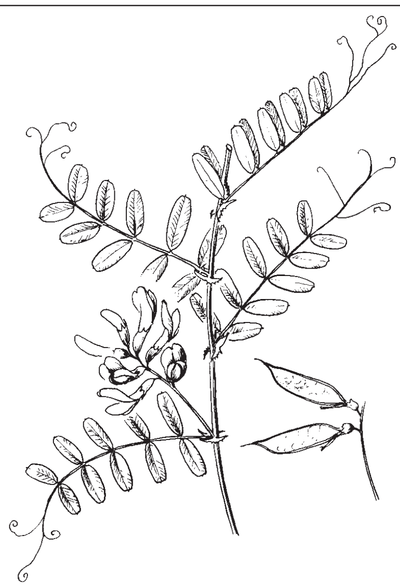
Name: Common Snowberry (*Symphoricarpos albus).* **Code**: SYAL. **Resistance**: Medium. **Response**: High. **Site Type**: Cool, Mesic. **Comments**: Common snowberry is a low, spreading shrub with opposite, elliptic leaves and small, white or pink flowers produced at the end of the branches. This widely distributed plant is common in mesic Douglas-fir and white fir plant associations. It increases after site disturbance, but seldom competes aggressively with conifer seedlings. Common snowberry regenerates from deep rhizomes and basal stem buds, and from seed. Although favored by cool or moderate fires, it usually survives severe ones too.

Name: Mtn. Snowberry (*Symphoricarpos oreophilus).***Code**: SYOR. **Resistance**: Low. **Response**: Medium. **Site Type**: Cool, Dry. **Comments**: Mountain snowberry is a medium-sized shrub with round or oval leaves and small, tubular, pink or white flowers. The flowers are followed by white, porcelain-like berries that are relished by wild turkeys. When compared with common snowberry, mountain snowberry is a taller plant, it occurs on dryer sites, and it grows in clumps rather than from spreading rhizomes. It sprouts weakly from its root crown, and from rhizomes. After cool or moderate burns, it usually maintains its prefire cover and abundance.

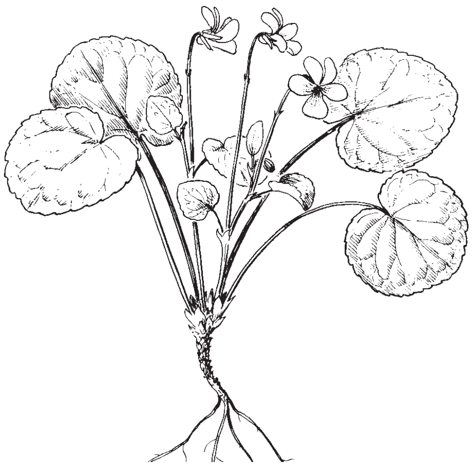
Name: Common Dandelion (*Taraxacum officinale).* **Code**: TAOF. **Resistance**: Medium. **Response**: Medium. **Site Type**: Disturbances. **Comments**: Common dandelion is a low, weedy forb with lance-shaped, deeply-toothed leaves and attractive blossoms dominated by narrow, yellow rays. It regenerates from the crown of a deep taproot, and from light, windborne seed. Since a large amount of seed is produced, common dandelion can quickly colonize burns located adjacent to areas providing an ample seed source (road sides, clearcuts, etc.).

Name: Huckleberry (*Vaccinium membranaceum).* **Code**: VAME. **Resistance**: High. **Response**: Medium. **Site Type**: Cool, Mesic. **Comments**: Big huckleberry is a low to mid-height shrub commonly found in high-elevation snow zones. In the central and southern Blue Mountains, it seldom competes with tree seedlings because of its relatively low stature. Big huckleberry regenerates from rhizomes and seed, although post-fire recovery may be slow. This shrub may be difficult to underburn without some type of pretreatment. Fire was used by native Americans to maintain huckleberry fields, both to remove encroaching conifers and to regenerate declining plants (Minore and others 1979). Big huckleberry is brittle and can be easily damaged by machine piling or other mechanical site preparation treatments.

Name: Grouse Huckleberry (*Vaccinium scoparium).* **Code**: VASC. **Resistance**: Medium. **Response**: Medium. **Site Type**: Cold, Mesic. **Comments**: Grouse huckleberry is a creeping sub-shrub with small, oval leaves and a tight, intricate branching pattern that often results in a broom-like appearance. It has bright-green stems, pinkish, urn-shaped flowers, and a bright red berry. This high-elevation species regenerates from shallow rhizomes and seed. It usually survives cool or moderate fires that don't consume all of the litter and duff layers. Grouse huckleberry typically grows on high, cold sites, but is sometimes found at lower elevations too, where it should then be considered an indicator of frost pocket conditions.



Name: American Vetch (*Vicia americana).* **Code**: VIAM. **Resistance**: Medium. **Response**: High. **Site Type**: Cool, Mesic. **Comments**: American vetch is a slender, climbing forb with reddish or lavender "pea" flowers produced on slender stalks arising from the leaf axils, and pinnately compound leaves with 8–12 small, oval leaflets. It may resemble a vine because the long, twining tendrils are used to climb on shrubs and small trees. This plant regenerates by sprouting from rhizomes located in the upper soil layers. It is seldom damaged by fire unless the litter and duff layers have been consumed and excessive soil heating has occurred. Vetches are similar to other legumes in that they are nitrogen fixers, which means they can help improve the nutrient capital of a site.



Name: Darkwoods Violet (*Viola orbiculata).* **Code**: VIOR2.
Resistance: Medium. **Response**: Medium. **Site Type**: Cool, Mesic.
Comments: Darkwoods violet is a perennial forb with round, wavy-edged leaves and small, yellow flowers that have purplish veins. It regenerates from short, slender rhizomes, and from seed stored in the upper soil and litter or duff layers. Darkwoods violet usually declines following fire, although the cool, moist sites on which it grows are seldom easy to burn.

Sources: Common and scientific plant names generally follow the nomenclature contained in "Flora of the Pacific Northwest" (Hitchcock and Cronquist 1973). Codes were taken from Powell (1989). Fire resistance and post-fire response ratings were obtained from the following sources: Bradley and others (1992), Crane and Fischer (1986), Fischer and Bradley (1987), Fischer and Clayton (1983), Flinn and Wein (1977), Geier-Hayes (1989), Hopkins and Rawlings (1985), Leege and Godbolt (1985), McLean (1968), Noste and Bushey (1987), Sampson (1917), Stickney (1986), and Volland and Dell (1981). Valuable information was also obtained from the Fire Effects Information System (FEIS) recently developed by the Intermountain Fire Sciences Laboratory at Missoula, Montana (Fischer 1990). For some plants, no literature sources were found for one or both of the fire ratings, so an estimate was made using information for species with similar morphological or reproductive characteristics.

Note: Many of the drawings in this table were reproduced from the 5-volume *Vascular Plants of the Pacific Northwest* (Hitchcock and others 1955, 1959, 1961, 1964, and 1969). They are copyrighted and are reproduced here with permission from the University of Washington Press.

Additional Information About Western Spruce Budworm

Many publications have been recently produced about the western spruce budworm and its management, particularly during a 7-year research, development, and application program called CANUSA (Canada–United States Spruce Budworm Program). The goal of CANUSA was to design and evaluate strategies for controlling or mitigating spruce budworm impacts, and for managing budworm-susceptible forests to meet a variety of resource objectives. This section summarizes some budworm publications that are useful for land managers of the Malheur NF.

Aho, Paul E. 1984. Losses associated with Douglas-fir and true fir tops killed by western spruce budworm in eastern Washington. Res. Pap. PNW–318. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 8 p.

A sample of 133 Douglas-firs and 69 true firs with dead tops caused by budworm defoliation were felled, dissected, and examined for height loss and decay incidence. Height loss was negligible for trees with only the last year or two of their tops killed because lateral branches quickly formed new tops. Infection of dead tops by decay fungi was low, probably because of their small basal diameters, the recency of topkilling, and the low incidence of secondary attack by bark beetles.

Alfaro, R.I.; Thomson, A.J.; Van Sickle, G.A. 1985. Quantification of Douglas-fir growth losses caused by western spruce budworm defoliation using stem analysis. Canadian Journal of Forest Research. 15: 5–9.

Periodic growth and volume losses are described for a Douglas-fir stand that was defoliated four times by western spruce budworm. Losses were calculated by comparing periodic growth for the years of reduced increment with potential growth, as estimated using a growth and yield program. Cumulative tree volume losses, calculated by adjusting growth during all loss periods to their potential values, were estimated to be 44% of the potential volume the trees should have reached by 1977 had they never been defoliated. The 1970s infestation caused an estimated volume loss of 60 cubic meters per hectare (cm/ha) in this stand, with 40 cm/ha from mortality, and 20 cm/ha from growth losses.

Alfaro, R.I.; Van Sickle, G.A.; Thomson, A.J.; Wegwitz, E. 1982. Tree mortality and radial growth losses caused by the western spruce budworm in a Douglas-fir stand in British Columbia. Canadian Journal of Forest Research. 12: 780–787.

This study examined the effects of budworm defoliation on Douglas-fir radial growth and tree mortality. Mortality reduced the number of stems per hectare by 39.3%, and basal area per hectare by 11.6%, with most of the losses occurring in the small-diameter trees (suppressed and intermediate crown classes). Four budworm outbreaks occurred during the life of the stand. The combined effect of the infestations amounted to a loss of about 12% of the estimated potential diameter. The most recent outbreak (1970–74) caused 10 years of subnormal growth, including 5 years due to defoliation and 5 years of recovery.

Anderson, Leslie; Carlson, Clinton E.; Wakimoto, Ronald H. 1987. Forest fire frequency and western spruce budworm outbreaks in western Montana. Forest Ecology and Management. 22: 251–260.

Reduced fire frequency for the past 75 years has allowed extensive areas with high budworm susceptibility to develop. Harvesting practices that removed the seral ponderosa pine and western larch aggravated the problem. Budworm susceptibility can be reduced significantly by using forest management practices that more closely resemble the pre-1911 fire effects. Following timber harvest, site preparation practices should be selected which encourage establishment and growth of seral, nonhost conifers. Prescribed fire would do that job well in many instances. Seral species should also be favored when planting. Prescribed fires in dense stands of Douglas-fir may reduce host-tree density and remove the lower canopy layers; that practice may be particularly effective in wilderness areas since timber harvests are prohibited, and yet budworm susceptibility is often high. Mosaics of even-aged, seral stands at a landscape level would be relatively resistant to budworm damage; if those conditions are present at some future date, budworm outbreaks may be less intense and of shorter duration.

Baskerville, G.L. 1975. Spruce budworm: super silviculturist. Forestry Chronicle. 51: 138–140.

This paper provides a history of spruce budworm outbreaks (eastern species) in New Brunswick, Canada. Periodic budworm outbreaks were not viewed as a sign of instability because ecological stability in the budworm–forest system must be measured on a time scale appropriate to its function—periods of at least 50 to 100 years. To some extent, management policy has been counterproductive; by spraying large areas of mature host type that is not being immediately harvested, managers are perpetuating an ideal food supply for the budworm. The forest cannot be managed by harvesting small “bites” because that practice maintains conditions that are conducive to an outbreak. The longer that susceptible forests are protected in excess of what can be harvested, the longer that high-risk areas are being exposed to an outbreak. Budworm outbreaks were rarely mentioned before 1900 because many of the host trees were not considered valuable; now that industry has decided that balsam fir, red spruce, and white spruce are desirable, it is competing with budworm for the opportunity to harvest those species.

