MISC0183

Forest Environment Pesticide Study Manual

Edited by
Donald P. Hanley,
David M. Baumgartner,
Gary L. Thomasson

Washington State University Cooperative Extension

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Several choices face forest managers as they attempt to control undesirable insects, animals, diseases or weeds. Managers must select one of the following: 1) do nothing and allow ecological processes, population dynamics, and forest succession to either enhance, modify or reduce the pest population; 2) attempt direct control through the application of pesticides; or 3) modify the pest's environment through silvicultural activities (Brookes, et al. 1987).

In intensively managed second growth forests, managers often choose direct control. Direct control in northwest forest environments, through the application of insecticides, rodenticides, herbicides, or fungicides, has been used since the mid 1940s with varying degrees of success. Direct control is often successful when the target organism has a relatively simple life cycle and if the pesticide is applied correctly. Long-term success and impacts are harder to assess, especially in the context of ecosystem management and environmental concern.

Silvicultural approaches to pest control are based on the simple fact that undesirable environments may reduce or eliminate pests. The long-term effects of silvicultural approaches have not been widely studied. Management conflicts can arise when silvicultural alternatives are used to control specific organisms. For example, multi-storied stand structures in the eastern Washington mixed conifer types are considered the structures most susceptible to the spread of western spruce budworm. Yet today, these same multi-storied stand structures are advocated for the northern spotted owl. The point is that forest land managers may not be able to manipulate an entire forest ecosystem for the elimination or reduction of *one undesirable species!* (Brookes, et al. 1987) As forest managers manipulate ecosystems, both positive and negative effects on all other aspects of that ecosystem are possible.

This publication provides an introduction to the concepts and practices to consider when applying pesticides in the forest environment. We hope this publication will help you choose safe and appropriate management options. We have included in this study guide a chapter addressing environmental concerns. This chapter addresses the fate of pesticides in the forest ecosystem. It is not a substitute for learning Washington pesticide laws and safety. Laws and safety information are presented in the publication (*Washington Pesticide Laws and Safety: A guide to safe use and handling for applicators and dealers,* MISC0056, edited by Carol Ramsay and Gary L. Thomasson. Available from Washington State University Cooperative Extension, College of Agriculture and Home Economics, Pullman, WA).

This updated study guide reflects the changes occurring in forest management in the Pacific Northwest, where forest managers and the public are increasingly concerned with entire ecosystems, and not simply the eradication of a target organism. No longer can the forester simply read a pesticide label to find out what chemical will kill the pest. Ecosystems should be viewed in terms of interactions, acceptable losses, environmental concerns, and public safety. We strongly encourage you to be cautious and to act appropriately if you choose to introduce pesticides into the forest environment.

Donald P. Hanley and David M. Baumgartner are Washington State University Cooperative Extension foresters, located in Seattle and Pullman, respectively.

Chapter One

Pest Control Ecology in Pacific Northwestern Forest Ecosystems

Alan E. Harvey

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Abstract

When dealing with forest pests and health issues it is important to consider factors underlying the development of the ecosystems affected. Many forests in the Pacific Northwest have experienced significant changes in the last 100 years that affect both composition and process. They are now operating well outside the norm of conditions for which they are adapted! Often, vegetative conditions (especially species composition and density), disturbances (especially fire, insects and pathogens), and populations of species dependent on historical internal environments are different. Insects and pathogens, both native and introduced, have increased substantially in these forests. These organisms are often viewed as the sole cause of health problems. Although that may be the case, poor health more often results from a combination of forest conditions. Past harvesting, site preparation, grazing, fire control and exotic pest proportions of late seral or climax species, have altered soil conditions, and support more fuel and fuel connectivity than ever can be expected to reduce inherent stability and productivity of forest lands. Aggressive management of specific pests, especially exotics, can help restore more normal forest conditions. Thus, in some cases, solving insect and pathogen problems emphasizes managing "causal organisms." However, when dealing with native insects and pathogens, successful control of the "causal organism" without an accompanying change in the environment, leaves the door open for immediate reinvasion. Directing forest conditions back toward those more prevalent during development of the system will be an extremely important aspect of successful pest management over the long term.

Introduction

The developmental history of western forest vegetation and environments is a key to understanding forest health and pest management ecology. The Idaho Panhandle, northeastern Oregon, eastern Washington and western Montana typify western vegetative patterns. This entire region represents rugged, mountainous terrain with diverse, often young geological origins and variable climates. It is summer dry (often moisture limiting) and variable at all scales across both time and space. Most moisture arrives as winter snow, and many soils are infertile.

In recent geological time major disturbances have been common. Ash fall from Cascade and Sierra volcanoes, for example, the deposition of Mt. Mazama ash 6,700 years ago (Fryxell 1965), and the close proximity of continental glacial ice near Spokane, Washington, only 14,000 years ago are representative. The ash depositions increase soil moisture storage in some of the regions, especially in some of the more productive forests of northern Idaho. This allows vegetation characteristic of a wet climate to occupy these sites (Geist and Cochran 1991, Meurisse et al. 1991). Glacial scouring of many valley bottoms created thin, compacted soils. Glacial melting results from a generally warming climate over the last 10-20,000 years. Climate change and the ash depositions have provided for constantly changing forest conditions (Whitlock 1992).

The temperature and moisture characteristics of forests in the dry regions (wet, cold winters and warm, dry summers) are severely limiting to biological decomposition (Olsen, 1963, 1981). These conditions allow accumulation of plant debris which, when combined with frequent lightning from summer thunderstorms (that yield little water), repeatedly sets the stage for wildfire ignition (Habeck and Mutch 1973, Arno 1980). These fires are important! In their absence critical nutrients are tied up in plant debris, and sites can become nutrient limited (Harvey 1994). Thus, such forests depend on a combination of biological (primarily microbes and insects) and fire decomposition to regulate carbon accumulation, nutrient availability and cycling (Harvey et al. 1979, Harvey 1994).

Such circumstances provide for constantly changing, often resource limited environments. Vegetation, and other forest occupants, often are near environmental limits. Many forests exist in transition, reflecting their constantly changing circumstances. Plant assemblages can be considered young, having poorly developed interdependencies (Whitlock 1992). These truly dynamic forests can be expected to respond to change and also to have an innate capability for change. The evolutionary origins of the forest demanded change as a prerequisite to survival.

In contrast, coastal forests are well buffered from environmental extremes, and have highly developed plant assemblages and interdependencies. They have much lower indigenous mortality than inland forests.

Forest Health Concepts

Applying the concept of "health," in an ecosystem context, to such differing forests demands incorporation of time-space variability and commonality of historical environment. We can describe a healthy forest as one having the following characteristics: 1) largely complex and sustainable through multiple cycles; 2) ever-changing; 3) "pest" activities variable (but not extreme) across time and space; 4) moderately productive or recovering on a historically appropriate timeline; and 5) basically similar to its most common historical condition.

Presence or absence of direct human involvement need not be considered, although we can recognize that even indirect human modifications of environment for natural systems may or may not provide for these requirements. The same can be said for a host of nonhuman disturbances as well. However, human ecology cannot be ignored as an integral part of forest sustainability and health over the long term. Direct interactions between humans and other ecosystem components include predation, competition and symbiosis (Grizzle 1994). Accepting the constraints of people pressure, future direct interactions may, or may not, retain a substantial element of choice.

Forest Decline

There is a heightened interest in forest health issues throughout the world. This interest is driven by a growing recognition of problems resulting from increasing pollution, soil acidification, drought, pest epidemics and potential climate change (Innes 1993). Such problems are usually referred to as forest declines. Often causal factors are complex (Schutt and Cowling 1985). In some cases concerns have been alleviated with the discovery that changes were caused by natural stand dynamics (Loehle 1988). Predictions in the early 1980s that central European forests would shortly collapse as a result of "decline," have not materialized. However, many forests in the world are experiencing extensive problems (Innes 1993).

Natural Roles for Native Insects and Pathogens

Since historical environments were diverse and constantly changing, vegetation experienced frequent stress. Biological decomposition was constrained, but recycling of nutrients was assured by fire (Olsen 1981). Fire-resistant species dominated sites that burned often.

Most native "pests" are stress sensitive, i.e., they tend to attack unthrifty or stressed individuals (Stoszek 1988, Waring 1987). This probably generates the highest mortality in the poorest adjusted vegetation, an obvious benefit (Harvey et al. 1992). With fungal pathogens and at least some insects, it also probably accelerates decomposition, another obvious benefit (Martin 1988, Haak and Byler 1993, Harvey 1994). Localized centers of insect and disease activities likely create diversity in forest structure and species composition, another benefit (van der Kamp 1991).

All of these help to stabilize and diversify long-lived (100-400 years) tree communities that occupied potentially resource limited sites having climates that varied over days to thousands of years. Insects and pathogens were integral to the development and function of these ecosystems (Martin 1988, Burdon 1991, Jarosz et al. 1991, Harvey et al. 1992, 1993b).

Introduced Organisms

In white pine (*Pinus monticola* Dougl.) and sugar pine (*Pinus lambertiana* Dougl.) country, our most productive and manageable forests, introduction of white pine blister rust (*Cronartium ribicola* J.C. Fisch.) early in this century created a major disruption of the systems. This pathogen is reducing representation of its pine hosts in many forest communities to less than half of what they were even 40 years ago (Monnig and Byler 1992, O'Laughlin 1993). Other introductions, worldwide, also have caused extensive disruptions of ecosystems (Burdon 1991). Such introductions create major problems for native vegetation (Jarosz et al. 1991). The operational rules for the system change. The ecosystem and its components also must change, or a new system must develop. Recovery may take extended periods of time, depending on the degree of disruption. During recovery, productivity and stability are likely to decrease.

Current Conditions in Western Interior Forests

A widely publicized health problem in dry western interior forests is typified

by conditions in eastern Oregon and Washington, especially the Blue Mountains of Oregon (Gast et al. 1991, Wickman 1992). A less widely publicized problem exists in moist, highly productive forests typical of northeastern Washington, northern Idaho and western Montana (Monnig and Byler 1992). Because of the importance of these problems, compared with others, they will be examined in depth. Causes are complex, different, and connected to environmental conditions as well as to various pest biologies. Changes in the species composition of Idaho's forests over the last 35 years are indicative of fundamental changes to the ecosystems. These alterations are quite different from those that would be expected if driven by historical trends.

Emphasizing these specific situations does not mean they are the only problems (see Hessburg 1993, Gast et al. 1991, Monnig and Byler 1992); nor are all affected ecosystems in a state of collapse (see Harvey et al. 1992, 1993a, Harvey 1994). Many ecosystems meet the criteria for health. All are behaving in a largely predictable manner. Problematic ecosystems are adjusting to circumstances directly or indirectly imposed as a result of relatively recent history.

Warm, Dry Forests

The most prominent aspect of dry forests characterizing the Northwest is the importance of regulating competition for resources, especially water, and of preventing excess carbon (C) buildup in the form of accumulating organic residue and high standing wood volumes, live or dead. The danger to forests from this accumulated fuel is not wildfire as such (Habeck and Mutch 1973). Rather, it is wildfire having fuel accumulations so high that fires are extremely hot by historical standards. The result is high reductions of critical organic matter storage, and an accompanying reduction in productivity potential (Harvey et al. 1993a).

The effectiveness of fire control in western forests in recent years has permitted high fuel accumulations, to the point where many fires are no longer containable. Fires now burn hotter and more extensively when compared with fires even 20 years ago (Brown 1983, Baker 1992, Auclair 1994). The potential for fire control to impact forests that historically burned every 15-25 years is very high compared to potential impact in long fire cycle forests.

The Boise Basin is typical of short fire cycle conditions. It historically supported low density forests dominated by ponderosa pine (*Pinus ponderosa* Laws). Starting in 1911, however, fire control began extending the fire cycle, thus causing large increases in stand density and a shift from ponderosa pine to shade tolerant, more pest susceptible Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) in habitats that would support this species. Accompanying these changes is a greatly increased mortality rate. This increase has created a situation where both the Boise and Payette National forests are now dying faster than they are growing (O'Laughlin 1993). These conditions also are considered typical of many forests in eastern Oregon and Washington (Hessburg et al. 1993).

According to the description of forest health, such forests appear quite unhealthy, with or without widespread pest activities. Many native pests are now highly active (Harvey et al. 1992, 1993a, Hessburg et al. 1993) because of high stress levels from resource competition and because succession has proceeded to the point where more insect and pathogen susceptible true firs and Douglas-fir are occupying sites from which they were historically excluded (Harvey 1994, Wickman, 1993). The rules have changed!

Although some dry forest ecosystems remain in relatively good shape, most are plagued by the effects of wildfire suppression. Without some form of intervention or change we can expect this situation to get worse (Sampson et al. 1994).

Warm, Moist Forests

In contrast, the moist forests of the Pacific Northwest incorporate a substantial role for biological decomposition and a reduced role for frequent wildfire (Harvey 1994, Edmonds 1991). The most prominent factor regulating forest health is reduction of white pine stocking in interior forests, a direct result of mortality caused by introduction of the white pine blister rust fungus early in the century. The striking increases in density and volume accompanying species composition changes of dry forests are not evident in moist forests. The long fire cycle (400 vs. 15 yrs), the substantial role for biological decomposition and the high carrying capacity of productive forests maintain a more balanced condition than in dry forests. As a result, insect and pathogen activities tend to initiate much lower rates of background mortality under balanced environmental and vegetative conditions.

Many low rust hazard forests, interior forests, or forests with a limited historical component of western white pine, remain in relatively good health. The exception is where recent disturbances have created conditions conducive to increased problems with root diseases (Baker 1988, McDonald 1991, Monning and Byler 1992).

In the high rust hazard forests, western white pine no longer dominates seral forests as in the past. They are now dominated by Douglas-fir, grand fir (*Abies grandis* [Dougl.] Lindl.), white fir (*Abies concolor* [Gord. & Glend.] Lindl), and western hemlock (*Tsuga heterophylla* [Raf.] Sarg.). The most prominent problem now in white pine impoverished stands is the effect of various root rots (Monnig and Byler 1992). In this case, the effects of white pine blister rust are no longer highly visible, although rust remains the principal cause of the problem. Most of the host base already has been lost. The replacement species, particularly Douglas-fir and grand fir, are far more susceptible to native root diseases than the white pine that should be dominating these sites (Monnig and Byler 1992, Harvey et al. 1992).

Although there is a large increase in numbers of living trees, concomitant fire management and damage problems are not as evident here as they are in dry forests. However, there is a residual fire-related problem. Fuel accumulation from large, dead white pine can be substantial and mortality of Douglas-fir and grand fir is a continuing process. In addition, the conversion from tall, well spaced white pines to shorter, denser stands of firs creates fuel ladders from accumulated surface fuel, to low foliage and upwards into the crowns of current stands. The potential for wildfires quite different in behavior from those in preceding history also is a characteristic of moist forests. As fire control becomes more difficult, the potential for wildfire to place ecosystem components at risk is higher than historically common. Both specific disease organisms and fire ecology are root causes for health problems in moist forests.

Cool Forests

White pine blister rust also is causing extensive mortality in high altitude, cool forests throughout the western interior (Hoff and Hagle 1990, Keane and Arno 1993). Additionally, the rust appears to have the potential to move into southwestern white pine forests where it has, thus far, not been a great problem. Mortality rates are rapidly increasing in white bark (*Pinus albicaulis* Engelm.) and limber pine (*Pinus flexilis* James) dominated forests throughout much of the northern Rocky Mountains. There will be an accompanying conversion to subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.) and Engelmann spruce (*Picea engelmanii* Parry). An increase in problems associated with the more pest susceptible, dominant species can be expected. The outcome in these forests, with respect to forest health issues, remains to be seen. Accumulating fuel will be a prominent part of the change. As in western white pine dominated ecosystems, a specific pathogen is the primary agent of change. But the fire ecology of the system and susceptibility of the replacement species to other insects and pathogens will figure in the eventual outcome.

Transition Forests

The current condition of transition forests (warm dry to warm moist) is potentially complicated by all the factors affecting either. The shorter the historical fire cycle (dry) the more likelihood for fuel accumulation accompanying interruption of the historical fire cycle and for subsequent fire control-related problems. The more white pines in the composition mix, the more potential for problems associated with white pine blister rust and white pine replacement processes. Since biological decomposition plays a more varied role in transition forests, depending on temperature and moisture, variations in stand history can cause extreme variations in fuel accumulations. Similarly, short term climatic events, such as drought, have varying effects on ecosystem stress, depending on current tree density and historical moisture regimes.

Management Approaches

Overall, management direction for regulating forest health processes in historically fire dominated (dry) and seral white pine dominated forests seems relatively clear. The former requires emphasizing fuel and density management (Oliver et al. 1994, Sampson et al. 1994), along with species composition control. The latter requires aggressive management of white pines (Hagel et al. 1989, McDonald et al. 1991, Monnig and Byler 1992) to return them to relative dominance in seral forests. Current activity of individual insects and pathogens, soil conditions and other factors may have important impacts on site by site diagnosis and management (Harvey et al. 1993, Hessburg et al. 1993).

Management of transition forests will be complex. Their varied nature and complex ecology require even more careful analyses than for dry or moist forests. Roles for insects, pathogens and other microbes are recognized as important, but may not be well understood (Wickman 1992, Harvey et al. 1992, 1993b, Haak and Byler 1993, Harvey 1994). Ordinating Northwestern ecosystems by habitat type groupings that reflect productivity, fire, insect and pathogen behavior has been proposed by McDonald (1991). Since all these processes are interlinked, such an approach appears to have considerable potential, both for site specific and more general ecosystem analyses. Such analyses will be critical to guiding complex ecosystems toward predictable, desirable future conditions.

Conclusions

Forest health conditions throughout dry regions of the Northwest have deteriorated significantly. The principal causes relate to fuel accumulation, increasing stand density and changes in species composition. All are primarily related to the effects of fire control since early in the century. Intervention in the form of countering these conditions, through a variety of prescribed fire and harvesting activities, is critical to preventing continued deterioration. Management of individual pests is a secondary issue in these forests.

Forest health conditions in moist, white pine dominated country-recently including many high altitude and some southwestern forests-have also deteriorated as a result of white pine blister rust, introduced early in this century. Aggressive management of the pathogen is the critical issue in this case. Management of stand conditions and other damaging agents, other than establishing a greater role for white pine, are secondary issues.

Management of transitional forests will require some management of both tree and stand parameters, plus careful consideration of pest problems on a site by site basis.

For the most part, management of coastal forests, except where ecosystems have been damaged by an extreme disturbance, requires dealing with low level damages that accumulate as the forests age, a natural, if sometimes problematic recycling process. As in dry forests, this is more a stand condition management problem than one of managing specific causal agents. In contrast to dry forests, most coastal forests remain in relatively good health.

Alan E. Harvey is a Research Forester with the USDA Forest Service, Intermountain Research Station in Moscow, Idaho.

Chapter Two

Environmental Concerns of Pesticide Use in the Forest Environment

Evan P. Gallagher and David L. Eaton

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Environmental Concerns of Pesticide Use in the Forest Environment

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Introduction

Prior to World War II, chemical control of insect and plant pests was accomplished by using a relatively small number of inorganic pesticides. However, with the development of DDT as an insecticide in the 1940s, there was a dramatic expansion in the development and use of a wide variety of synthetic organic pesticides. DDT was not only very effective in killing a wide range of insect pests and was relatively easy to manufacture, it also exhibited very persistent properties that allowed it to remain active for years. Such success lead to the development of other structurally similar organochlorine chemicals such as aldrin, chlordane, heptachlor, and dieldrin, which shared the persistent properties of DDT. While the long residual life of these chemicals was a major factor in their effectiveness against pests, it also contributed to their toxic effects on fish and wildlife. Ultimately, the banning of DDT and other commonly used organochlorine pesticides led to increased use of other, more acutely toxic, synthetic compounds that also would be effective in pest control, but were much less persistent in the environment.

Research led to the development of different types of organic compounds such as organophosphates and carbamates. Organophosphate pesticides currently used in forest applications are much less persistent in the environment than the early organochlorines. In fact, broad spectrum organophosphates and carbamates were the foundation of insect control chemicals in the 1980s. More recently, new chemical groups of pesticides and herbicides-such as pyrethroids and plant growth regulators-as well as biological controls, have been developed for agricultural and forest use. These chemicals may ultimately prove to be more selective in regards to their toxicity to pests and, therefore, more compatible with the environment.

Pesticide Use in the Forest Environment

When compared with use in agriculture, the use of chemicals in the forest environment is relatively low. Most of these applications involve herbicides and are administered in conjunction with federal programs. Presented in Table 1 are some of the most commonly used chemicals in the forest environment. These include herbicides, insecticides, and fungicides. Although at first glance the list appears to be relatively long, the majority of forest use is accounted for by relatively few compounds. For example, 2,4-D and picloram, either alone or in combination, accounted for 70% of forest herbicide use in the Northwest during the fiscal year 1980.

Behavior of Pesticides in the Forest Environment

As soon as a pesticide is applied in the forest environment it is affected by a variety of processes. Sometimes these processes are advantageous and enhance the effect of the pesticide. For example, a root-adsorbed herbicide may leach through the top layers of soil into the root zone, where it can enhance weed control. However, processes such as drift or runoff can carry a chemical away from its primary target, causing contamination of nearby soil and water. Chemical transport through these processes may increase the chance of damage to beneficial plants and insects and also may threaten human health.

To a great extent, the physical properties of chemicals (i.e., vapor pressure, melting point, etc.) will determine the behavior of a chemical in the forest environment. While it is not necessary to know the physical properties of all forest chemicals, pesticides do vary greatly with respect to their chemical properties. While some pesticides are simple inorganic compounds, many pesticides used in the forest environment are complex organic molecules that may vary greatly with respect to their environmental behavior. In general terms, two broad types of processes determine environmental behavior of a pesticide: those which involve the transport of a chemical or influence the movement of a chemical in the environment, and those which contribute to the stability and persistence of a chemical. Important chemical and physical transport processes include adsorption, absorption, runoff, leaching, volatilization and spray drift, whereas the primary processes that affect the environmental persistence of a chemical include microbial degradation, chemical degradation and photodegradation. Physicochemical characteristics, such as water solubility, can affect both the fate and persistence of a pesticide in the forest environment. The following is a brief discussion of these chemical properties and also of environmental processes that contribute to the environmental behavior and hazard of pesticides.

Processes that affect pesticide transport in forest environments

Adsorption and Absorption

Adsorption is an important pesticide transport process that occurs in forest soils and has implications for the persistence and leaching of pesticides in the forest environment. Adsorption is an equilibrium phenomenon, i.e., some of the chemical remains in solution while some of the chemical remains bound to soil particles. These amounts remain essentially the same, hence the chemical remains in equilibrium between the two phases. The degree to which a pesticide adsorbs to soil particles depends upon the chemical properties of the pesticide as well as soil type, pH and soil moisture content. For example, many pesticides tend to adsorb more to soils high in organic matter or clay content, than to sandy soils, which are low in organic matter or clay content. The increased adsorptive capacity of soils high in organic matter or clay content is a direct result of their high surface area, which provides for an increased number of pesticide binding sites.