Beveridge, Ron L.; Cahill, Donn B. 1984. Western spruce budworm feeding effects on conifers located on the Boise and Payette National Forests. Rep. No. 84–7. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region, State and Private Fores-try, Forest Pest Management. 25 p.

During 1981 and 1982, 85 stands comprised mostly of grand fir or Douglas-fir were surveyed on the Boise and Payette National Forests to evaluate spruce budworm damages sustained during the late 1970s. Tree attributes were backdated to predefoliation levels and then projected through the defoliation period by using the Prognosis model. Differences between projected and measured increment provided an estimate of radial-growth loss for true firs, and it ranged between 30 and 40 percent. Douglas-fir and spruce had a 15 percent reduction in radial growth, while ponderosa pine and some lodgepole pine had a slight increase in growth. Topkill, which was common on true firs, affected 10 to 20 percent of the sampled trees; host-tree mortality was infrequent.

Blais, J.R. 1962. Collection and analysis of radial-growth data from trees for evidence of past spruce budworm outbreaks. Forestry Chronicle. 38 (4): 474–484.

Studies of a spruce budworm outbreak showed that an average radial-growth reduction of 50 percent was usually related to incipient mortality for highly vulnerable trees. Radial-growth suppression in white spruce and balsam fir does not coincide with the onset of defoliation; at breast height, it starts two to four years after the first severe year of defoliation and continues for some years after feeding has stopped.

Brookes, Martha H.; Campbell, Robert W.; Colbert, J.J.; Mitchell, Russel G.; Stark, R.W., tech. coords. 1987. Western spruce budworm. Tech. Bull. 1694. Washington, DC: U.S. Department of Agriculture, Forest Service, Coop. State Research Service. 198 p.

This comprehensive book summarizes current knowledge about the western spruce budworm and its hosts. Chapter titles are: History; Taxonomy of Spruce Budworms and Recognition of Associates; Life History and Behavior; Description of Host Species; Host Responses; Population Dynamics; Survival of Late Larvae and Early Pupae; Site

and Stand Characteristics; Modeling Budworm and Its Hosts; and Recommendations.

Brookes, Martha H.; Colbert, J.J.; Mitchell, Russel J.; Stark, R.W., tech. coords. 1985. Managing trees and stands susceptible to western spruce budworm. Tech. Bull. 1695. Washington, DC: U.S. Department of Agriculture, Forest Service, Cooperative State Research Service. 111 p.

This book is a guide for detecting and evaluating budworm effects on susceptible forests, comparing budworm management strategies, and providing support for budworm-related decisions. It focuses on budworm effects for both trees and stands, and describes detection, evaluation, and control operations. Chapter titles are: Historical Considerations; Western Budworm and Its Hosts; Effects of Infestations on Trees and Stands; Site and Stand Characteristics; Surveys and Sampling Methods for Population and Damage Assessment; Rating Stand Hazard to Western Spruce Budworm; Tactics for Managing Trees and Stands; and Selecting Management Tactics.

Brookes, Martha H.; Colbert, J.J.; Mitchell, Russel G.; Stark, R.W., tech. coords. 1987. Western spruce budworm and forest-management planning. Tech. Bull. 1696. Washington, DC: U.S. Department of Agriculture, Forest Service, Cooperative State Research Service. 88 p.

This book provides information for forest planners and policy makers about protection of forests against outbreaks of the western spruce budworm. Because its approach to forest protection—integrated pest management (IPM)—is relatively new, it also describes the procedural, structural, and legislative issues and constraints related to IPM. Chapter titles are: Forest Conditions and the Western Spruce Budworm; Management Considerations in Integrated Pest Management; Damage and Socioeconomic Impact; Management Strategies; Evaluating Management Options; and Institutional and Legal Factors Affecting Management of Western Spruce Budworm.

Brubaker, Linda B.; Greene, Shannon K. 1979. Differential effects of Douglas-fir tussock moth and western spruce budworm defoliation on radial growth of grand fir and Douglas-fir. Canadian Journal of Forest Research. 9: 95–105.

This study compared the effects of separate Douglas-fir tussock moth and western spruce budworm infestations on the radial growth of two host species: grand fir and Douglas-fir. Tussock-moth effects did not differ statistically between the 2 species, but the impact of budworm defoliation on grand fir was significantly greater than on Douglas-fir. Differences occurred between the overall effects of tussock moth and

budworm, with tussock moth causing more rapid growth reductions and greater growth losses than budworm.

Carlson, Clinton E.; Fellin, David G.; Schmidt, Wyman C. 1983. The western spruce budworm in northern Rocky Mountain forests: a review of ecology, insecticidal treatments and silvicultural practices. In: O'Loughlin, J.; Pfister, R.D., eds. Management of Second-Growth Forests: The State of Knowledge and Research Needs. Missoula, MT: Montana Forest and Conservation Experiment Station, School of Forestry, University of Montana: 76–103.

The western spruce budworm occupies a wide amplitude of ecological niches in northern Rocky Mountain forests. Successful adaptation to coniferous forest ecosystems has influenced several attributes of western spruce budworm in the northern Rockies, including 1) its extent and persistence, 2) the periodicity of outbreaks, 3) its biology, behavior and ecology on a variety of host trees growing on differing habitats, 4) the factors that regulate it, and 5) the character of many forests and management decisions over the past three decades.

Carlson, C.E.; McCarthy, G.J. 1989. Dispersal of second-instar western budworm above and below forest canopies in western Montana. Res. Note INT–388. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 6 p.

Dispersal of second-instar western spruce budworm above and below stand canopies was determined, using sticky traps, at two distinct locations in western Montana. There was no significant difference between catches above the canopy and 6 feet above ground. The presence of significant larvae numbers above forest canopies suggests that budworm may be dispersed over long distances during vigorous frontal systems and other periods with strong horizontal windflow.

Carlson, Clinton E.; McCaughey, Ward W. 1982. Indexing western spruce budworm activity through radial increment analysis. Res. Pap. INT–291. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 10 p.

Past spruce budworm activity in Douglas-fir forests of western Montana was assessed through radial increment analysis. A cumulative growth function was graphically compared between a budworm host (Douglas-fir) and a nonhost (ponderosa pine) species. Analysis showed that Douglas-fir radial increment was very similar to that of ponderosa pine in an area with no history of spruce budworm, and both growth patterns appeared to be correlated with precipitation. During budworm activity in mixed-species stands, acceleration of ponderosa pine radial growth was observed.

Carlson, Clinton E.; Schmidt, Wyman C. 1989. Influence of overstory removal and western spruce budworm defoliation on growth of advance conifer regeneration in Montana. Res. Pap. INT–409. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 14 p.

The influence of four overstory removal levels on the height and diameter growth of advance regeneration was assessed in larch/Doug-las-fir stands growing on subalpine fir habitat types of northwestern Montana. Radial growth prior to treatment was the best indicator of post-treatment height and diameter growth for all species. Mortality was lowest where either all or none of the overstory was removed, and was greatest where about 50% of the overstory was removed. Following an overstory removal, growth response was mediocre and budworm susceptibility increased. For those reasons, future volumes in stands of shade-tolerant species may be substantially below volumes expected from stands of seral trees on the same high-quality sites.

Carlson, Clinton E.; Wulf, N. William. 1989. Silvicultural strategies to reduce stand and forest susceptibility to the western spruce budworm. Agric. Handbk. 676. Washington, DC: U.S. Department of Agriculture, Forest Service, Coop. State Research Service. 31 p.

Silvicultural methods can be used to reduce forest and stand susceptibility to western spruce budworm and may be the most effective means of dealing with budworm over the long run. Silvicultural methods provide immediate protection for treated stands, and presumably will provide long-term protection for large forested areas when enough area has been treated. This publication describes a rating scheme for budworm susceptibility that is based on the following factors: regional climate, site climate, species composition, stand density, stand height-class structure, tree and stand vigor, maturity of trees and shrubs, and adjacent host type.

Clancy, Karen M.; Itami, Joanne K.; Huebner, Daniel P. 1993. Douglas-fir nutrients and terpenes: potential resistance factors to western spruce budworm defoliation. Forest Science. 39 (1): 78–94.

Differences in the nutritional quality of Douglas-fir foliage may explain why some individual trees are more resistant or susceptible than others to damage from western spruce budworm. Susceptible trees also had lower levels of nitrogen and sugars than resistant trees. Susceptible trees had a greater proportion of total terpenes that were monoterpenes, whereas resistant trees had a greater percentage of oxygenated monoterpenes. Resistant trees had delayed bud burst and shoot expansion as compared to susceptible trees; they also had accumulated more radial growth over the past 25 years, implying they were more vigorous than susceptible trees.

Dolph, R. E., Jr. 1980. Budworm activity in Oregon and Washington, 1947–1979. Pub. R6–FIDM–033–1980. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region, State and Private Forestry, Forest Pest Management. 54 p.

This paper summarizes western spruce budworm and Modoc budworm activity, and projects undertaken to suppress them, in Oregon and Washington between 1947 and 1979. Infestation acreages, and accompanying maps, are provided for each year from 1947 to 1979, and for each national forest in Oregon and Washington.

Fellin, David G. 1983. Chemical insecticide vs the western spruce budworm: after three decades, what's the score? Western Wildlands. 9 (1): 8–12.

DDT spray programs treated more than eight million acres of budworm-infested forests in six Rocky Mountain states from the early 1950s to early 1960s. By the late 1950s, most managers in the northern Rockies recognized that: 1) spraying was not a "one-shot" operation, 2) budworm control was difficult where conditions favored the insect's development, and 3) the spruce budworm outbreak in the region had not been controlled by spraying. The last time that DDT was used against spruce budworm in the northern Rockies was in 1963, when the President's Science Advisory Committee recommended that governmental agencies curtail their use of persistent chemicals.

Fellin, David G.; Dewey, J.E. 1982. Western spruce budworm. Forest Insect and Disease Leaflet 53. Washington, DC: U.S. Department of Agriculture, Forest Service. 10 p.

This informative leaflet covers the following topics as related to western spruce budworm: description; life history; host trees; damage; natural regulating factors; and management.

Fellin, David G.; Shearer, Raymond C.; Carlson, Clinton E. 1983. Western spruce budworm in the northern Rocky Mountains: biology, ecology and impacts. Western Wildlands. 9 (1): 2–7.

Despite tremendous ecological diversity, or perhaps because of it, most Rocky Mountain forests appear to be susceptible to budworm outbreaks. Weather conditions may be the natural factor with the most dramatic effect on spruce budworm populations. Radial increment reduction from budworm defoliation was highest for dry Douglas-fir habitat types located at low elevations and on steep slopes. In Douglas-fir stands, budworm defoliation increased as crown closure increased. Stands comprised of mixed species were less vulnerable to budworm damage than pure stands of host species.

Ferguson, Dennis E. 1988. Growth of regeneration defoliated by spruce budworm in Idaho. Res. Pap. INT–393. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 13 p.

This paper describes budworm effects on four major aspects of regeneration development—dieback (topkill), height growth, crown ratio, and mortality. Eleven percent of the host trees had dieback during the 5-year measurement period. The probability of dieback increased with increasing defoliation, increasing tree height, and decreasing crown ratio. The amount of dieback varied from 0 to 67 percent of tree height. Increasing defoliation was associated with decreasing height growth. Only 3 percent of the sample trees died. Indications are that small crown ratios or high defoliation levels increase the probability of small-tree mortality. Mathematical equations are provided to predict the growth and development of regeneration for four conifer species defoliated by western spruce budworm in Idaho.