Know the adsorptive nature of the soil of your treatment area, since adsorption influences processes that contribute to the environmental fate of pesticides. For example, pesticides that greatly adsorb to soil particles are less likely to be available for degradation by microorganisms or are less likely to volatilize into the atmosphere. In addition, pesticides that are highly adsorbed by forest soils may be less available for absorption by plants. As a result, using certain pesticides on highly adsorptive soils may require higher rates of application to be effective. Unfortunately, adsorpted chemicals can be transported on eroding soil or sediment.

Absorption by plants and microorganisms also can affect the environmental fate of a chemical. Absorption refers to the uptake of the chemical by the plant or microorganism. Once the chemical has been absorbed, it is usually degraded to nontoxic products or residues. These residues may persist in the plants or be released back into the environment as the plant dies and the tissues decay. Because absorption can occur in nontarget plants as well as unwanted vegetation, carefully avoid damaging sensitive species or contaminating food crops with pesticide residues.

Water solubility

Pesticides have a wide range of water solubilities. For example, the water solubility of DDTis 1.2×10^{-4} mg/L (parts per million) whereas the water solubility of 2,4-D is 8.9×10^{2} mg/L. In other words, 2,4-D is almost a million times more water soluble than DDT. Pesticides such as DDT and other organochlorines, which are relatively insoluble in water, can be very detrimental if allowed to contaminate surface waters such as streams or ponds. These compounds tend to partition into body fat and accumulate in the tissues of fish and wildlife, potentially allowing for exposure over a relatively long period of time. Pesticides that are water insoluble also tend to bind to organic matter and bottom sediments and may be moved with soil during erosion and sediment transport to water where they are picked up by bottom organisms. They are then eaten by larger organisms. The DDT is stored in body fat and thus it begins to accumulate in the food chain, whereas highly water soluble chemicals tend to disperse and become widely distributed in surface waters. Such highly water soluble chemicals do not tend to bind to organic matter or sediments, and are generally less persistent than pesticides of relatively low water solubility.

Volatilization and Spray drift

Volatilization (also termed vapor drift) is an important process for the removal of certain pesticides from a treated area. Volatilization occurs when a solid or liquid turns into a gas and evaporates into the air. While this route of environmental transport of pesticides is often overlooked, it can contribute greatly to the dispersion of a chemical away from the site of application. Once in the gaseous state a chemical can be easily carried away by air currents. Not only does volatilization reduce the effectiveness of pesticide treatment, but it also increases the likelihood that nontarget plants or animals may be affected.

The rate of chemical volatilization into the atmosphere generally increases with increasing air temperature and movement. Volatilization also tends to occur more readily when pesticide spray droplets are small. Thus, pesticide applicators, to some extent, can control the extent of volatilization simply by controlling the size of the droplet. Volatilization also increases with decreasing relative humidity, and with increasing temperature of the surface of the target being sprayed. Pesticides that exhibit high vapor pressures will volatilize more readily than chemicals with lower vapor pressures. Accordingly, the tendency for a pesticide to volatilize can be determined from its vapor pressure rating on the label (pesticides usually carry precautionary statements on the labels that indicate their potential for volatilization). In general, avoid using volatile pesticides when environmental conditions favor volatilization (i.e., warm temperatures, low humidity, coarse textured soils).

Spray drift is the movement of airborne pesticides away from the intended target or spray area. Spray drift commonly results from the type of equipment used and the weather conditions at the time of spraying. While high winds can contribute to the downwind drifting of pesticides, temperature inversions (when the temperature of the air near the ground is cooler than the temperature of the air above it), can carry small spray droplets suspended in the air over particularly long distances. Small droplets are most likely to drift away from the intended spray area while big droplets tend to fall faster and move much less laterally. Smaller spray droplets are produced in the greatest amounts when using high pressures and spray nozzles with small diameter spray openings. The potential for spray drift also increases as the distance between the applicator and intended target increases. Thus, applicators can effectively minimize the amount of spray drift by selecting the correct nozzle type, using a low enough spray pressure that produces the largest droplet that will adequately cover an area, and by making applications as close as possible to the target area being sprayed.

Runoff

Runoff occurs when the amount of liquid (water or chemical) applied is more than enough to wet a plant surface. The excess liquid runs off to the ground. Typically, runoff occurs on sloped areas by carrying pesticides that are either dissolved in the water or bound to soil, debris, or surface particles. Four key factors may influence the extent of pesticide runoff, including:

1) physical characteristics of the soil,
2) slope of the targeted spray area,
3) extent and timing of rainfall, and
4) physical properties of the pesticide.

Soil structure and texture can markedly influence the extent of pesticide runoff. For example, applications to water-saturated soils that are high in clay content may be particularly susceptible to runoff. Pesticides that do not tend to bind to soil particles also are more susceptible to runoff than those that adsorb tightly to soil particles. Herbicide runoff from sloped wooded areas can be a significant source of contamination to forest streams or lakes, and can kill nontarget land and aquatic plant species. Since pesticide runoff is greatest when heavy rainfall occurs after an application, pay careful attention to weather conditions before application.

Processes that affect the stability and persistence of pesticides in forest environments

The chemical structure of a pesticide determines how long the chemical will persist in the forest environment. Typically, pesticides range from very stable compounds that can persist for many years, to compounds that break down within a few hours after application. For example, if allowed to contaminate ponds or streams, malathion and carbaryl may break down in the water to nontoxic metabolites within a few hours. In contrast, organochlorine compounds such as DDT and dieldrin may persist for years under the same conditions. Persistent pesticides tend to pose a greater long term threat to the environment than do nonpersistent pesticides since fish and wildlife can be exposed long after application.

In addition to the physical and chemical characteristics of pesticides, three main environmental degradation processes determine the persistence of pesticides. These include microbial degradation, chemical degradation and photodegradation. Microbial degradation occurs when microorganisms such as bacteria and fungi actually use the pesticide as a food substrate. Under conditions such as warm soil temperature, proper pH, adequate soil moisture and oxygen content, the rate of microbial degradation can be rapid. Interestingly, the rate of microbial degradation in some soils can be so high that pesticides may require higher rates of application to compensate for pesticide loss. Since adsorbed pesticides are less available to microorganisms, the rate of microbial degradation also may be influenced by the extent of soil adsorption that a chemical undergoes.

As opposed to microbial degradation, chemical degradation involves the breakdown of pesticides by environmental conditions that do not involve living organisms. These include the degradation of pesticides by chemical reactions in the soil or water. As in microbial degradation, the products of these chemical reactions are usually nontoxic. Environmental factors such as soil pH and moisture content, as well as soil temperature can affect the chemical breakdown of pesticides in forest soils. In ponds and streams, the pH and organic content of the water and sediments can strongly influence both the rate and extent of chemical degradation.

Photodegradation involves the breakdown of pesticides by sunlight. These sunlight-induced modifications to pesticides can occur in the water, air, or on soil or plant surfaces. Not only can sunlight alter the chemical properties of a pesticide, typically rendering it less toxic, it also can make the chemical further susceptible to degradation by other chemical and microbial processes. As with other degradation processes, pesticides vary greatly with respect to their susceptibility to photodegradation. In addition, for photodegradation to play an important role in the environmental degradation of a pesticide, the chemical has to be accessible to direct sunlight exposure. Thus, the pesticide needs to be on some exposed surface (such as soil or plant) or distributed in the air in the gaseous phase. It follows that a pesticide that readily leaches into soil is not going to be available for photodegradation, whereas compounds that volatilize or evaporate may be susceptible to photodegradation.

Pesticide Leaching and Groundwater Contamination

Leaching occurs as water moves through, as opposed to over, the soil surface. The degree to which a pesticide will leach through soil depends on soil properties (texture, permeability, organic matter content) and the physical characteristics of the pesticide. Other factors, such as rainfall and the method of pesticide application, also can affect the extent of pesticide leaching. Pesticides that adsorb strongly to soil particles are less likely to undergo leaching, whereas highly water soluble pesticides that do not adsorb to soil move readily with water as it seeps through the soil.

When a pesticide moves beyond the target area through processes such as leaching, its effectiveness can be greatly reduced. In addition, groundwater contamination is a major problem associated with the leaching of pesticides away from spray areas. Groundwater, found at some distance below the earth's surface, occurs in aquifers (permeable zones of rock, limestone or gravel that are saturated with water). In general, groundwater moves very slowly through aquifers and is accessed by drilling wells into the aquifer or through natural outlets such as springs or streams. Groundwater is the sole source of drinking water, and is the major source of water for irrigation in many areas of Washington. The extent or ability of a pesticide to contaminate groundwater depends, to a large degree, on processes that govern pesticide fate and transport in the environment. Thus, a pesticide that is highly water soluble, relatively stable, and does not readily adsorb to soil is likely to leach into groundwater. While some processes control whether pesticides leach into groundwater or are degraded prior to reaching groundwater, factors such as the presence of sink holes and depth of the water table also are important. For example, if the water table lies far beneath the soil surface the pesticide has more opportunity to degrade or adsorb soil particles as it travels through the soil zone. Once a pesticide contaminates groundwater, however, there is little light or oxygen available to catalyze breakdown processes. This is why pesticides that have contaminated groundwater can be found years following application, typically at other locations due to groundwater movement.

To minimize groundwater contamination, choose pesticides that have the least potential to undergo leaching. Such chemicals typically exhibit low water solubility, rapid degradation, and high potential for soil adsorption. Study the characteristics of the soils and the hydrology of target spray areas. In other words, be familiar with the water table depth or the presence of any sinkholes that may allow pesticides to leach quickly into groundwater. Such information can be obtained through the local Geological Survey Office or through Natural Resources Conservation Service personnel in your region.

Target and Nontarget Organisms

Although pesticides are important in controlling destructive pests, they also can harm plants and wildlife that are not destructive in the forest environment. Learn to distinguish among target and nontarget species. For example, pesticides are typically applied to streams or ponds to control unwanted pests such as mosquito larvae or algae, which are targets of chemical application. In contrast, nontarget organisms, such as fish or beneficial insects, also may be killed during pesticide application. Because these nontarget organisms often play key ecological roles, their destruction can seriously upset the delicate balances that exist in the forest environment. Ultimately, the ideal situation for pesticide applicators is to destroy the pest species at chemical concentrations that will have the least effect on the surrounding environment. Select the least toxic and least persistent pesticide that will adequately do the job. While it is impossible to prevent some degree of chemical contamination of the environment, minimize nontarget effects by using proper rates and methods of applications, and also by observing the environmental precautions on the pesticide label.

The following is a general overview of some of the nontarget species that chemical application in the forest environment can affect.

Effects of pesticides on beneficial insects and soil microorganisms

Many beneficial insects that inhabit the forest environment are susceptible to pesticide poisoning. Bees and other pollinating insects are necessary for the successful production of many fruit and seed crops. These insects can be poisoned when they come into direct contact with blooming plants that are treated with pesticides. Some of the organophosphate insecticides (e.g., guthion) as well as the carbamate insecticides (e.g., carbaryl) are highly toxic to bees. These compounds can kill bees either directly or through the taking of poisoned nectar, pollen or water into the hive. Malathion is considered to be safer to bees than most of the organophosphorous chemicals, but has been reported to kill large numbers of honey bees when used in high concentrations. In general, insecticidal dusts are more hazardous than sprays, and oil solutions or concentrates are more hazardous than emulsions or suspensions in water.

To minimize the probability of poisoning bees it is important for the pesticide operator to select the pesticide least harmful to bees and to avoid applying pesticides that are toxic to bees during bloom. In addition, evening applications are generally less hazardous to bees than early morning applications, whereas mid-day applications are generally the most hazardous to bees.