Ferrell, George T.; Scharpf, Robert F. 1982. Stem volume losses in grand firs topkilled by western spruce budworm in Idaho. Res. Pap. PSW–164. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Exp. Station. 10 p.

Two stands in the Little Salmon River drainage of west-central Idaho, one cutover and one unmanaged, were affected by spruce budworm outbreaks during the periods of 1922–30, 1952–55, and 1969–78. Forty mature grand firs from the two stands were felled and dissected to determine growth losses and decay associated with budworm-induced topkilling. Stem decays, mainly from Indian paint fungus, caused most of the volume loss. Almost all of the decay was associated with larger tops killed during the 1922–30 outbreak. Little decay was present unless the top had been killed more than 30 years ago, and had a basal diameter exceeding 3 inches. All but 2 of the 40 sample trees had been topkilled at least once; one tree had been topkilled eight times. Decay was associated with only 30% of the topkills. Topkills that were intact (spikes), broken-off (stubs), or embedded all had associated decay. Wetwood was almost always associated with topkilling in grand fir, but it was not a reliable indicator that decay was present. Height growth of topkilled firs in the cutover stand averaged 72.6% of predicted increment, while height growth in the uncut stand was 73.9% of the undamaged amount. Radial growth was apparently not related to topkill incidence. Volume losses associated with stem deformities (form defects) never exceeded 5 percent of stem volume. In managed stands, grand firs with dead tops having a basal diameter of 3 inches or more should be harvested within 30 years to avoid extensive decay losses.

Gast, William R., Jr.; Scott, Donald W.; Schmitt, Craig; Clemens, David; Howes, Steven; Johnson, Charles G., Jr.; Mason, Robert; Mohr, Francis; Clapp, Robert A., Jr. 1991. Blue Mountains forest health report: "new perspectives in forest health." Portland, OR: US Department of Agriculture; Forest Service; Pacific Northwest Region; Malheur, Umatilla, and Wallowa–Whitman National Forests.

This report summarizes the forest health situation for the Malheur, Umatilla, and Wallowa–Whitman National Forests. It describes 12 issues related to forest health, and provides some strategies and recommendations for restoring forest health in the Blue Mountains of northeastern Oregon and southeastern Washington. Of particular interest is Chapter II (Forest Insects and Diseases), which provides detailed descriptions of western spruce budworm and 7 other insects, as well as informative discussions for 14 important tree diseases. Other chapter titles are: Watershed Management and Forest Health; The Role of Fire in the Blue Mountains; Long-Term Productivity; and Diversity.

Kemp, William P.; Everson, Dale O.; Wellington, W.G. 1985. Regional climatic patterns and western spruce budworm outbreaks. Tech. Bull. 1693. Washington, DC: U.S. Department of Agriculture, Forest Service, Cooperative State Research Service. 31 p.

This study examined the hypothesis that if climatic characteristics are important to budworm development and survival, then regional outbreak frequency should be related to regional weather conditions. The authors found that generalized weather information, when combined with stand level hazard-rating systems, could measurably improve our present ability to forecast the onset of unacceptable budworm defoliation. Three classes of outbreak frequency were developed for the forested areas of Idaho, Montana, Oregon, and Washington.

Langelier, Lisa A.; Garton, Edward O. 1986. Management guidelines for increasing populations of birds that feed on western spruce budworm. Agric. Handbk. 653. Washington, DC: U.S. Department of Agriculture, Forest Service, Coop. State Research Service. 19 p.

This manual is for managers who wish to enhance populations of predaceous birds in budworm-susceptible stands. Foraging behavior and habitat preferences are summarized for the following birds that feed on western spruce budworm (all 14 species occur on the Malheur NF): American robin, Cassin's finch, chipping sparrow, dark-eyed junco, evening grosbeak, golden-crowned kinglet, Hammond's flycatcher, mountain chickadee, pine siskin, red-breasted nuthatch, Swainson's thrush, Townsend's warbler, western tanager, and yellow-rumped warbler. These are management recommendations for increasing populations of budworm-feeding birds: plan for horizontal diversity; plan for vertical diversity; avoid large clearcuts; provide edges; avoid

high-grading; avoid homogeneous, plantation-like stands; leave some slash; reduce herbicide use; control grazing; provide for cavity-nesting birds; provide salt; and provide water.

MacLean, David A. 1990. Impact of forest pests and fire on stand growth and timber yield: implications for forest management planning. Canadian Journal of Forest Research. 20: 391–404.

The impact of forest pests and fire on stand growth and timber yield is reviewed, with emphasis on spruce budworm impacts. Damaging agents reduce tree growth, kill trees, destroy the commercial value of stands, and sometimes reduce yield in subsequent rotations. Sustainable harvest may be reduced up to 60% by a severe spruce budworm outbreak, and up to 40% by a 1% annual loss to fire. Serious overestimation of future timber supply can result from the failure to account for catastrophic or continuous losses caused by fire or biotic agents. Current efforts to explicitly incorporate the effects of spruce budworm defoliation into forest management planning are described, including research studies about protection planning and delivery, damage detection, and defoliation-based growth forecasting. An improved understanding of the impact of insects, disease, and fire on stand yield, and methods to incorporate this information into timber supply analyses, are essential to reduce uncertainty about future timber supply.

MacLean, David A.; Ostaff, Donald P. 1983. Sample size-precision relationships for use in estimating stand characteristics and spruce budworm caused tree mortality. Canadian Journal of Forest Research. 13: 548–555.

Comparison of three plot types (prism point samples with BAF = 2.3; circular, 0.01-hectare, fixed-area plots; and 0.05-hectare, fixed-area plots) indicated that using larger numbers of small plots (either prism or fixed-area) within each sampled stand would be the best method for estimating tree mortality. Curves showing the required number of plots to obtain a desired precision level were provided for estimating both annual mortality and cumulative (total) mortality. As a rough approximation, sampling about 15 prism points in each stand should allow estimation of cumulative mortality to a precision of about plus or minus 10 percent.

Mason, Richard R.; Wickman, Boyd E.; Beckwith, Roy C.; Paul, H. Gene. 1992. Thinning and nitrogen fertilization in a grand fir stand infested with western spruce budworm. Part I: insect response. Forest Science. 38 (2): 235–251.

Thinning and nitrogen fertilization were completed in a grand fir stand near King Mountain on the southern part of the Malheur NF. In general, defoliating insects seemed to benefit from both treatments, but es-

pecially from the fertilization. Overall budworm survival and prevailing trends of the outbreak were unaffected by the treatments and seemed to be determined mostly by other factors, probably natural enemies. This means that the ultimate value of thinning and fertilization in budworm-infested forests must be based on their effect on tree and stand vulnerability, rather than any direct impact on budworm populations.

McDonald, G. I. 1981. Differential defoliation of neighboring Douglas-fir trees by western spruce budworm. Res. Note INT–306. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 10 p.

Color photographs document the phenotypic variation of inland Douglas-fir populations in response to defoliation by western spruce budworm. Host-insect literature was reviewed, and tentative hypotheses to explain the non-defoliated trees were suggested.

Montgomery, B.A.; Dimond, John B.; Witter, John A.; Simmons, Gary A. 1984. Insecticides for control of the spruce budworm. Agric. Handbk. 615. Washington, DC: U.S. Department of Agriculture, Forest Service, Cooperative State Research Service. 29 p.

This handbook is for forest entomologists, biologists, and extension workers who are responsible for making recommendations about the use of insecticides. It provides an application guide for common chemical and microbial insecticides registered for spruce budworm control (eastern species) in the United States. Because application rates are given as ranges, and because registrations change, actual pesticide labels must be used as the final source of insecticidal information. The differences between chemical insecticides and *Bacillus thuringiensis* (B.t.), a bacterial insecticide, are also provided.

Murphy, C.F.; Croft, B.A. 1990. Forest ant composition and foraging following aerial spraying of carbaryl to suppress western spruce budworm. Canadian Entomologist. 122 (July/August): 595–606.

This study examined the effect of carbaryl treatment on foraging ants. Four plots on the Malheur NF were used in the study—two treated plots at Dan's Creek and Murderer's Creek, and two untreated plots at Starr Ridge and Herberger Spring. After spraying, ant species diversity declined in treated plots. Post-spray ant foraging decreased in all plots, but the decrease was more rapid and pronounced in treated plots. Among ground-foraging ants, budworm predators were obviously affected by spraying. Ants that are arboreal foragers, nearly all of which are also budworm predators, showed a significantly lower foraging rate in the treated plots. Ant foraging continued at depressed levels for at least 6 weeks after spraying, which was long enough for budworm to reach the adult stage. This study concluded that carbaryl spraying may inhibit some of the natural enemies that help keep budworm populations in check. Reduced ant predation on the sparse bud-worm populations present after spraying may contribute to budworm resurgence.

Muzika, Rose-Marie; Engle, Judith; Parks, Catherine; Wickman, Boyd. 1993. Variation in phenology and monoterpene patterns of defoliated and nondefoliated Douglas-fir (*Pseudotsuga menziesii* var. *glauca*). Res. Pap. PNW–RP–459. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 10 p.

Foliage was collected from paired Douglas-fir trees characterized as either "resistant" or "susceptible" to western spruce budworm attack. Although there were no compositional differences in terpenes, foliage from nondefoliated trees produced a greater amount of monoterpenes than foliage from susceptible trees. Phenology patterns between the two groups of trees differed greatly—severely-defoliated trees broke bud 7 to 10 days earlier than nondefoliated trees. The results of this study may have implications for breeding Douglas-firs that are less susceptible to budworm defoliation.

Nichols, Thomas J. 1988. The relationship between western spruce budworm defoliation levels and growth of individual Douglas-fir and grand fir trees. Forest Science. 34 (2): 496–504.

This study concluded that previous tree condition had a strong impact on current-year growth. In budworm-infested stands, defoliation had a major influence on tree condition. Proportional growth loss at a given level of defoliation was the same regardless of growth rates prior to defoliation. Variations in height and basal-area growth for defoliated trees were best explained using models that predicted nondefoliated growth, foliage level, and preceding-year tree condition.

Sanders, C.J.; Stark, R.W.; Mullins, E.J.; Murphy, J., eds. 1985. Recent advances in spruce budworms research. Proceedings of the CANUSA Spruce Budworms Research Symposium; 1984, September 16–20; Bangor, ME. Ottawa, Ontario, Canada: Canadian Forestry Service. 527 p.

This volume summarizes scientific advances achieved during the CANUSA program, the largest international cooperative forestry project ever conducted. Information is provided in four major parts, whose titles are: Part I: Spruce Budworms—Biology, Ecology, and Population Dynamics; Part II: Economic and Social Impacts of Spruce Budworms in North American Forests; Part III: Tactics and Strategies for Prevention and Suppression of Damage by Spruce Budworm; and Part IV: Integrated Forest and Pest Management.

Schmidt, Wyman C.; Fellin, David G.; Carlson, Clinton E. 1983. Alternatives to chemical insecticides in budworm-susceptible forests. Western Wildlands. 9 (1): 13–19.

Silvicultural treatment, an approach given little consideration in the past, now appears to be a promising option for reducing budworm impacts. As forest management becomes more intensive, most commercial forests will warrant some sort of silvicultural manipulation, whether spruce budworm remains a threat or not. Therefore, foresters have only to select the silvicultural treatment most suited to the stand in question, and least favorable to budworm. This requires that both silviculturists and forest managers better understand the ecology of western spruce budworm in the northern Rockies.

Swetnam, Thomas W.; Lynch, Ann M. 1989. A tree-ring reconstruction of western spruce budworm history in the southern Rocky Mountains. Forest Science. 35 (4): 962–986.

Tree-ring chronologies from ten mixed-conifer stands in southern Colorado's Front Range and northern New Mexico's Sangre de Cristo Mountains were used to reconstruct the timing, duration, and radial growth impacts of past budworm outbreaks. At least nine outbreaks were identified in the stands between 1700 and 1983. The average growth reduction period was 12.9 years; it ranged from 5 to 26 years. There was a relatively long period of reduced budworm activity in the first few decades of the twentieth century. Since that time, outbreaks have been markedly more synchronous, probably because of changes in age structure and species composition following partial cutting and fire suppression in the twentieth century.

Thomson, A.J.; Alfaro, R.I. 1990. A method to calculate yield correction factors for the overstory component of budworm-attacked Douglas fir. Forest Ecology and Management. 31: 255–267.

A method was developed to estimate yield reductions, at rotation age, in overstory Douglas-fir trees after defoliation in a single budworm outbreak. Budworm impact was expressed as correction factors which could be applied to the expected volume at rotation. These factors varied by site quality, stand age, and with the duration and severity of defoliation. Yield loss was greater in stands attacked at young ages than those attacked when older. Loss estimates were most sensitive to changes in site quality, and defoliation duration and severity.

Torgersen, Torolf R.; Mason, Richard R.; Campbell, Robert W. 1990. Predation by birds and ants on two forest insect pests in the Pacific Northwest. Studies in Avian Biology. 13: 14–19.

A variety of techniques were used to identify bird and ant predation on Douglas-fir tussock moth and western spruce budworm. Fourteen bird species were observed to prey on tussock moth larvae. Both birds and foliage-foraging ants were important predators of budworm larvae and pupae. When crown enclosures and ant barriers were used to protect larvae from predation, 2 to 15 times as many budworm survived to the pupal stage. Predation was influenced by crown stratum: ants were most effective in the lower crowns, while birds excelled at higher levels. Populations of predatory ants and many of the insectivorous birds are enhanced by the availability of dead wood and stumps.

Van Sickle, G.A.; Alfaro, R.I.; Thomson, A.J. 1983. Douglas-fir height growth affected by western spruce budworm. Canadian Journal of Forest Research. 13: 445–450.

Detailed dissections of Douglas-fir trees repeatedly defoliated by western spruce budworm in two areas of British Columbia indicated that budworm severely affected height growth. Dissected trees lost an average of 7.3 internodes in each infestation, of which 4.2 were destroyed or failed to grow during the defoliation and recovery periods, and 3.1 were existing internodes lost to dieback (topkill). Total height was reduced by 32 percent and 19 percent in areas that sustained four and two infestations, respectively. Height growth reductions were attributed to 1) prevention of height growth during active defoliation periods, 2) reduced height growth during recovery, and 3) dieback of the existing stem from the terminal leader downward (topkill). It was also found that budworm infestations resulted in an underestimation of site index for Douglas-fir in the affected area.

Wickman, Boyd E. 1992. Forest health in the Blue Mountains: the influence of insects and disease. Gen. Tech. Rep. PNW–GTR–295. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 15 p.

This summary report concluded that many of the current pest problems in the Blue Mountains are related to human activities occurring over the last 90 years. The virtual exclusion of low-intensity fires since 1900, in combination with extensive logging of ponderosa pine, has resulted in the establishment of fir on many thousands of acres that previously supported pine. The fir forests are highly susceptible to insects and diseases, and to catastrophic forest fires. Some long-term management strategies are now needed to alleviate a variety of problems associated with the change in forest composition.

Wickman, Boyd E.; Mason, Richard R.; Paul, H. Gene. 1992. Thinning and nitrogen fertilization in a grand fir stand infested with western spruce budworm. Part II: tree growth response. Forest Science. 38 (2): 252–264.

Thinning and nitrogen fertilization were completed in a grand fir stand near King Mountain on the southern part of the Malheur NF. This study found that fertilization of a defoliated stand provided the following benefits, as compared to an untreated stand: defoliation was reduced, height growth was greater, and radial growth was increased. Fertilized trees apparently produced fewer buds per square meter of foliage, but more foliage was produced on each shoot than could be consumed by budworm. The study also found that the radial growth of trees on plots that were thinned, but not fertilized, was significantly greater than the untreated controls after 5 years.

Williams, Carroll B., Jr. 1967. Spruce budworm damage symptoms related to radial growth of grand fir, Douglas-fir, and Engelmann spruce. Forest Science. 13 (3): 274–285.

This study examined the effect of budworm damage during the 1944–1956 outbreak on the radial increment of host trees. After the outbreak subsided, measurements were collected from four stands on the Wallowa National Forest. Grand fir had the most variation in budworm-caused damage; growth losses ranged from 23.9 to 41.1 percent, and topkilling caused 7.7 to 15 years of lost height growth, depending on damage intensity. Douglas-fir had the least budworm damage, with little growth loss and no topkilling observed. Engelmann spruce had intermediate damage levels, ranging from 6.1 to 24.8 percent for radial growth losses, and 6 to 7 years of height growth reduction.

References

Adams, David L.; Ferguson, Dennis E. 1990. A forest regeneration mystery—the grand fir mosaic. Focus on Renewable Natural Resources. 15: 21–22.

Agee, James K. 1993. Fire ecology of Pacific Northwest forests. Washington, DC: Island Press. 493 p.

Anderson, Leslie; Carlson, Clinton E.; Wakimoto, Ronald H. 1987. Forest fire frequency and western spruce budworm outbreaks in western Montana. Forest Ecology and Management. 22: 251–260.

Barrett, James W. 1978. Height growth and site index curves for managed, even-aged stands of ponderosa pine in the Pacific Northwest. Res. Pap. PNW–232. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 14 p.

Beckham, Stephen Dow. 1991. The Grande Ronde Valley and Blue Mountains: impressions and experiences of travelers and emigrants, the Oregon Trail, 1812–1880. Report No. 2. Lake Oswego, OR: Beckham and Associates. 103 p.

Beveridge, Ron L.; Cahill, Donn B. 1984. Western spruce budworm feeding effects on conifers located on the Boise and Payette National Forests. Rep. No. 84–7. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region, State and Private Forestry, Forest Pest Management. 25 p.

Blais, J.R. 1962. Collection and analysis of radial-growth data from trees for evidence of past spruce budworm outbreaks. Forestry Chronicle. 38 (4): 474–484.

Bradley, Anne F.; Fischer, William C.; Noste, Nonan V. 1992. Fire ecology of the forest habitat types of eastern Idaho and western Wyoming. Gen. Tech. Rep. INT–290. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 92 p.

Brickell, James E. 1966. Site index curves for Engelmann spruce in the northern and central Rocky Mountains. Res. Note INT–42. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 8 p.

Brock, Gene; Brock, Linda. 1993. Snapshot in time: repeat photography on the Boise National Forest, 1870–1992. Boise, ID: U.S.

Department of Agriculture, Forest Service, Intermountain Region, Boise National Forest. 239 p.

Campbell, Robert W. 1993. Population dynamics of the major North American needle-eating budworms. Res. Pap. PNW–RP–463. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 222 p.

Caraher, David L.; Henshaw, John; Hall, Fred; Knapp, Walter H.; McCammon, Bruce P.; Nesbitt, John; Pedersen, Richard J.; Regenovitch, Iral; Tietz, Chuck. 1992. Restoring ecosystems in the Blue Mountains: a report to the Regional Forester and the Forest Supervisors of the Blue Mountain forests. Portland, OR: U.S. Dept. of Agriculture, Forest Service, Pacific Northwest Region. 14 p.

Carlson, Clinton E.; Fellin, David G.; Schmidt, Wyman C. 1983. The western spruce budworm in northern Rocky Mountain forests: a review of ecology, insecticidal treatments and silvicultural practices. In: O'Loughlin, J.; Pfister, R.D., eds. Management of Second-Growth Forests: The State of Knowledge and Research Needs. Symposium Proceedings; 1982 May 14; Missoula, MT. Missoula, MT: Montana Forest and Conservation Experiment Station, School of Forestry, University of Montana: 76–103.

Carlson, Clinton E.; Schmidt, Wyman C. 1989. Influence of overstory removal and western spruce budworm defoliation on growth of advance conifer regeneration in Montana. Res. Pap. INT–409. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 14 p.

Carlson, Clinton E.; Wulf, N. William. 1989. Silvicultural strategies to reduce stand and forest susceptibility to the western spruce budworm. Agric. Handbk. 676. Washington, DC: U.S. Department of Agriculture, Forest Service, Coop. State Research Service. 31 p.

Carolin, V.M.; Coulter, W.K. 1971. Trends of western spruce budworm and associated insects in Pacific Northwest forests sprayed with DDT. Journal of Economic Entomology. 64 (1): 291–297.

Clancy, Karen M. 1992. The role of sugars in western spruce budworm nutritional ecology. Ecological Entomology. 17: 189–197.

Clancy, Karen M.; Itami, Joanne K.; Huebner, Daniel P. 1993. Douglas-fir nutrients and terpenes: potential resistance factors to western spruce budworm defoliation. Forest Science. 39 (1): 78–94.

Cochran, P.H. 1979a. Site index and height growth curves for managed, even-aged stands of Douglas-fir east of the Cascades in Oregon and Washington. Res. Pap. PNW–251. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 16 p.

Cochran, P.H. 1979b. Site index and height growth curves for managed, even-aged stands of white or grand fir east of the Cascades in Oregon and Washington. Res. Pap. PNW–252. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 13 p.

Cochran, P.H. 1985. Site index, height growth, normal yields, and stocking levels for larch in Oregon and Washington. Res. Note PNW–424. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Exp. Station. 24 p.

Cochran, P.H.; Geist, J.M.; Clemens, D.L.; Clausnitzer, Rodrick R.; Powell, David C. 1994. Suggested stocking levels for forest stands in northeastern Oregon and southeastern Washington. Res. Note PNW–RN–513. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 21 p.

Cochran, W.G. 1977. Sampling techniques. Third edition. New York, NY: John Wiley and Sons. 428 p.

Cooper, Charles F. 1961. The ecology of fire. Scientific American. 204: 150–158.

Cowlin, R.W.; Briegleb, P.A.; Moravets, F.L. 1942. Forest resources of the ponderosa pine region of Washington and Oregon. Misc. Pub. No. 490. Washington, DC: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 99 p (and maps).

Coville, Frederick V. 1898. Forest growth and sheep grazing in the Cascade Mountains of Oregon. Bull. No. 15. Washington, DC: U.S. Department of Agriculture, Division of Forestry. 54 p.

Covington, W. Wallace; Moore, Margaret M. 1994. Southwestern ponderosa forest structure: changes since Euro-American settlement. Journal of Forestry. 92 (1): 39–47.

Crane, Marilyn F.; Fischer, William C. 1986. Fire ecology of the forest habitat types of central Idaho. Gen. Tech. Rep. INT–218. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 86 p.

Crookston, Nicholas L. 1991. Foliage dynamics and tree damage components of the western spruce budworm modeling system. Gen.

Tech. Rep. INT–282. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 40 p.

Crookston, Nicholas L.; Colbert, J.J.; Thomas, Paul W.; Sheehan, Katharine A.; Kemp, William P. 1990. User's guide to the western spruce budworm modeling system. Gen. Tech. Rep. INT–274. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 75 p.