A number of other highly beneficial insects also live in forests. Some of the most beneficial insects are predators of pests. Unfortunately, treatment of forests to control target pests also can reduce predatory insects. In one documented case, malathion sprayed in a deciduous forest in Ohio greatly reduced the numbers of insects. Judging by tree band traps, the initial loss of insects was approximately 90% (by weighing the insects that fell in catch cloths). The groups that particularly suffered were moths, flies, wasps and beetles.[1] In another study, fenitrothion applied in two successive sprays in a northwestern Ontario forest greatly reduced the number of predatory insects. In particular, some spider species were half as numerous as prespray, whereas some other predatory insects were reduced by as much as two-thirds. Many of these species were about half as numerous in the sprayed areas as in a control nonsprayed area a year after spraying. Since fenitrothion did not persist in the forest from one year to the next, this effect was probably the result of a persistent disturbance of the forest ecosystem.[2]

Pesticides also can affect the populations of small, soil-living arthropods and microorganisms. In particular, applications of organophosphate and carbamate insecticides may selectively kill certain soil-dwelling arthropods such as springtails and predacious mites. The loss of these soil-living arthropods can substantially affect the breakdown of leaf litter on the forest floor. In extreme cases, the undecomposed plant debris can build up dramatically on the forest floor, and affect the physical nature of the underlying soil. Malathion degrades too fast to affect many soil-living arthropods, whereas carbaryl may be markedly toxic to the forest-floor population of predacious mites. Pesticides also can kill beneficial centipedes and spiders that inhabit the soil or surface litter and are predators of pest insects. Earthworms, which play important ecological roles by oxygenating forest soils, are sensitive to poisoning by certain pesticides. Organophosphorous insecticides generally have little long-term effect on earthworm populations, whereas some of the carbamate insecticides can be quite toxic and can affect earthworm populations over long periods of time.

The best way to limit injury to beneficial forest insects and microorganisms is to minimize the use of pesticides as much as possible, preferably in the context of an integrated pest management program.

Effects of pesticides on plants

While some insecticides may harm plants, herbicides are typically responsible for the destruction of nontarget plant species. Many herbicides used in forest applications are not particularly selective with respect to their intended target pest species. In many cases, nontarget plants are killed as herbicides drift or run off from spray areas. In other situations, plants can be killed by herbicides that are carelessly discarded at mixing or disposal sites. Aerial application of herbicides can substantially disrupt a forest ecosystem, causing reversion back to the initial grass-sedge stage of forest succession in extreme cases. Other secondary effects of large-scale plant loss can include substantial losses of soil and soil nutrients due to increased runoff. Careful selection of time of application, whether preplanting, preemergence, or postemergence (foliar), may help limit the destruction of nontarget plants or shrubs.

Effects of pesticides on fish and other aquatic life

Pesticides enter forest streams and lakes through intentional application, accidental release, aerial drift, or runoff from spray areas. While some pesticides are directly applied to the water to control aquatic weeds, algae, nongame fish and insect pests, the major route of pesticide entry into forest streams and lakes is usually through pesticide runoff. Once these chemicals enter the water, they may either rapidly disperse or become attached to suspended organic material or bottom sediments. They also may be absorbed by fish or other aquatic invertebrates where they can be either detoxified or bioaccumulated. Bioaccumulation is a general term referring to the uptake of chemicals by living organisms. A related concept, bioconcentration, applies to those circumstances where a net increase in chemical residues occurs in living organisms when bioaccumulation and elimination processes are considered together. Finally, the term biomagnification refers to the efficient transfer of certain types of environmental chemicals from food organisms to consumers, such that residue concentrations increase from one trophic level to the next.

Significant atmospheric transport of pesticides into forest surface waters can occur by means other than runoff. Atmospheric transport can occur through a combination of three mechanisms, including aerial drift, volatilization, and wind erosion from treated soils. Even if the distance between the spray nozzle and intended target is short, air-transport of chemicals can significantly contribute to pesticide contamination of forest surface waters. In general, frogs, toads, and their tadpoles are much less sensitive to pesticide poisoning than are fish. However, some organophosphate pesticides, including carbophenothion and azinphos methyl are highly toxic to tadpoles. In contrast, malathion is not particularly toxic to forest amphibians and reptiles. Organophosphate insecticides can be especially toxic to insects and invertebrates that are food for many fish species. Particular environmentally sensitive areas include small ponds or streams that have a low water volume or turnover. Although fish are generally less sensitive to the toxic effects of organophosphate insecticides than are invertebrates, fish kills can result from surface water contamination by these compounds. Salmonid species such as trout are much more sensitive to organophosphate poisoning than ictalurid species such as catfish or bullheads.

In addition to insecticide poisoning, herbicides such as 2,4-D can be toxic to bottom-feeding and open water invertebrates that may serve as a food source for some fish species. When selecting a pesticide to apply in a forest environment containing streams or rivers with sensitive aquatic species, choose pesticides that are safe to these organisms.

Effects of pesticides on wildlife

Certain pesticides can be particularly harmful to wildlife, especially over long-term exposure. Some cyclodiene organochlorine pesticides used for rodent control during the 1960s were particularly toxic to nontarget wild mammals. While reports of wild mammal kills with modern organophosphate insecticides are few, these compounds may affect some rodent populations that feed on contaminated insects. Mexacarbate, a carbamate that has been used in the forest environment, may be quite toxic to deer. In contrast, carbaryl represents a carbamate pesticide considered to be relatively nontoxic to wildlife.[3]

Birds may consume granular formulations of pesticides that are mistaken for food. In other cases birds may ingest contaminated seeds, drink contaminated water, or feed on pesticide-contaminated insects. In addition, birds may be directly exposed to aerially-sprayed pesticides. Although a number of organophosphate and carbamate insecticides are toxic to birds, bird species tend to differ with respect to susceptibilities to insecticide poisoning. Malathion is probably one of the safest organophosphate pesticides for birds, whereas parathion can be quite toxic to mallard ducks and quail. Of the carbamates, carbaryl (Sevin) is generally nontoxic to birds, whereas carbofuran (Furadan) and aldicarb (Temik) can be quite toxic to these species.

Environmental Fate Properties of Selected Forest Chemicals

Herbicides

2,4-D

2,4-D undergoes rapid breakdown on land (one day to several weeks) due primarily to microbial degradation and does not appreciably adsorb to most soils. However, 2,4-D may readily leach into groundwater if used in an area with coarse-grain sandy soils with low organic content. In most areas, soil adsorption and rapid breakdown of 2,4-D will prevent its leaching into groundwater. 2,4-D usually persists in vegetation for less than a few weeks. If released into water, 2,4-D tends to biodegrade according to the characteristics of the particular water body, with slower breakdown occurring in waters that have low dissolved oxygen content. Amine and mineral salts of 2,4-D are very soluble in water and are not readily bioaccumulated by aquatic organisms. However, esters of 2,4-D are usually lower in water solubility and, therefore, may tend to bioaccumulate to a greater degree than other 2,4-D formulations. Typical persistence in water is 20-100 days.

Dicamba

Dicamba is used to control annual broadleaf weeds and cut surfaces such as stumps. The main route of breakdown in the soil is by microbial degradation. Dicamba persistence in soils may range from 4 to >500 days, with the typical half-life being 1 to 4 weeks. Dicamba has a fairly high potential to leach through forest soils and may contaminate groundwater. In most cases dicamba undergoes breakdown in the soil within 1 or 2 months. Significant amounts of dicamba may be released into the atmosphere by aerial spraying, although the compound is not particularly volatile. Dicamba released into ponds or rivers is degraded primarily through microbial degradation, and does not readily bioaccumulate in aquatic life such as fish or clams.

Glyphosate (Roundup)

Once released into the forest environment, glyphosate tends to strongly adsorb on soil and is readily degraded by soil microorganisms. In most forest soils, 90% of the chemical will undergo breakdown within 12 weeks of application. In addition, glyphosate exhibits little tendency to undergo leaching in forest soils. Accordingly, glyphosate has relatively little potential to contaminate groundwater. Once absorbed by plants, glyphosate remains fairly persistent in plant tissues. If released into surface waters, it does not tend to bioaccumulate in aquatic organisms.

Picloram

Picloram is used as an all-season broadcast herbicide, often in mixtures containing 2,4-D. In contrast to 2,4-D, picloram may persist in the soil for several years. However, picloram does not significantly bioaccumulate in nontarget organisms. Picloram does not evaporate from soils or plant surfaces, and it is subject to biodegradation in soils, surface waters, and groundwater. However, its high mobility in soils may result in extensive leaching into groundwater. If allowed to contaminate surface waters, picloram is subject to photodegradation in the near-surface water, and does not tend to adsorb to sediments or bioaccumulate in aquatic organisms.

Insecticides

Bacillus thuringiensis (B.t. or Foray)

Bacillus thuringiensis is a naturally occurring soil bacterium that produces toxins which can kill insects. B.t. is very specific for insect pests and also nontoxic to humans and wildlife. Different strains of B.t. have differing toxicities towards various strains of insect pests. *Bacillus thuringiensis kurstaki*, the most widely used strain in forests, paralyzes the digestive system of certain leaf-eating caterpillars. To be effective, B.t. must be eaten by the larval (immature) stage of insects during development. It is relatively ineffective against adult insects. Since B.t. is formulated to stick to the surfaces of leaves when it dries, apply B.t. under dry weather conditions.

Although B.t. generally breaks down rapidly in the environment, it can persist for several months in soils having a pH greater than 5.1. B.t. is extremely susceptible to photodegradation and will break down rapidly if directly exposed to sunlight. It is not considered a threat to groundwater contamination as it is relatively immobile and breaks down rapidly in most soil types. The bacterium is not toxic to plants and thus far has not been reported as toxic to fish or birds.

Diazinon

Diazinon is a broad spectrum insecticide that can persist in soils for 3-14 weeks after application, usually for 10-12 weeks when used at recommended rates for most soil types. Microbial degradation is a primary process for the breakdown of diazinon in soils, with breakdown occurring within 1 to 12 weeks of application, depending upon soil conditions. In addition, diazinon is susceptible to photodegradation in soils exposed to natural sunlight. Evaporation from soil is not considered a major transport route for diazinon. If diazinon is released into water, it may biodegrade or adsorb to sediments, but will not significantly bioconcentrate in fish or other aquatic organisms.

Malathion

Malathion rapidly undergoes microbial and chemical degradation in forest soils. Typical half-lives of malathion in soil range from 4-6 days. Malathion does not typically leach into groundwater. If malathion is allowed to contaminate surface waters, it may adsorb to sediments. Chemical breakdown in water is an important route for the loss of malathion, whereas volatilization from water is not an important pathway for malathion transport. The importance of chemical and microbial breakdown of malathion in water depends on the pH of the water. Biodegradation becomes a more important route of breakdown in water having pH less than 7.0 (acidic), whereas chemical breakdown readily occurs at pH greater than 7.0 (alkaline). While malathion does not tend to bioaccumulate in freshwater fish, it may bioaccumulate in other aquatic organisms such as shrimp.

Carbaryl (Sevin)

Carbaryl undergoes rapid chemical breakdown in neutral or alkaline soils. In contrast, chemical breakdown of carbaryl is relatively slow in acidic soils. Carbaryl also undergoes rapid microbial degradation in most forest soils. As much as 80% of the chemical usually degrades within 4 weeks of application. Carbaryl does not tend to bind to soil particles and, thus, may readily leach into groundwater. It may readily break down if released into ponds or streams, particularly if the pH of the water is less than 7.0. However, at pH greater than 7.0 (alkaline water), the breakdown of carbaryl occurs primarily through other routes. Typically, carbaryl released into most forest streams or rivers degrades rapidly and does not tend to bioaccumulate in aquatic organisms.

Fungicides

Chlorothalonil

The route of chlorothalonil breakdown in forest soils is primarily through microbial degradation. Chlorothalonil is fairly resistant to other routes of degradation such as chemical breakdown and photodegradation. It is immobile in most soil types, with the exception of sandy soils, where it can move readily. Since chlorothalonil is highly toxic to fish, take care when applying in the vicinity of forest waters. While chlorothalonil itself is not particularly toxic to birds, a 4-hydroxy breakdown product of chlorothalonil may be moderately toxic to certain bird species.