Dahms, Walter G. 1975. Gross yield of central Oregon lodgepole pine. In: Baumgartner, David M., ed. Management of lodgepole pine ecosystems, volume 1. Symposium Proceedings; 1973 Oct. 9–11; Pullman, WA. Pullman, WA: Cooperative Extension Service, College of Agriculture, Washington State University: 208–232.

Daniel, Theodore W.; Helms, John A.; Baker, Frederick S. 1979. Principles of silviculture. Second edition. New York, NY: McGraw-Hill Book Company. 500 p.

Denevan, William M. 1992. The pristine myth: the landscape of the Americas in 1492. Annals of the Association of American Geographers. 82 (3): 369–385.

Dolph, R.E., Jr. 1980. Budworm activity in Oregon and Washington, 1947–1979. Publication R6–FIDM–033–1980. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region, State and Private Forestry, Forest Pest Management. 54 p.

Donk, M.G.; Shattuck, C.H.; Marshall, W.D. 1921. The distillation of stumpwood and logging waste of western yellow pine. Bull. No. 1003. Washington, DC: U.S. Department of Agriculture. 69 p.

Dunning, Duncan. 1923. Some results of cutting in the Sierra forests of California. Bull. No. 1176. Washington, DC: U.S. Department of Agriculture. 24 p.

Eaton, C.B.; Beal, J.A.; Furniss, R.L.; Speers, C.F. 1949. Airplane and helicopter spraying with DDT for spruce budworm control. Journal of Forestry. 47: 823–827.

Erickson. 1906. Report on Blue Mountains (W); silvics. Unpublished Typescript Report. [Place of Publication Unknown]: U.S. Department of Agriculture, Forest Service. 4 p. On file with: Umatilla National Forest, Supervisor's Office, 2517 SW Hailey Avenue, Pendleton, Oregon 97801.

Evans, John W. 1990. Powerful rockey: the Blue Mountains and the Oregon Trail, 1811–1883. Enterprise, OR: Eastern Oregon State College, Pika Press. 374 p.

Evans, R.M. 1912. General silvical report; Wallowa and Minam Forests. Unpublished Typescript Report. [Place of Publication Unknown]: U.S. Department of Agriculture, Forest Service. 54 p. On file with: Umatilla National Forest, Supervisor's Office, 2517 SW Hailey Avenue, Pendleton, Oregon 97801.

Fellin, David G. 1983. Chemical insecticide vs the western spruce budworm: after three decades, what's the score? Western Wildlands. 9 (1): 8–12.

Fellin, David G.; Schmidt, Wyman C. 1973. How does western spruce budworm feeding affect western larch? Gen. Tech. Rep. INT–7. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 25 p.

Ferguson, Dennis E. 1988. Growth of regeneration defoliated by spruce budworm in Idaho. Res. Pap. INT–393. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 13 p.

Ferguson, Dennis E. 1991. Allelopathic potential of western coneflower (*Rudbeckia occidentalis*). Canadian Journal of Botany. 69: 2806–2808.

Ferguson, Dennis E.; Boyd, Raymond J. 1988. Bracken fern inhibition of conifer regeneration in northern Idaho. Res. Pap. INT–388. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 11 p.

Ferrell, George T.; Scharpf, Robert F. 1982. Stem volume losses in grand firs topkilled by western spruce budworm in Idaho. Res. Pap. PSW–164. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Exp. Station. 10 p.

Filip, Gregory M.; Colbert, J.J.; Shaw, C.G., III; Hessburg, Paul F.; Hosman, Kevin P. 1993. Influence of dwarf mistletoe and western spruce budworm on growth and mortality of Douglas-fir in unmanaged stands. Forest Science. 39 (3): 465–477.

Filip, Gregory M.; Schmitt, Craig L. 1990. R_x for *Abies*: silvicultural options for diseased firs in Oregon and Washington. Gen. Tech. Rep. PNW–GTR–252. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 34 p.

Filip, Gregory M.; Wickman, Boyd E.; Mason, Richard R.; Parks, Catherine A.; Hosman, Kevin P. 1992. Thinning and nitrogen fertilization in a grand fir stand infested with western spruce budworm. Part III: tree wound dynamics. Forest Science. 38 (2): 265–274.

Fischer, William C., compiler. 1990. The fire effects information system [Data base]. Missoula, MT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Intermountain Fire Sciences Laboratory.

Fischer, William C.; Bradley, Anne F. 1987. Fire ecology of western Montana forest habitat types. Gen. Tech. Rep. INT–223. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 95 p.

Fischer, William C.; Clayton, Bruce D. 1983. Fire ecology of Montana forest habitat types east of the Continental Divide. Gen. Tech. Rep. INT–141. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 83 p.

Flinn, Marguerite A.; Wein, Ross W. 1977. Depth of underground plant organs and theoretical survival during fire. Canadian Journal of Botany. 55: 2550–2554.

Forman, Richard T.T.; Russell, Emily W.B. 1983. Evaluation of historical data in ecology. Bulletin of the Ecological Society of America. 64: 5–7.

Foster, H.D. 1907. Report on the silvics of the Blue Mountains (E) National Forest, Oregon. Unpublished Typescript Report for July–September. [Place of Publication Unknown]: U.S. Department of Agriculture, Forest Service. 1 p. On file with: Umatilla National Forest, Supervisor's Office, 2517 SW Hailey Avenue, Pendleton, Oregon 97801.

Foster, H.D. 1908. Report on the silvics of the Blue Mountains (E) National Forest, Oregon. Unpublished Typescript Report. [Place of Publication Unknown]: U.S. Department of Agriculture, Forest Service. 30 p. On file with: Umatilla National Forest, Supervisor's Office, 2517 SW Hailey Avenue, Pendleton, Oregon 97801.

Franklin, Jerry F.; Dyrness, C.T. 1973. Natural vegetation of Oregon and Washington. Gen. Tech. Rep. PNW–8. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 417 p.

Gannett, Henry. 1902. The forests of Oregon. Professional Paper No. 4, Series H, Forestry, No. 1. Washington, DC: U.S. Department of Interior, Geological Survey. 36 p (and map).

Garton, Edward O. 1987. Habitat requirements of avian predators. In: Brookes, Martha H.; Campbell, Robert W.; Colbert, J.J.; Mitchell, Russel G.; Stark, R.W., tech. coords. Western spruce budworm.

Tech. Bull. 1694. Washington, DC: U.S. Department of Agriculture, Forest Service, Cooperative State Research Service: 82–85.

Gary, Howard L.; Currie, Pat O. 1977. The Front Range pine type—a 40-year photographic record of plant recovery on an abused watershed. Gen. Tech. Rep. RM–46. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 17 p.

Gedney, Donald R. 1963. Toward complete use of eastern Oregon's forest resources. Res. Bull. PNW–3. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 71 p.

Geier-Hayes, Kathleen. 1989. Vegetation response to helicopter logging and broadcast burning in Douglas-fir habitat types at Silver Creek, central Idaho. Res. Pap. INT–405. Ogden, UT: U.S. Dept. of Agriculture, Forest Service, Intermountain Research Station. 24 p.

Griffiths, David. 1903. Forage conditions and problems in eastern Washington, eastern Oregon, northeastern California, and northwestern Nevada. Bulletin No. 38. Washington, DC: U.S. Department of Agriculture, Bureau of Plant Industry. 52 p.

Gruell, George E. 1980. Fire's influence on wildlife habitat on the Bridger–Teton National Forest, Wyoming. Res. Pap. INT–235. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 207 p.

Gruell, George E. 1983. Fire and vegetative trends in the northern Rockies: interpretations from 1871–1982 photographs. Gen. Tech. Rep. INT–158. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 117 p.

Gruell, George E. 1985. Fire on the early western landscape: an annotated record of wildland fires 1776–1900. Northwest Science. 59 (2): 97–107.

Gruell, George E.; Schmidt, Wyman C.; Arno, Stephen F.; Reich, William J. 1982. Seventy years of vegetative change in a managed ponderosa pine forest in western Montana—implications for resource management. Gen. Tech. Rep. INT–130. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 42 p.

Habeck, James R. 1990. Old-growth ponderosa pine–western larch forests in western Montana: ecology and management. The Northwest Environmental Journal. 6 (2): 271–292.

Haig, Irvine T.; Davis, Kenneth P.; Weidman, Robert H. 1941. Natural regeneration in the western white pine type. Tech. Bull. No. 767. Washington, DC: U.S. Department of Agriculture. 98 p.

Hall, Frederick C. 1977. Ecology of natural underburning in the Blue Mountains of Oregon. R6–ECOL–79–001. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 11 p.

Hall, Frederick C. 1991. Ecology of fire in the Blue Mountains of eastern Oregon. Draft Manuscript. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 27 p.

Harley, F.W. 1918. Letter from District Ranger to Forest Supervisor; subject: Klamath—Fires. Orleans, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Region, Klamath National Forest. 3 p.

Harvey, Alan E.; Geist, J. Michael; McDonald, Gerald I.; Jurgensen, Martin F.; Cochran, Patrick H.; Zabowski, Darlene; Meurisse, Robert T. 1994. Biotic and abiotic processes of eastside ecosystems: the effects of management on soil properties, processes, and productivity. Gen. Tech. Rep. PNW–GTR–323. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 71 p.

Harvey, A.E.; Meurisse, R.T.; Geist, J.M.; Jurgensen, M.F.; McDonald, G.I.; Graham, R.T.: Stark, N. 1989. Managing productivity processes in the Inland Northwest—mixed conifers and pines. In: Perry, D.A.; and others, eds. Maintaining the long-term productivity of Pacific Northwest forest ecosystems. Portland, OR: Timber Press: 164–184.

Harvey, Robert D., Jr. [1982.] Loss assessment: western spruce budworm infestation on the Okanogan and Wenatchee National Forests. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region, Forest Pest Management. 36 p.

Hays, J.D.; Imbrie, John; Shackleton, N.J. 1976. Variation in the Earth's orbit: pacemaker of the ice ages. Science. 194 (4270): 1121–1132.

Hedrick, D.W.; Young, J.A.; McArthur, J.A.B.; Keniston, R.F. 1968. Effects of forest and grazing practices on mixed coniferous forests of northeastern Oregon. Tech. Bull. 103. Corvallis, OR: Agricultural Experiment Station, Oregon State University. 24 p.

Helson, Blair. 1992. Naturally derived insecticides: prospects for forestry use. Forestry Chronicle. 68 (3): 349–354.

Hessburg, Paul F.; Mitchell, Russel G.; Filip, Gregory M. 1994. Historical and current roles of insects and pathogens in eastern Oregon and Washington forested landscapes. Gen. Tech. Rep. PNW–GTR–327. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 72 p.

Hitchcock, C. Leo; Cronquist, Arthur. 1973. Flora of the Pacific Northwest. Seattle, WA: University of Washington Press. 730 p.

Hitchcock, C. Leo; Cronquist, Arthur; Ownbey, Marion; Thompson, J.W. 1955. Vascular plants of the Pacific Northwest. Part 5: Compositae. Seattle, WA: University of Washington Press. 343 p.

Hitchcock, C. Leo; Cronquist, Arthur; Ownbey, Marion; Thompson, J.W. 1959. Vascular plants of the Pacific Northwest. Part 4: Ericaceae through Campanulaceae. Seattle, WA: University of Washington Press. 510 p.

Hitchcock, C. Leo; Cronquist, Arthur; Ownbey, Marion; Thompson, J.W. 1961. Vascular plants of the Pacific Northwest. Part 3: Saxifragaceae to Ericaceae. Seattle, WA: University of Washington Press. 614 p.

Hitchcock, C. Leo; Cronquist, Arthur; Ownbey, Marion; Thompson, J.W. 1964. Vascular plants of the Pacific Northwest. Part 2: Salicaceae to Saxifragaceae. Seattle, WA: University of Washington Press. 597 p.

Hitchcock, C. Leo; Cronquist, Arthur; Ownbey, Marion; Thompson, J.W. 1969. Vascular plants of the Pacific Northwest. Part 1: Vascular Cryptogams, Gymnosperms, and Monocotyledons. Seattle, WA: University of Washington Press. 914 p.

Hopkins, William E.; Rawlings, Robert C. 1985. Major indicator shrubs and herbs on national forests of eastern Oregon. Pub. R6–TM–190–1985. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region.

Hunter, Malcolm L. 1990. Wildlife, forests, and forestry: principles of managing forests for biological diversity. Englewood Cliffs, NJ: Prentice–Hall, Inc. 370 p.

Johnson, Charles Grier, Jr.; Clausnitzer, Rodrick R. 1992. Plant associations of the Blue and Ochoco Mountains. Pub. R6–ERW–TP–036–92. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region, Wallowa–Whitman National Forest. 164 p.

Johnson, Ralph R. 1990. The Blue Mountains geographic variant of the stand prognosis model. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Washington Office, Division of Timber Management. 19 p.

Johnston, Verna R. 1970. The ecology of fire. Audubon. 72: 76–119.

Jones, Forrest W.; Welch, Dehn S.; Schramek, Robert. 1961. Forest inventory statistics for the Malheur and Ochoco National Forests; Burns Working Circle, John Day Working Circle, and the Middle Fork Working Circle. Portland, OR: U.S. Department of Agriculture, Forest Service, Division of Timber Management. 114 p.

Keen, F.P. 1937. Climatic cycles in eastern Oregon as indicated by tree rings. Monthly Weather Review. 65 (5): 175–188.

Kemp, William P.; Everson, Dale O.; Wellington, W.G. 1985. Regional climatic patterns and western spruce budworm outbreaks. Tech. Bull. 1693. Washington, DC: U.S. Department of Agriculture, Forest Service, Cooperative State Research Service. 31 p.

Kent, W.H.B. 1904. The proposed Wenaha Forest Reserve, Washington and Oregon: examination and report. Unpublished Typescript Report. [Place of Publication Unknown]: U.S. Department of Agriculture, Bureau of Forestry. 22 p. On file with: Umatilla National Forest, Supervisor's Office, 2517 SW Hailey Avenue, Pendleton, Oregon 97801.

Kuchler, A.W. 1964. Potential natural vegetation of the conterminous United States (map and manual). Special Publication 36. New York, NY: American Geographical Society. 116 p.

Laudenslayer, William F., Jr.; Darr, Herman H.; Smith, Sydney. 1989. Historical effects of forest management practices on eastside pine communities in northeastern California. In: Tecle, Aregai; Covington, W. Wallace; Hamre, R.H., tech. coords. Multiresource management of ponderosa pine forests. Symposium Proceedings; 1989 Nov. 14–16; Flagstaff, AZ. Gen. Tech. Rep. RM–185. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 26–34.

Lauridsen, Morten J. 1937 (August 5). Forest statistics for Grant County, Oregon. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest Experiment Station. 14 p.

Leege, T.A.; Godbolt, G. 1985. Herbaceous response following prescribed burning and seeding of elk range in Idaho. Northwest Science. 59 (2): 134–143.

Lindgren, Waldemar. 1901. The gold belt of the Blue Mountains of Oregon. Washington, DC: U.S. Department of Interior; Twenty-Second Annual Report of the United States Geological Survey; Part II—Ore Deposits: 551–776.

MacCleery, Douglas W. 1992. American forests: a history of resiliency and recovery. Publication FS–540. Durham, NC: Forest History Society. 59 p.

Marr, John W. 1967. Ecosystems of the east slope of the Front Range in Colorado. Boulder, CO: Colorado Associated Univ. Press. 134 p.

Martinez, Dennis. 1993. Back to the future: ecological restoration, the historical forest, and traditional Indian stewardship. Remarks delivered at "A Watershed Perspective on Native Plants" conference, Olympia, Washington, February 26, 1993.

Maruoka, Kathleen R. 1993. A fire history survey in selected *Pseudotsuga menziesii* and *Abies grandis* stands in the Blue Mountains of Oregon and Washington. Preliminary Results. Report Prepared for USDA Forest Service Coop. Agreement No. PNW92–0179. Seattle, WA: University of Washington, College of Forest Resources. 28 p.

Mason, Richard R. 1992. Populations of arboreal spiders (Araneae) on Douglas-firs and true firs in the interior Pacific Northwest. Environmental Entomology. 21 (1): 75–80.

McConnell, Tim; Joseph, Paul; McComb, David; Twardus, Daniel. 1980. Western spruce budworm in eastern Oregon, 1980. Unnumbered Report. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region, Forest Pest Management. 4 p.

McLean, A. 1968. Fire resistance of forest species as influenced by root systems. Journal of Range Management. 22: 120–122.

Meinecke, E.P. 1916. Forest pathology in forest regulation. Bull. No. 275. Washington, DC: U.S. Department of Agriculture. 62 p.

Miles, Herbert J. 1911. Annual silvical report: Malheur National Forest. Unpublished Typescript Report. [Place of Publication Unknown]: U.S. Department of Agriculture, Forest Service. 38 p. On file with: Umatilla National Forest, Supervisor's Office, 2517 SW Hailey Avenue, Pendleton, Oregon 97801.

Minore, Don. 1979. Comparative autecological characteristics of northwestern tree species—a literature review. Gen. Tech. Rep. PNW–87. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Exp. Station. 72 p.

Minore, Don; Smart, Alan W.; Dubrasich, Michael E. 1979. Huckleberry ecology and management research in the Pacific Northwest. Gen. Tech. Rep. PNW–93. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 50 p.

Mlot, Christine. 1991. Diversity and dwarf mistletoe. BioScience. 41 (11): 755.

Monnig, Edward; Byler, James. 1992. Forest health and ecological integrity in the northern Rockies. Second edition. FPM Rep. 92–7; R1–92–130. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region, Forest Pest Management.

Moore, James A.; Mika, Peter G.; Schwandt, John W.; Shaw, Terry M. 1993. Nutrition and forest health. Moscow, ID: University of Idaho, Intermountain Forest Tree Nutrition Cooperative. 16 p.

Moravets, F.L. 1936 (May 7). Forest statistics for Harney County, Oregon. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest Experiment Station. 12 p.

Mosgrove, Jerry L. 1980. The Malheur National Forest: an ethnographic history. John Day, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region, Malheur National Forest. 253 p.

Munger, Thornton T. 1917. Western yellow pine in Oregon. Bull. No. 418. Washington, DC: U.S. Department of Agriculture. 48 p.

Mutch, Robert W.; Arno, Stephen F.; Brown, James K.; Carlson, Clinton E.; Ottmar, Roger D.; Peterson, Janice L. 1993. Forest health in the Blue Mountains: a management strategy for fire-adapted ecosystems. Gen. Tech. Rep. PNW–GTR–310. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 14 p.

Muzika, Rose-Marie; Engle, Judith; Parks, Catherine; Wickman, Boyd. 1993. Variation in phenology and monoterpene patterns of defoliated and nondefoliated Douglas-fir (*Pseudotsuga menziesii* var. *glauca*). Res. Pap. PNW–RP–459. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 10 p.

Noste, Nonan V.; Bushey, Charles L. 1987. Fire response of shrubs of dry forest habitat types in Montana and Idaho. Gen. Tech. Rep. INT–239. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 22 p.

O'Laughlin, Jay; MacCracken, James G.; Adams, David L.; Bunting, Stephen C.; Blatner, Keith A.; Keegan, Charles E., III. 1993. Forest health conditions in Idaho. Rep. No. 11. Moscow, ID: Idaho Forest, Wildlife and Range Policy Analysis Group, Idaho Forest, Wildlife and Range Experiment Station, University of Idaho. 244 p.

Omernik, James M.; Gallant, Alisa L. 1986. Ecoregions of the Pacific Northwest. EPA/600/3–86/033. Corvallis, OR: U.S. Environmental Protection Agency, Research and Development, Environmental Research Laboratory. 39 p.

Patterson, J.E. 1929. The pandora moth, a periodic pest of western pine forests. Tech. Bull. No. 137. Washington, DC: U.S. Department of Agriculture. 19 p.

Perkins, Randall F.; Dolph, Robert E., Jr. 1967. Operational and entomological report, 1965 Burns project, Douglas-fir tussock moth control. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region, Division of Timber Management, Insect and Disease Control Branch. 28 p.

Plummer, Fred G. 1912. Lightning in relation to forest fires. Bull. No. 111. Washington, DC: U.S. Department of Agriculture, Forest Service. 39 p.

Powell, David C. 1987. How to prepare a silvicultural prescription for uneven-aged management. Pueblo, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Region, Pike and San Isabel National Forests. 53 p.

Powell, David C. 1989. Plants of the Malheur National Forest. Unpublished Paper. [John Day, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region, Malheur National Forest.] 21 p.

Pyne, Stephen J. 1982. Fire in America: a cultural history of wildland and rural fire. Princeton, NJ: Princeton University Press. 654 p.

Randall, J.M.; Rejmanek, M. 1993. Interference of bull thistle (*Cirsium vulgare*) with growth of ponderosa pine (*Pinus ponderosa*) seedlings in a forest plantation. Canadian Journal of Forest Research. 23 (8): 1507–1513.

Robbins, William G.; Wolf, Donald W. 1994. Landscape and the Intermontane Northwest: an environmental history. Gen. Tech. Rep. PNW–GTR–319. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 32 p.

Sampson, Arthur W. 1917. Important range plants: their life history and forage value. Bull. No. 545. Washington, DC: U.S. Department of Agriculture. 63 p.

Schreuder, H.T.; Thomas, C.E. 1991. Establishing cause–effect relationships using forest survey data. Forest Science. 37 (6): 1497–1512.

Seidel, K.W.; Beebe, Tom. 1983. Grand fir, Douglas-fir, and associated species (eastern Oregon and Washington). In: Burns, Russell M., tech. comp. Silvicultural systems for the major forest types of the United States. Agric. Handbk. 445. Washington, DC: U.S. Department of Agriculture, Forest Service, Division of Timber Management: 19–22.

Seidel, K.W.; Cochran, P.H. 1981. Silviculture of mixed conifer forests in eastern Oregon and Washington. Gen. Tech. Rep. PNW–121. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 70 p.

Show, S.B.; Kotok, E.I. 1924. The role of fire in the California pine forests. Bull. No. 1294. Washington, DC: U.S. Department of Agriculture. 80 p.

Silver, G.T. 1960. Notes on a spruce budworm infestation in British Columbia. Forestry Chronicle. 36: 362–374.

Snedecor, George W.; Cochran, William G. 1989. Statistical methods. Eighth edition. Ames, IA: Iowa State University Press. 503 p.

Steinhoff, R.J. 1978. Distribution, ecology, silvicultural characteristics, and genetics of the *Abies grandis—Abies concolor* complex. In: Proceedings of the IUFRO joint meeting of working parties, volume 2: lodgepole pine, sitka spruce, and *Abies* provenances. Vancouver, B.C., Canada; British Columbia Ministry of Forests: 123–132.