Mancozeb

Mancozeb undergoes rapid breakdown by hydrolysis. However, Mancozeb may be contaminated with ethylenethiourea (ETU), which is resistant to hydrolysis and is also highly toxic to fish. Minimize runoff or drift from spray areas into forest surface waters. ETU has a potential to leach through forest soils and contaminate groundwater.

Conclusions

Several precautions can minimize the environmental damage from pesticide use in the forest.

1. Use pesticides only when necessary.
2. Whenever possible, use integrated pest management programs.
3. Select pesticides carefully and observe the environmental precautions on the label.
4. Select the least toxic and least persistent pesticide that will adequately do the job.
5. Treat only the intended areas and leave a buffer zone of at least 50 feet between any bodies of water and the spray area.
6. Avoid spraying trees that overhang streams or ponds.
7. Consider weather conditions, and also the geology and soil characteristics of your area.
8. During bloom, do not apply pesticides that are toxic to bees.
9. Reduce drift during application.

You can minimize environmental damage if you use pesticides carefully and according to the instructions on the label. In addition, since very strict laws have been enacted to protect wildlife from accidental pesticide poisoning, be aware of any legal restrictions when using pesticides in your area.

Authors Evan P. Gallagher, Ph.D. and David L. Eaton, Ph.D. are with the Department of Environmental Health and Institute for Environmental Studies, University of Washington, Seattle, Washington 98195.

[1] T. J. Peterle and R. H. Giles. 1964. *New Tracer Techniques for Evaluating the Effects of an Insecticide on the Ecology of a Forest Fauna.* Ohio State University. Res. Found. Rep. 1207. 435 pp.

[2] R. Freitag and F. Poulter. 1970. *Effects of Sumithrin and phosphamidon on populations of carabid beetles and a spider.* Can. Entomology 102: 1307-1311.

[3] R.K. Tucker and D. G. Crabtree. 1970. *Handbook of Toxicity of Pesticide to Wildlife.* U.S.D.I. F.W.S. publication No. 84. 131 pp.

Table 2-1. Commonly used Chemicals in the Forest Environment

Pesticide Class	Chemical	Typical Application
Herbicides	2,4-D	Foliar spray to woody plants. Amine formulations are effective on stump, cut surface or injection treatments
	Dichlorprop (2,4-DP)	Mixed brush control in forests and utility rights-of-way
	Dicamba (Banvel)	Limited use in forests. Used as a cut surface, basal, stump, or foliage treatment
	Hexazinone (Velpar)	Foliar applied, preemergence used on broadleaf weeds and grasses. Controls undesirable vegetation primarily through soil uptake.
	Imazapyr (Arsenal)	Used as a foliage, frill, or stump treatment to control brush
	Metsulfuron (Escort)	Foliar spray or soil treatment for brush control
	MSMA	Foliar applied herbicide, commonly used on grasses and broad-leaved weeds, also cut surface or injection treatment
	Picloram (Tordon)	All-season broadcast, frill, or injection treatment to control woody plants
	Tebuthiuron (Spike)	All season broadcast, lacing, or spot treatment to control undesirable broad-leaved or woody vegetation
	Triclopyr (Garlon)	Woody plant control used typically in early summer
	Malathion 50EC	Broad spectrum insecticide and miticide
	Thiodan 50WP or 3EC	Broad spectrum insecticide used typically on firs and pines to control aphids. mites and adelgid
	Carbaryl 50W	Broad spectrum insecticide typically used on conifers and hardwoods
Insecticides	Diazinon	Available in a variety of formulations, extensive use on Christmas trees
Miticides	Orthene	Often used on conifers to control cone and seed insects
	Bacillus thuringiensis (B.t.) (Foray)	Microbial insecticide available as different strains for different pests. *B.t. kurstaki* used typically for gypsy moth control
	Metasystox-R	Applied as a foliar spray on pine and sitka spruce for aphid and mite control
	Cygnon 2E	Broad spectrum insecticide/miticide typically applied to pine and hemlock
	Imidan	Nonsystemic acaracide and insecticide
	Guthion	Broad spectrum insecticide/miticide and molluscicide, typically used as foliar spray
	Dursban	Broad spectrum insecticide
	Kelthane 35WP	Miticide, typically used as a foliar spray
Fungicides	Chlorothalonil (Bravo 500)	Broad spectrum fungicide, broadcast, band and soil surface applications
	Mancozeb	Broad spectrum fungicide with minor insecticide applications, typically applied as a foliar spray
	Carbamate WDG	Used on conifers to control fusiform rust
	Bayleton 25WP	Systemic fungicide used for fusiform rust
Rodenticides	Strychnine	
	Chlorophacinone	
	Diphacinone	

Chapter Three

Forest Vegetation Control

Donald Hanley and David Baumgartner

Appendix 1

Chapter Three

Forest Vegetation Control

Donald Hanley & David Baumgartner

Introduction

Undesirable woody and herbaceous plants create problems in commercial forests. Researchers have developed safe, dependable methods of chemical vegetation control for most forestry needs. Reforestation, in particular, may depend heavily on weed control. Depending on local conditions and weed composition, the results sought differ strikingly in degree of control and composition of residual vegetation, hence in the choice of method.

The objective of vegetation control on commercial forest land is to provide larger and higher-quality harvests and to reduce the length of time required to bring the crop to maturity. Weed control alone cannot produce a harvest, but must be combined with cultural practices involving either seeding or planting, and subsequent practices that bring the crop to maturity. Growing trees is the ultimate objective, not killing brush; brush control is merely a phase of the reforestation procedure.

Classification of Weeds

It is important to recognize grass and broadleaf plants because they differ in reaction to herbicides, cultural aspects, desirability, and method of control. For weed control purposes, plants are divided into three main categories-grass, broadleaf, and woody (Figure 3-1).

Grass

Grass plants have one seed leaf. They generally have narrow, upright, parallel veined leaves and fibrous root systems.

Broadleaf

Broadleaf plants have two seed leaves. They generally have broad, net-veined leaves and tap roots, or coarse root systems.

Woody Plants

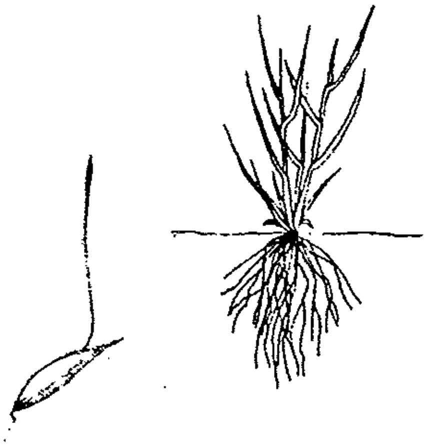
Woody plants include brush, shrubs, and trees. Brush and shrubs are regarded as woody plants that have several stems and are less than 10 feet tall. When trees are present, brush or shrubs may be understory. Trees usually have a single stem (trunk) and are over 10 feet tall.

Growth Habits

Annuals complete their life cycle from seed in less than 1 year. Winter annuals germinate in the fall, overwinter, mature, set seed, and die in the spring or early summer. For best results, control winter annuals in the seedling stage of growth in fall or early spring. Summer annuals germinate in the spring, make growth, set seed, and die before fall. For best results, control summer annuals soon after germination in the seedling stage of growth. Some weeds are specifically winter or summer annuals. Other species are adapted and can germinate and grow either in the fall or spring. Knowing the growth habits of annuals is important in planning how and when to control. Biennials complete their life cycle within 2 years. The first year the plant forms basal leaves (rosette) and a tap root; the second year it flowers, matures, and dies. For best results, control biennial weeds in their first year of growth. Perennials live more than 2 years and may live almost indefinitely. They reproduce by seed and many are able to spread and reproduce

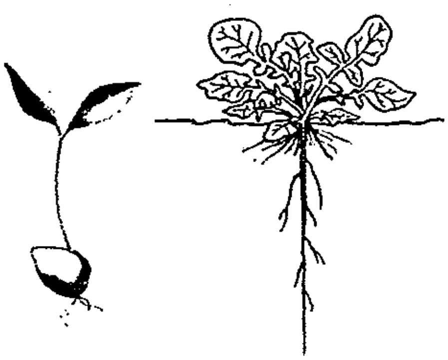
Figure 3-1

Grass



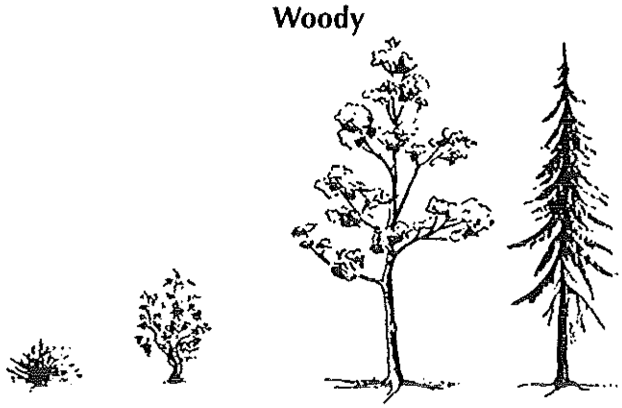
Grass plants have one seed leaf.

Broadleaf



Broadleaf plants have two seed leaves.

Woody



Woody plants include brush, shrubs, and trees.

vegetatively. Perennials are difficult to control due to the persistent root system. Do not let seedling perennials become established. For best results, adapt control of established perennials to the yearly growth cycle of the specific species. Control during the fast growth period prior to flowering or during the regrowth period after fruiting or cutting. Simple perennials spread by seed, crown buds, and cut root segments. Most have large and fleshy tap roots. Creeping perennials spread vegetatively as well as by seed. Grass plants generally have a shallow root system compared with the deep root system of broadleaf plants. Bulbs and tubers reproduce vegetatively from underground bulbs or tubers. Many also produce seed. Brush, shrubs, and trees may spread vegetatively as well as by seed. Woody plants can be controlled at any time of the year (Figure 3-2).

Methods of Weed Control

Biological

Animals, birds, insects and competing plants are used for biological control. Plant competition is the most successful.

Mechanical

Mechanical is the oldest method of weed control. This includes hand-pulling, hoeing, blading, mowing, burning, flooding, cultivation, and other tillage operations. Woody plants may be mowed, chained, bulldozed, or sawed. All these methods are used.