Stevens, William K. 1990. New eye on nature: the real constant is eternal turmoil. New York, NY: The New York Times, Science Column for Tuesday, July 31, 1990. 2 p.

Stickney, Peter F. 1986. First decade plant succession following the Sundance forest fire, northern Idaho. Gen. Tech. Rep. INT–197. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 26 p.

Swetnam, Thomas W.; Lynch, Ann M. 1989. A tree-ring reconstruction of western spruce budworm history in the southern Rocky Mountains. Forest Science. 35 (4): 962–986.

Swetnam, Thomas W.; Lynch, Ann M. 1993. Multicentury, regional-scale patterns of western spruce budworm outbreaks. Ecological Monographs. 63 (4): 399–424.

Swetnam, Thomas W.; Thompson, Marna Ares; Sutherland, Elaine Kennedy. 1985. Using dendrochronology to measure radial growth of defoliated trees. Agric. Handbk. 639. Washington, DC: U.S. Department of Agriculture, Forest Service, Cooperative State Research Service. 39 p.

Swezy, D. Michael; Agee, James K. 1991. Prescribed-fire effects on fine-root and tree mortality in old-growth ponderosa pine. Canadian Journal of Forest Research. 21: 626–634.

Teply, John. 1980. Malheur National Forest; summary tables for timber resource inventory. Portland, OR: U.S. Department of Agriculture, Forest Service, Division of Timber Management. Three-ring binders with variable pagination.

Thomas, Jack Ward, tech. ed. 1979. Wildlife habitats in managed forests: the Blue Mountains of Oregon and Washington. Agric. Handbk. No. 553. Washington, DC: U.S. Department of Agriculture, Forest Service. 512 p.

Torgersen, Torolf R.; Mason, Richard R.; Campbell, Robert W. 1990. Predation by birds and ants on two forest insect pests in the Pacific Northwest. Studies in Avian Biology. 13: 14–19.

Tucker, Gerald J. 1940. History of the northern Blue Mountains. Unpublished Report. [Pendleton, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region, Umatilla National Forest.] 170 p.

U.S. Department of Agriculture, Forest Service. 1916. Sale Prospectus; 124,000,000 feet of western yellow pine and other species; lower Middle Fork John Day River unit, Whitman National Forest, Oregon. Portland, OR: U.S. Department of Agriculture, Forest Service, District Forester. 18 p.

U.S. Department of Agriculture, Forest Service. 1961. Timber management plan; Malheur National Forest. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region, Division of Timber Management. 80 p.

U.S. Department of Agriculture, Forest Service. 1970. Forest inventory statistics for the Malheur National Forest; Malheur Working Circle. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region, Division of Timber Management, Branch of Plans and Silviculture. 61 p.

U.S. Department of Agriculture, Forest Service. 1980. Field instructions for timber resource inventories, Region 6. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region, Division of Timber Management. Variable pagination.

U.S. Department of Agriculture, Forest Service. 1982. Environmental assessment: western spruce budworm management in northeastern Oregon. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 39 p.

U.S. Department of Agriculture, Forest Service. 1983. Environmental assessment: western spruce budworm management in northeastern Oregon. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 36 p.

U.S. Department of Agriculture, Forest Service. 1985. Environmental assessment: operational evaluation of *Bacillus thuringiensis* for suppression of western spruce budworm populations on the Bear Valley and Burns Ranger Districts, Malheur National Forest. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region, Malheur National Forest. 22 p.

U.S. Department of Agriculture, Forest Service. 1987a. Calculations and formulas used to derive R6TSE output tables. Program User's Guide Appendix II, R6TSE Program User's Guide. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 16 p.

U.S. Department of Agriculture, Forest Service. 1987b. Environmental assessment: western spruce budworm management in Oregon and Washington during 1987. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 73 p.

U.S. Department of Agriculture, Forest Service. 1990. Land and resource management plan: Malheur National Forest. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. Variable pagination.

U.S. Department of Agriculture, Forest Service. 1992. Policy statement: reduce clearcutting on the national forests. Washington, DC: U.S. Department of Agriculture, Forest Service, Washington Office. 2 p.

U.S. Department of Agriculture, Forest Service. 1993. Healthy forests for America's future: a strategic plan. Pub. MP–1513. Washington, DC: U.S. Department of Agriculture, Forest Service, Washington Office. 58 p.

Veblen, Thomas T.; Lorenz, Diane C. 1991. The Colorado Front Range: a century of ecological change. Salt Lake City, UT: University of Utah Press. 186 p.

Volland, Leonard A.; Dell, John D. 1981. Fire effects on Pacific Northwest forest and range vegetation. Pub. R6–RM–067–1981. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region, Range Management and Aviation and Fire Management. 23 p.

Ware, George W. 1989. The pesticide book. Third edition. Fresno, CA: Thomson Publications. 336 p.

Waring, R.H.; Savage, T.; Cromack, K., Jr.; Rose, C. 1992. Thinning and nitrogen fertilization in a grand fir stand infested with western spruce budworm. Part IV: an ecosystem management perspective. Forest Science. 38 (2): 275–286.

Weaver, Harold. 1943. Fire as an ecological and silvicultural factor in the ponderosa-pine region of the Pacific Slope. Journal of Forestry. 41: 7–14.

Weaver, Harold. 1947a. Fire—nature's thinning agent in ponderosa pine stands. Journal of Forestry. 45: 437–444.

Weaver, Harold. 1947b. Management problems in the ponderosa pine region. Northwest Science. 21 (4): 160–163.

Weaver, Harold. 1957. Effects of prescribed burning in ponderosa pine. Journal of Forestry. 55: 133–138.

Weidman, R.H. 1936. Timber growing and logging practice in ponderosa pine in the Northwest. Tech. Bull. No. 511. Washington, DC: U.S. Department of Agriculture. 91 p.

Whiteside, John M. 1956. Spruce budworm control in Oregon and Washington, 1949–1956. Unnumbered Report. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, Division of Forest Insect Research. 23 p.

Whiteside, J.M.; Wessela, C.P.; Compton, L.M. 1956. Report of the 1955 Oregon spruce budworm control project. Unnumbered Report. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 60 p.

Wickman, Boyd E. 1992. Forest health in the Blue Mountains: the influence of insects and disease. Gen. Tech. Rep. PNW–GTR–295.

Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 15 p.

Wickman, Boyd E.; Mason, Richard R.; Paul, H. Gene. 1992. Thinning and nitrogen fertilization in a grand fir stand infested with western spruce budworm. Part II: tree growth response. Forest Science. 38 (2): 252–264.

Wickman, B.E.; Mason, R.R.; Swetnam, T.W. 1994. Searching for long-term patterns of forest insect outbreaks. In: Leather, S.R.; Walters, K.F.A.; Mills, N.J.; Watt, A.D., eds. Individuals, Populations and Patterns in Ecology. Conference Proceedings; late 1992; Norwich, United Kingdom. Andover, United Kingdom: Intercept Ltd: 251–261.

Wickman, Boyd E.; Mason, Richard R.; Thompson, C.G. 1973. Major outbreaks of the Douglas-fir tussock moth in Oregon and California. Gen. Tech. Rep. PNW–5. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 18 p.

Willhite, Elizabeth A. 1993. 1992 Douglas-fir tussock moth pheromone trapping summary for Oregon and Washington. Pub. R6–93–02. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 13 p.

Williams, Carroll B., Jr. 1966. Differential effects of the 1944–56 spruce budworm outbreak in eastern Oregon. Res. Pap. PNW–33. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 16 p.

Woolsey, Theodore S., Jr. 1911. Western yellow pine in Arizona and New Mexico. Bull. No. 101. Washington, DC: U.S. Department of Agriculture, Forest Service. 64 p.

Wright, Henry A. 1978. The effect of fire on vegetation in ponderosa pine forests: a state-of-the-art review. College of Agricultural Sciences Pub. No. T–9–199. Lubbock, TX: Texas Tech University, Department of Range and Wildlife Management. 21 p.

Wulf, N. William; Cates, Rex G. 1987. Site and stand characteristics. In: Brookes, Martha H.; Campbell, Robert W.; Colbert, J.J.; Mitchell, Russel G.; Stark, R.W., tech. coords. Western spruce budworm. Tech. Bull. 1694. Washington, DC: U.S. Department of Agriculture, Forest Service, Cooperative State Research Service: 89–115.

Appendix 1: Common and Scientific Names

	Common Name	Scientific Name
Bacteria	B.t.	*Bacillus thuringiensis*
Birds	American Robin	*Turdus migratorius*
	Cassin's Finch	*Carpodacus cassinii*
	Chipping Sparrow	*Spizella passerina*
	Dark-Eyed Junco	*Junco hyemalis*
	Evening Grosbeak	*Coccothraustes vespertinus*
	Golden-Crowned Kinglet	*Regulus satrapa*
	Hammond's Flycatcher	*Empidonax hammondii*
	House Sparrow	*Passer domesticus*
	Mountain Chickadee	*Parus gambeli*
	Northern Spotted Owl	*Strix occidentalis caurina*
	Pileated Woodpecker	*Dryocopus pileatus*
	Pine Siskin	*Carduelis pinus*
	Red-Breasted Nuthatch	*Sitta canadensis*
	Red-Winged Blackbird	*Agelaius phoeniceus*
	Ruby-Crowned Kinglet	*Regulus calendula*
	Swainson's Thrush	*Catharus ustulatus*
	Townsend's Warbler	*Dendroica townsendi*
	Western Tanager	*Piranga ludoviciana*
	Yellow-Rumped Warbler	*Dendroica coronata*
Herbs	Bracken Fern	*Pteridium aquilinum*
	Bull Thistle	*Cirsium vulgare*
	Elk Sedge	*Carex geyeri*
	Marigold	*Calendula officinalis*
	Peavines	*Lathyrus* spp.
	Pinegrass	*Calamagrostis rubescens*
	Tailcup Lupine	*Lupinus caudatus*
	Vetch	*Vicia americana*
	Western Coneflower	*Rudbeckia occidentalis*
Insects and Other Arthropods	Bark Beetles	*Dendroctonus* spp. (primarily)
	Carpenter Ants	*Camponotus* spp.
	Carabid Beetle	Carabidae
	Douglas-fir Beetle	*Dendroctonus pseudotsugae*
	Douglas-fir Tussock Moth	*Orgyia pseudotsugata*
	Fir Engraver	*Scolytus ventralis*
	Jumping Spider	*Metaphidippus aeneolus*
	Mountain Pine Beetle	*Dendroctonus ponderosae*
	Pandora Moth	*Coloradia pandora*
	Pine Engraver Beetles	*Ips* spp.
	Spruce Budworm (Eastern)	*Choristoneura fumiferana*
	Stink Bug	Pentatomidae

	Common Name	Scientific Name
Insects and Other Arthropods (cont.)	Thatch Ants	*Formica* spp.
	Western Pine Beetle	*Dendroctonus brevicomis*
	Western Spruce Budworm	*Choristoneura occidentalis*
	Yellowjacket (Western)	*Vespula pennsylvanica*
Mammals	Black Bear	*Ursus americanus*
	Coyote	*Canus latrans*
	Raccoon	*Procyon lotor*
Pathogens	Annosus Root Disease	*Heterobasidion annosum*
	Armillaria Root Disease	*Armillaria ostoyae*
	Douglas-fir Dwarf Mistletoe	*Arceuthobium douglasii*
	Dwarf Mistletoes	*Arceuthobium* spp.
	Indian Paint Fungus	*Echinodontium tinctorium*
Trees and Shrubs	Black Cottonwood	*Populus trichocarpa*
	Bull Pine	(See Ponderosa Pine)
	Douglas-fir	*Pseudotsuga menziesii*
	Engelmann Spruce	*Picea engelmannii*
	Grand Fir	*Abies grandis*
	Lodgepole Pine	*Pinus contorta*
	Mountain Mahogany	*Cercocarpus ledifolius*
	Neem Tree	*Azadirachta indica*
	Ponderosa Pine	*Pinus ponderosa*
	Quaking Aspen	*Populus tremuloides*
	River Birch	*Betula occidentalis*
	Snowbrush Ceanothus	*Ceanothus velutinus*
	Subalpine Fir	*Abies lasiocarpa*
	Tamarack	(See Western Larch)
	Thinleaf Alder	*Alnus incana*
	Western Hemlock	*Tsuga heterophylla*
	Western Juniper	*Juniperus occidentalis*
	Western Larch	*Larix occidentalis*
	Western White Pine	*Pinus monticola*
	Western Yellow Pine	(See Ponderosa Pine)
	White Fir	*Abies concolor*
	Willows	*Salix* spp.
	Yellow Pine	(See Ponderosa Pine)

APPENDIX 2: SURVEY DESIGN AND RELIABILITY OF RESULTS

Prepared by Dr. John W. Hazard, Statistical Consulting Service

The budworm impact survey remeasured a subsample of permanent plots established earlier for a different objective. Thus, to understand the budworm design and estimation procedures, it is necessary to understand the designs which produced the permanent plots that were remeasured.