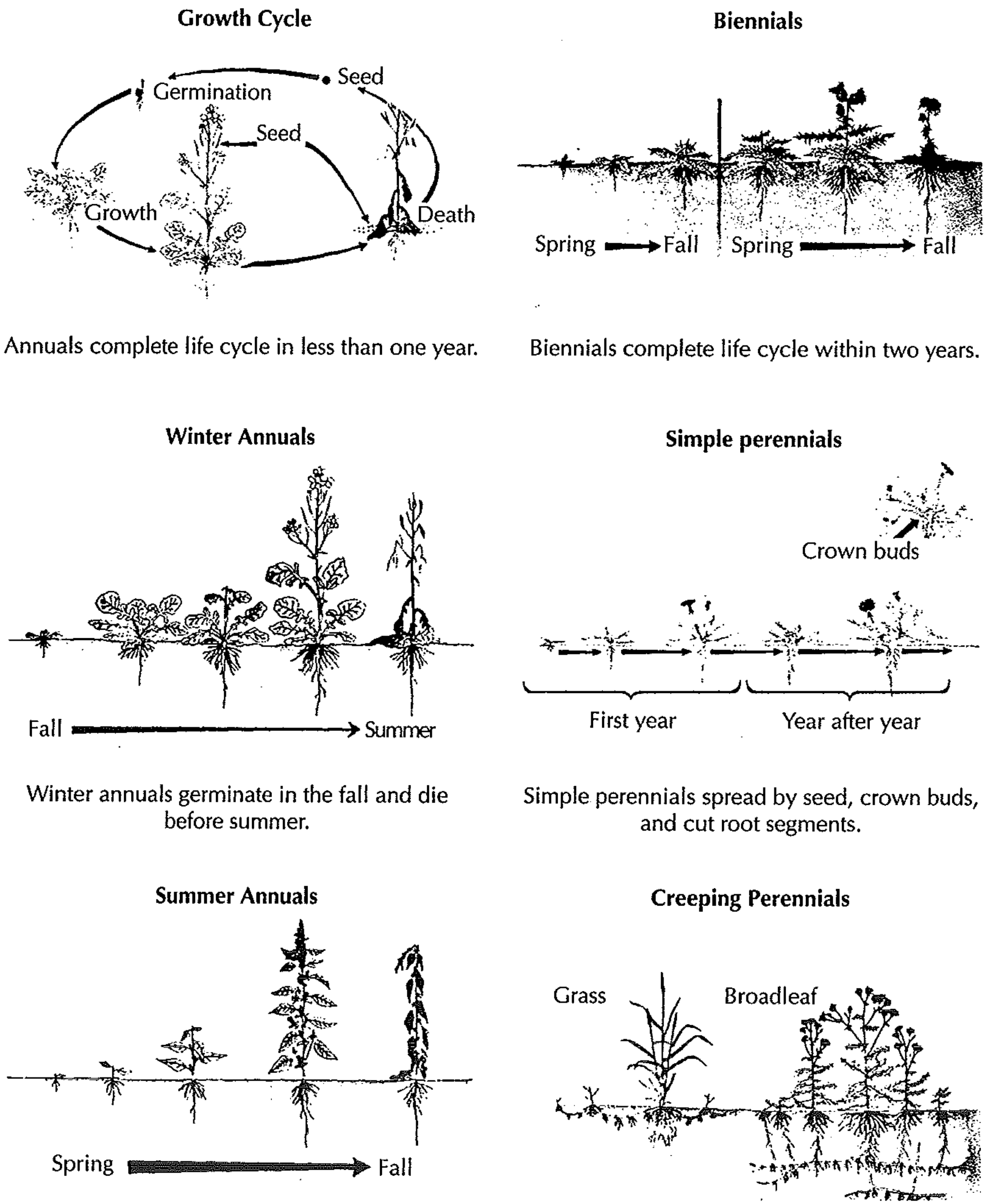
Chemical

Herbicides are chemicals that control by changing normal growth or causing plant death.

Classification and Types of Herbicides

The most satisfactory classification of herbicides is based upon how they are used for weed control and how they work.

Figure 3-2



Annuals complete life cycle in less than one year.

Biennials complete life cycle within two years.

Winter annuals germinate in the fall and die before summer.

Simple perennials spread by seed, crown buds, and cut root segments.

Summer annuals germinate in the spring and die before fall.

Creeping perennials spread vegetatively and by seed.

Classification by Use

Selective herbicide implies that certain weeds are killed but most desirable plants are not significantly injured. **Nonselective** refers to chemicals that are generally toxic to plants without regard to species. Remember, plants differ in susceptibility to any specific chemical and the choice of herbicide and application rate depends on the species to be controlled. Herbicides generally fall into three classes based on activity (Figure 3-3). All may be selective or nonselective.

Classification by Mode of Activity

Contact herbicides—foliage applied—control weeds by direct contact with plant parts. They are referred to as chemical "mowers," as only the plant area contacted is controlled. Good coverage is necessary. **Translocated herbicides—foliage applied**—products move through the entire plant system in both the water stream and the food stream. They accumulate in, and affect the active growth centers. In general, these compounds are selective. Some are effective in the soil and can be taken into the plant through the roots. However, they are most effective when applied to the plant foliage.

Root or emerging shoot-absorbed herbicides—soil applied—are referred to as the residual herbicides. The length of time the soil remains relatively weed-free depends upon the chemical used, amount applied, rainfall, soil type, and the plant species invading the treated area.

Compounds that can be used selectively in some situations may be used nonselectively by increasing the rate of application. Soil residual herbicides generally have little effect upon plants when sprayed on foliage. The main effect occurs when they are absorbed through the shoot or root and move in the water stream of the plant to the leaves.

Herbicide Formulations

Most herbicides, as packaged, do not contain 100% active ingredients. The portion that is not active herbicide is composed of inert chemicals. The ways the various forms are marketed follow.

Dry Formulations

Wettable powders (WP)
Water dispersible granules or dry flowables (WDG-DF)
Water soluble powders (SP)
Granules (G)

Liquid Formulations

Water soluble concentrate (WS). Like a water soluble powder, this forms a true solution in water, requiring little agitation.

Emulsifiable concentrate (EC). The active ingredient is not soluble in water but is dissolved in a solvent along with emulsifiers. This mixture forms a milky looking emulsion in water and requires moderate agitation.

Liquid suspension (L). This is equivalent to a concentrated suspension of a wettable powder. Fine particles are suspended in a liquid concentrate which disperses readily in the spray tank. Constant agitation of the spray mix is required.

Special Formulations

Oil Solubles
Invert emulsions

Factors Affecting Efficient Chemical Weed Control

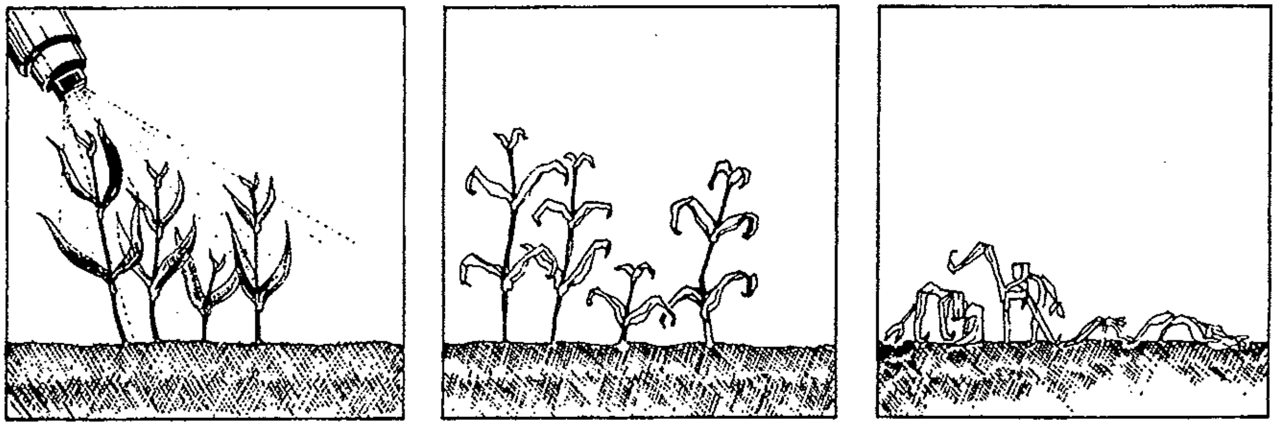
Stages of Growth

Weeds go through four stages of growth: seedling, vegetative, flowering, and maturity. There is a best stage for weed control. If control is not obtained at the best stage of growth, the method of control may need to be changed.

Seedling. The seedling stage of growth is the same for annual, biennial, and perennial weeds. They are all starting from seed. The weeds are

Figure 3-3

Contact herbicides halt visible plant growth, at least for a short time

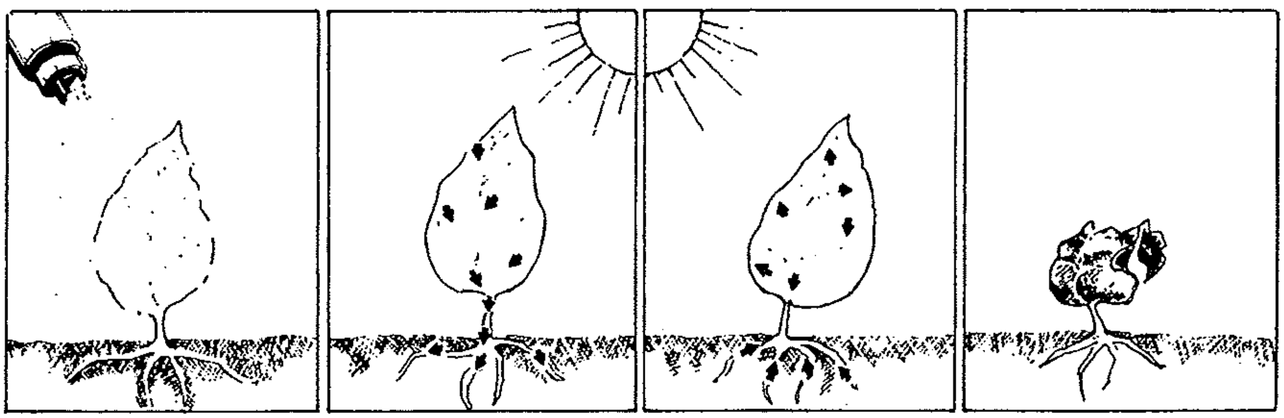


Spraying of visible plant foliage initiates action of contact herbicide. Use spray wand or boom.

Herbicide enters plant leaves where it affects growth processes. Plant curls, withers, turns brown.

Visible weed growth is stopped. Many weeds won't reappear. Others may as some seeds, roots escape.

How a foliage translocated herbicide works

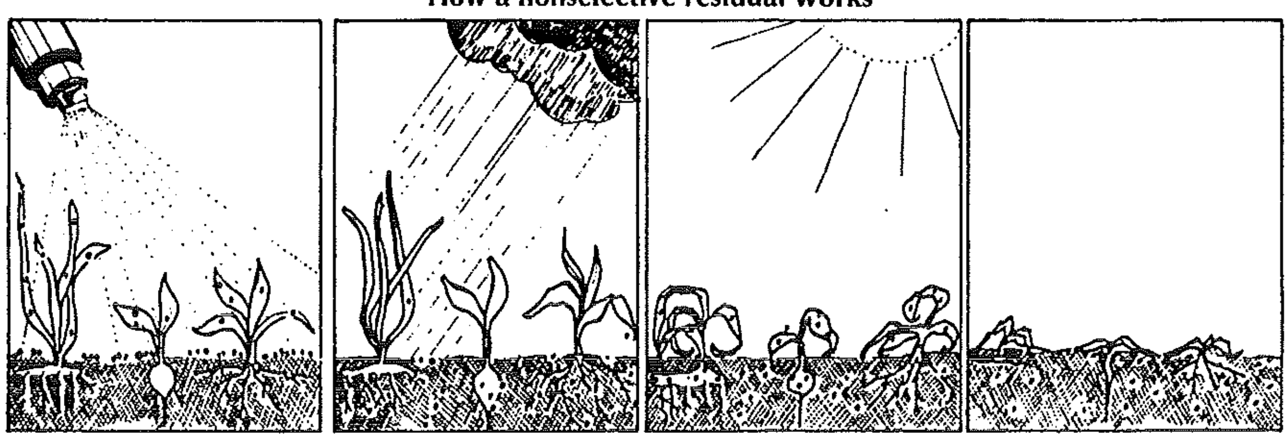


Spray growing vegetation for complete coverage.

Chemical translocated down to roots, growing points and throughout entire plant system.

Susceptible plant then slowly withers and dies.

How a nonselective residual works



Apply to soil and young plants in early spring.

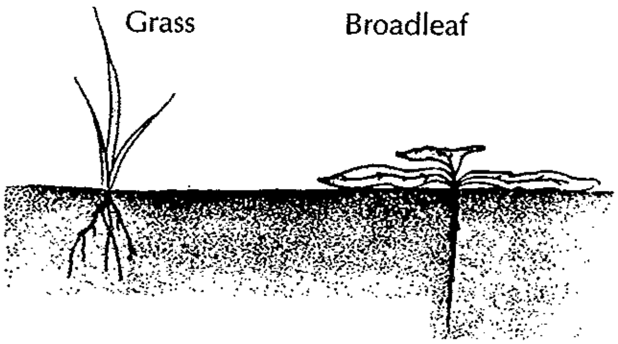
Rain washes herbicide into soil where it is available for absorption by shoots or root systems.

Herbicide is translocated to growing points; plant yellows and gradually dies.

Plants die and ground is bare for a year or so.

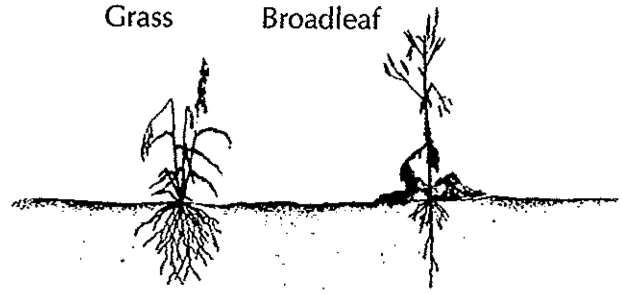
Figure 3-4

Seedling (All)



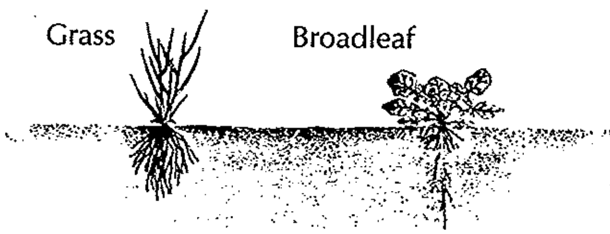
Control easiest at seedling stage.

Maturity (Annuals)



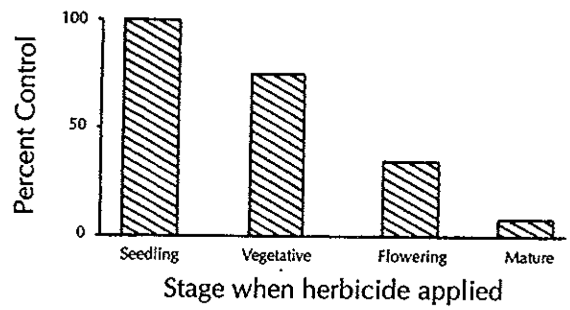
No herbicide control at maturity.

Vegetative (Annuals)



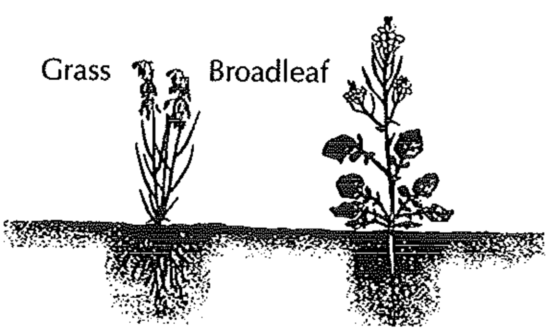
Vegetative-stage control dificult.

Weed Control (Annuals)



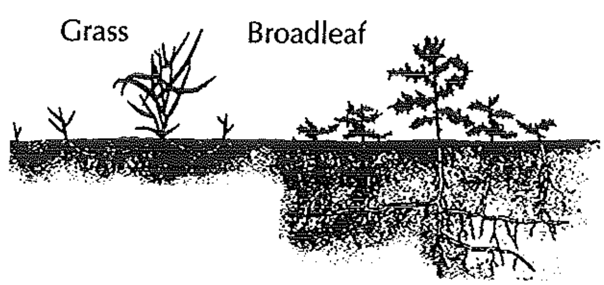
Seedling is best stage for control.

Flowering (Annuals)



Chemical control here not feasible.

Vegetative (Perennials)



Mediocre control at this stage.

small and succulent; therefore, less energy is required for control at this stage of growth than any other. This is true whether the energy be mechanical, chemical, or management.

Vegetative (annuals). The vegetative stage of growth occurs when the energy being produced by the plant is going into the production of stems, leaves, and roots. Control at this stage is still feasible but more difficult than at the seedling stage of growth.

Vegetative (perennials). Part of the energy used in the production of stems and leaves for the vegetative stage of growth is derived from energy stored in the underground roots and stems. Other energy comes from production in the plant leaves. Chemical control is mediocre at this stage of growth.

Flowering (annuals). At a certain stage of growth and time of year, a chemical messenger formed by the plant tells it to change from the vegetative to the flowering stage of growth. At this time most of the weed's energy goes into the production of seed. Chemical control at this stage, for both grass and broadleaf, is not feasible because eliminating these older plants requires much more energy.

Flowering (perennials). Again, as with the annuals, a messenger is manufactured by the plant at a certain time and stage of growth. The plant's energy then goes into the production of flowers and seeds. Food storage in the roots is initiated and continues through maturity. Chemical control is effective just prior to flowering (bud stage).

Maturity (annuals). Maturity and seed set of annuals completes the life cycle. Chemical control is not effective at this stage.

Biennials. Biennials, in 2 years, go through the same stages as annuals.

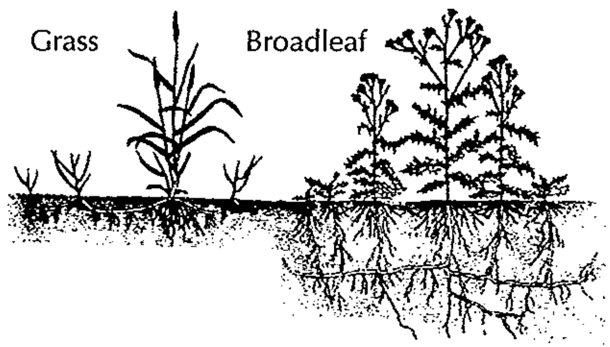
Seedling (perennials). The seedling stage of growth and its control is the same as for annuals and biennials. However, the stages of growth from vegetative through maturity are different.

Maturity (perennials). For these plants only the aboveground portions die each year. The underground roots and stems remain alive through the winter months and send up new plant growth the following spring. Chemical control is not feasible at this stage.

Figures 3-4 and 3-5 show the expected weed control of annuals and perennials from an

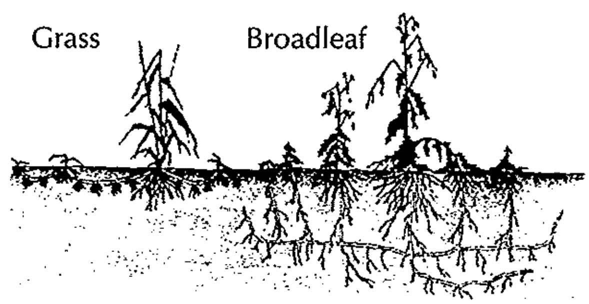
Figure 3-5

Flowering (Perennials)



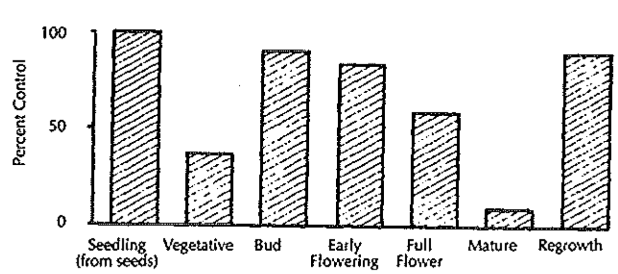
Chemical control is effective prior to flowering stage.

Maturity (Perennials)



Chemical control is not feasible at this stage.

Weed Control (Perennials)



Good control of perennials is at bud or regrowth stage.

herbicide application. Note that almost 100% weed control is obtained when the herbicide is applied at the seedling stage of growth. When applied at other vegetative stages, control drops. Little control is obtained when the herbicide is applied at the mature stage.

Factors Affecting Foliage Application

Location of growing points

Growing points and regrowth of weeds are plant factors.

Grass. A seedling has its growing point below the soil surface. Control is more difficult when the growing point is protected in this manner. Neither herbicide nor cultivation may reach the growing point and the plant regenerates. Creeping perennial grasses have protected buds below the soil surface.

Broadleaf. Growing points and regrowth of broadleaf plants are different from those of grass plants. Seedling broadleaf weeds, in contrast to grass weeds, have an exposed growing point at the top of the young plant. They also have growing points in the leaf axils. Herbicides can reach these points more readily and cultivation will control the plant easily. The perennial broadleaf plant is difficult to control because of the many buds on the creeping roots and stems.

Woody. Many woody plants, either cut or uncut, will sprout from the base or roots (Figure 3-6).

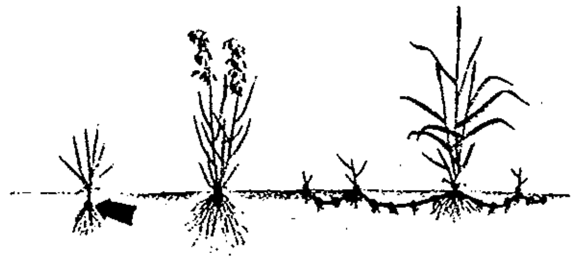
Herbicide entrance into the weed

Leaf shape and surface are factors in herbicide retention and penetration.

Leaf shape. Differential foliar wetting affects herbicide selectivity. Plants with narrow vertical leaves; the herbicide spray solution tends to bounce or run off. In contrast, the broadleaf plants with the flat, wide leaves, tend to retain the spray solution. Retention of spray solution is important.

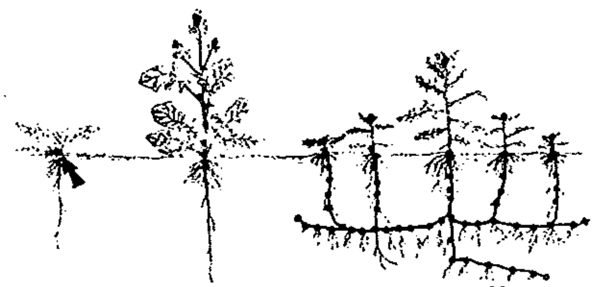
Figure 3-6

Grass



Protected growing points make control difficult.

Broadleaf



Growing points of broadleaf.

Woody

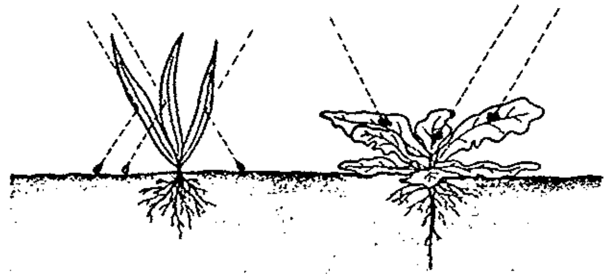
Woody plants may sprout from the base or roots.

Leaf surface (wax and cuticle). It is important for the chemical to penetrate the weed surface. Thickness of wax and cuticle are factors partially governing entrance of an herbicide into a leaf. Wax and cuticle are less thick on young weeds. Best results are obtained by treating with herbicides at the early growth stage.

Leaf surface (hairs). Other factors that tend to keep herbicide droplets from entering the leaf are surface hairs. Some weeds are hairless, others have many and varied hairs. Hairs are generally fewer and shorter on seedling weeds compared with the older stages of growth. This is another reason for early control (Figure 3-7).