The 1967–1968 Timber Inventory

In 1967 and 1968, a timber management inventory was conducted on the Malheur National Forest. This inventory was installed on "available" national forest lands to assess their current status, and to identify trends in area and volume statistics. The primary use of the 1967–68 inventory was for management planning.

The 1967–68 survey design was a systematic grid sample uniformly distributed over the entire Forest. The grid interval was 1.7 miles on a side. This produced 766 grid locations distributed over 1,419,659 acres of available forest land (AFL). Each grid location corresponded to a field plot location, and each field plot represented 1853.34 acres. Estimates of subpopulation parameters for available forest land were made by dividing the number of plots in the subclass of interest by the original 766 plots and multiplying by the known acres of AFL. For example, the estimated acres of commercial forest land (CFL) was equal to:

$$CFL = \{638 \div 766\} \times 1{,}419{,}659 \text{ acres} = 1{,}182{,}432 \text{ acres.}$$

Traditionally, the estimates of such systematic samples have been treated as simple random samples for estimating sample variances. Systematic samples maximize the sample variance among plots; thus, in most cases, they produce an estimated variance that is larger than the variance which would have been obtained if simple random sampling had been used. In other words, simple random sampling estimators produce conservative estimates of sample variances. Systematic sampling does provide the best spatial coverage of an area being inventoried.

The 1980 Timber Inventory

In 1980, a new timber management inventory was completed. The objectives of this new inventory differed from the 1967–68 inventory, which resulted in a new survey design. In addition, the entire Forest was mapped into model component polygons. Thus, the total area of each model component was known within the accuracy limitations of the mapping procedures. The objectives were still to assess the current status and trends in area and volume statistics, but it was also desired to control the precision estimates by model component. The precision requirements were $\pm$ 10% for ponderosa pine and mixed conifer strata, and $\pm$ 20% for lodgepole pine strata, both at the 68% probability level.

The 604 plots established in 1967–68 were transferred to the model component map and the total number of 1967–68 plots were arrayed by strata. Using variance estimates of board-foot volume from the 1967–68 plot measurements by stratum, the number of plots necessary to satisfy the specified levels of precision were computed. The computed number of plots was compared to the number of 1967–68 plots for each stratum. If the 1967–68 sample satisfied the specified precision, no new plots were selected. If too few plots existed for a particular stratum, then the number of additional plots necessary to satisfy the precision requirement was determined.

For those strata that did not require new plots, the required number of 1967–68 plots was distributed uniformly among townships within ranger districts, attempting to get equal numbers of plots per township.

Plot Selection

For those strata requiring additional plots, the number of new plots equalled the required number of plots minus the existing number of 1967–68 plots. New plots were distributed to strata first by district, and then by township. Within townships, new plots were distributed by numbering polygons by strata and randomly selecting the required number. Plot locations within polygons were determined by placing a grid template over the polygon, and then randomly selecting a grid point. The number of 1967–68 plots, new plots, and the total for each stratum appear in Table 6.

Thus, the 1980 sample was a combination of remeasured 1967–68 plots and supplemental plots installed in 1980. The strata areas were determined from the model component map. Estimates for the entire Forest were made by assuming a stratified random sample. The sampling intensities varied considerably among strata. Expansion factors for the 1980 combined sample appear in Table 6 (see “Acres/Plot” column).

The combined number of 1980 plots required to satisfy the specified levels of precision for all strata was 400. Actually, 402 plots were established in the field.

The 1988–1989 Budworm Survey

The 1988–89 spruce budworm survey, the basis for this report, used a subset of the 1980 timber inventory plots. It was decided that only plots which were determined to be budworm-host type would be visited in the field. Thus, the 1988–89 spruce budworm survey was conditioned on the selection rules used in the 1980 timber inventory survey, and had the added condition that only host type plots within the various strata would be visited and remeasured. Budworm host type was defined as those plots containing 50% or more of their live trees in host species (Engelmann spruce, white or subalpine fir, Douglas-fir, and western larch). There were 130 of the 1980 plots selected for the 1988–89 budworm survey (Table 6). Note that there were 12 strata in the 1980 timber management inventory (Tables 6 and 8). The fact that only 130 of the 402 plots were used in the budworm survey resulted in some strata with few or no host type plots. To insure that estimates of host types by strata contained an adequate sample, the 12 management strata from 1980 were collapsed into 5 budworm-analysis strata (Table 7). Strata with similar timber types were combined. For purposes of estimation in this report, the 1988–89 budworm survey was assumed to be a stratified random sampling design.

Calculating Sample Means

There are two approaches that can be taken to estimate the average amounts of topkill, defoliation, and mortality for the subpopulations of interest. One way is to use the measured values for those plots in the host type and zero for all the rest, and then form strata means according to the strata delineations from the 1980 timber inventory. This method is an exact one based on random sampling, but it produces means that are averaged over all plots in each stratum. Thus, the means are diluted by the zero values associated with the nonhost plots. Forest managers don't find this type of mean useful for management planning because it includes situations where budworm damage will not occur (i.e., the nonhost type). Instead, they prefer stratum estimates that include only those plots on which damage could potentially occur (host type).

The second approach is to form means, as suggested, by using only the host type plots included within strata defined for the 1980 timber inventory. These means can be formed quite readily and weighted by stratum areas to derive population estimates. The problem with this estimation method is that the amount of host type by stratum is unknown. It can only be estimated by calculating the proportion of host plots by strata, and then multiplying this proportion by the known strata areas. When forming averages for strata with unknown strata areas or sizes, sampling error is introduced for the estimates of host type areas. An approximate method is to use the variability among host plots within strata, since the estimated area of host type is not used for the host strata means. Readers should keep in mind that if an exact method existed for computing standard errors of average topkill, defoliation, and mortality by host type, estimates of these parameters would be larger than the approximations included in this report.

Sample Sizes for Tree-Related Variables

Confidence intervals are computed for a wide variety of subpopulations of interest. In the bar graphs (figs. 43–60), error bars appear as 68% confidence intervals. The estimated standard errors are computed as stratified random sampling estimates, with effective degrees of freedom (Cochran 1977). Note that for analysis factors pertaining to tree characteristics (species, diameter, height, age, crown ratio, and crown class), the plot percentages for the categories associated with each factor will sum to more than 100%. This occurred because each sample plot could support trees that were assigned to different categories for a particular analysis factor. For example, a plot may have supported Douglas-firs, white firs, and other hosts (Engelmann spruce, subalpine fir, or western larch). In that instance, the plot supplied 3 values when assessing budworm impacts by tree species—one mean for the Douglas-firs, another mean for the white firs, and a third value for the other hosts. The same situation was true for other tree-based analysis factors—a plot could have both dominant and suppressed trees, old and young trees, large- and small-diameter trees, tall and short trees, and so forth. For the tree-related variables, the sample sizes provided in the report include only those plots which contained trees that existed in the subpopulation of interest.

Table 6—Distribution of inventory plots by measurement period and model component.

Mod Com	1968 Plots	1980 Plots Old	New	Tot	1988–89 Plots Old	New	Tot	Acreages Total	Sample	Acres/ Plot
101	10	7	84	91	2	12	14	21037	3237	231.2
201	12	10	66	76	1	11	12	12154	1919	159.9
501	154	30	0	30	4	0	4	240378	32050	8012.6
601	25	14	7	21	1	1	2	60430	5755	2877.6
102	7	6	31	37	4	20	24	22217	14411	600.5
202	9	6	26	32	3	19	22	16716	11492	522.4
502	295	40	1	41	27	0	27	542400	357190	13229.3
602	15	15	14	29	9	7	16	54321	29970	1873.1
103	1	1	9	10	1	0	1	4545	455	454.4
203	8	5	10	15	1	2	3	15244	3049	1016.3
503	23	9	2	11	2	0	2	30451	5537	2768.3
603	6	5	4	9	1	2	3	12707	4236	1411.9
Total	565	148	254	402	56	74	130	1032600	469301	

Notes: "Mod Com" is Model Component; "Tot" is Total. For the "acreages" section, the "total" column is the total acreage associated with that model component in the 1980 timber inventory. The "sample" column is the estimated acreage of budworm host type represented by plots that were remeasured for the 1988–89 budworm survey. For a description of model components, see Table 8. **Source**: forest inventory records available at the Malheur NF, Supervisor's Office.

Table 7—Data summary by analysis stratum.

Stratum	Model Components	Total Acreage	Total Plots	Expansion: Acres/Plot
PPine	101/201	33191	167	198.75
Regen	102/103	26762	47	569.40
CThin	202/203	31960	47	680.00
OvRem	501/502/503	813229	82	9917.43
NoTmt	601/602/603	127458	59	2160.31
TOTAL		1032600	402	

Table 8—Model components that were field sampled.

Component	Description
101	Ponderosa pine, regeneration treatment recommendation.
201	Ponderosa pine, commercial thinning recommendation.
501	Ponderosa pine, overstory removal recommendation.
601	Ponderosa pine, no treatment recommendation.
102	Mixed conifer, regeneration treatment recommendation.
202	Mixed conifer, commercial thinning recommendation.
502	Mixed conifer, overstory removal recommendation.
602	Mixed conifer, no treatment recommendation.
103	Lodgepole pine, regeneration treatment recommendation.
203	Lodgepole pine, commercial thinning recommendation.
503	Lodgepole pine, overstory removal recommendation.
603	Lodgepole pine, no treatment recommendation.

Notes: Model components are a combination of 2 factors—forest type (referred to as a working group in inventory terminology), and a silvicultural opportunity class or treatment recommendation. In the 1980 timber inventory, there were 3 working groups (ponderosa pine, mixed conifer, and lodgepole pine), and four treatment opportunity classes for which field plots were allocated (regeneration, commercial thinning, overstory removal, and no treatment). Since the 1980 inventory was based on timber volume, no field plots were allocated to the reforestation and precommercial thinning opportunity classes because there were no timber volumes associated with those strata.