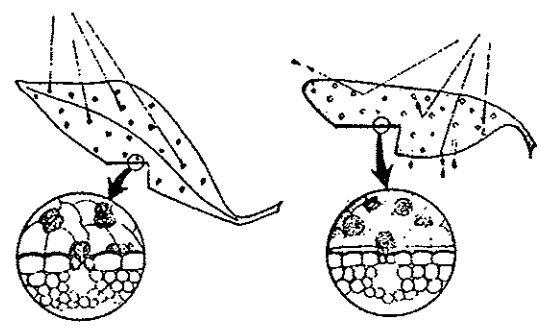
Figure 3-7

Leaf Shape



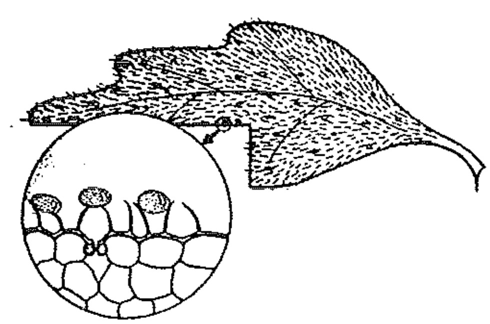
Leaf shape affects spray solution retention.

Surface thickness



Surface thickness and wax affect spray solution contact.

Hair



Leaf surface hair may cause poor spray droplet contact.

Soil Applied Factors

Herbicide characteristics and soil particle tie-up

Herbicides have different properties. One of the properties is magnetism. These chemicals vary, having from no to strong magnetism. Those without a magnetic charge tend to leach through the soil profile more readily. Others, with magnetic charges, tend to tie-up on the negative charge sites of soil particles. Another property is **solubility** in water or the soil solution. Herbicides vary from insoluble to soluble. Solubility is somewhat related to movement in the soil.

Leaching is related to herbicide characteristics and soil factors. Herbicides and soils vary from nonleachable to completely leachable.

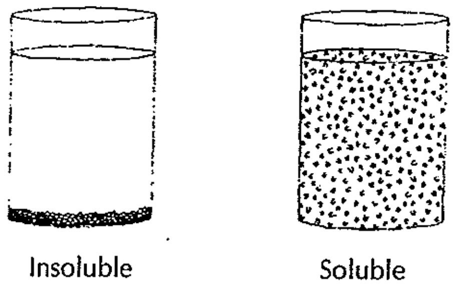
Persistence. Persistence of an herbicide in the soil is governed mainly by the chemical's properties, rate of application, precipitation, temperature, and the soil's properties (Figure 3-8).

Soil type

Some herbicides are applied to the foliage of weeds. Other herbicides are soil-active and are applied to the soil surface. Soil type and herbicide movement are important considerations. Two important factors in herbicide movement in the soil are the texture of the soil (sand, silt, and clay), and organic matter.

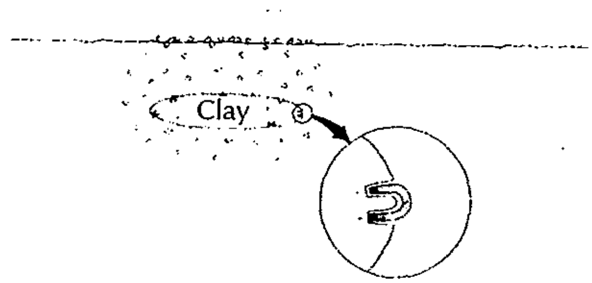
Figure 3-8

Solubility



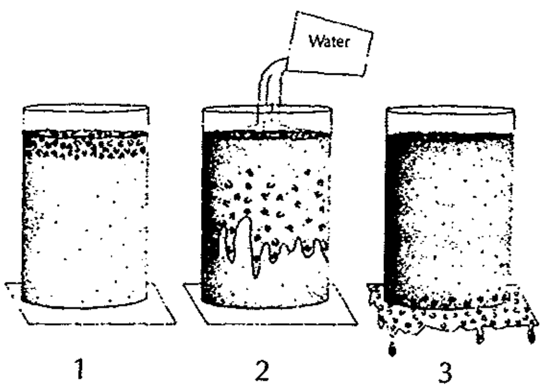
Herbicides vary from soluble to insoluble.

Texture



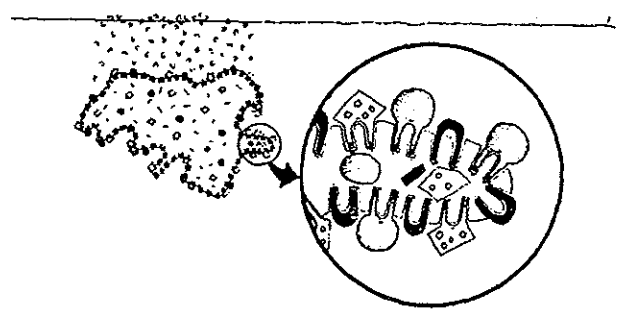
Soil texture affects movement of herbicide.

Leaching



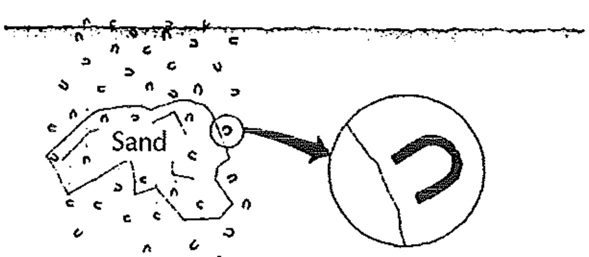
Soils and herbicides vary from leachable to nonleachable.

Organic Matter

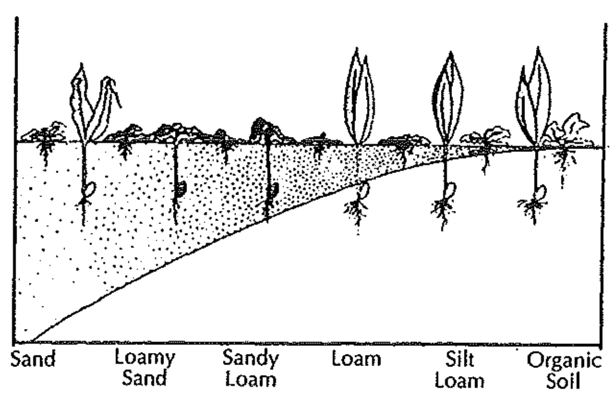


Organic matter ties up many of the plus-charged particles.

Texture



Chemical particles move past smooth sand surface.



Effectiveness of chemicals varies with type of soil.

Texture

Sand is coarse and does not have many charge sites. The illustration shows a magnified sand particle in the soil. The magnet-shaped particles are herbicide molecules moving down through the soil profile. The magnified circle shows the herbicide particle moving on past the smooth sand surface, deeper into the soil profile. It does not tie up.

Silt is intermediate in charge sites. It has more sites than sand but fewer than clay and organic matter.

Clay is fine and has many charge sites. The illustration shows a magnified clay particle. Again, the herbicide molecules are moving through the soil profile. In the magnified circle, note that the plus-charged herbicide particle has fit into the negatively charged slots on the clay particle. Thus, it is tied up, like a magnet, and will not continue moving through the soil profile.

Organic matter

Organic matter has many, many times more negative charge sites to tie up plus-charged particles; many moving through the soil profile are tied up by both organic matter and clay. Note in the magnified circle different types of particles on the organic matter. These particles include water, herbicides, sodium, calcium, ammonia.

Remember, sandy soils have few charge sites to tie up herbicide molecules, and they tend to move on through the soil profile. Soils with clay and organic matter tend to tie up and hold herbicides and other charged particles.

Salt content of soils, increased by snow and ice control, increases activity of soil residual herbicides. In soils with high salt content, lower rates may give acceptable control.

Climatic Factors

Temperature

As temperature increases, the effect of this herbicide activity speeds up. Weed control results are the same, regardless of temperature. It is merely the number of days taken to see the full effect.

Humidity. Approaching 100% humidity, a foliar-applied herbicide will enter the leaf more easily and rapidly than at low humidity where penetration is slow. At high humidity, the weed leaf is more succulent, has less wax layer and a thinner cuticle.

Precipitation. Rainfall is an important factor in right-of-way weed control. Precipitation, occurring after a foliar-applied herbicide treatment, may decrease effectiveness. Rain will activate soil-applied herbicides. But it also can move the herbicide through or from the target area.

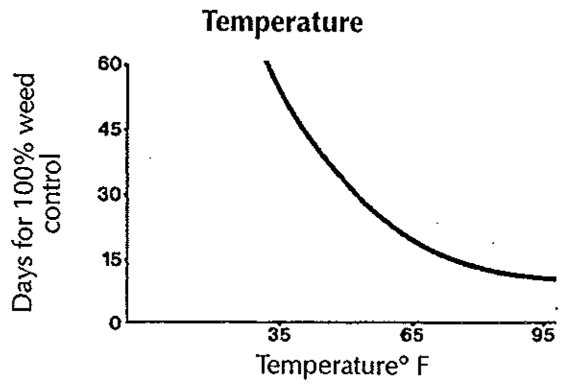
Wind and temperature. Wind can cause spray drift as well as move dust-laden herbicide particles. Wind and temperature also can affect the weed. A hot, dry wind will cause plant stomata to close, leaf surface to thicken, and wax layer to harden. These factors make foliar herbicide penetration more difficult (Figure 3-9).

Nonchemical Methods

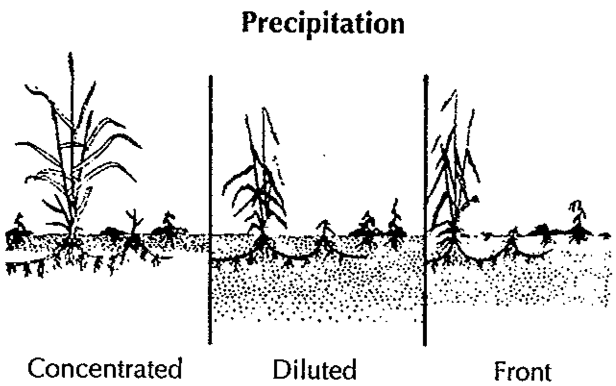
Grazing

Grazing intensively can in some circumstances remove palatable herbs and many brush species. Take great care when grazing among conifers to keep animals out of plantations when trees are actively growing. Grazing is among the most difficult methods of control because weed removal must be relatively complete to provide significant benefits.This degree of control is difficult to achieve without the animals causing great damage to the trees. However, intensive pasturing of a cutover hardwood stand for the 2 years immediately after logging will remove many of the sprouting brush species and may help simplify the weeding job to herb removal only. However, herbs may recover too quickly for this procedure to do the whole job of site preparation. The need to reduce cover to very low levels will mean that the livestock will not gain weight well in programs such as this. If they are not grazed to this intensity, some supplemental weeding will be necessary, either with paper mulch or chemicals.

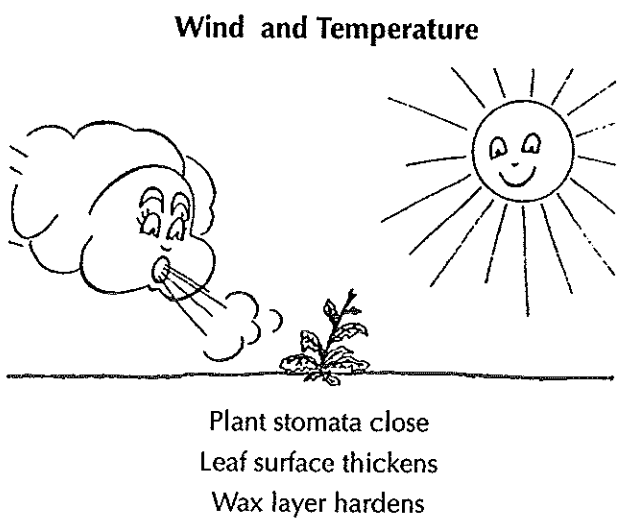
Figure 3-9



Higher temperatures mean fewer days for results.



Rainfall may change herbicide effectiveness.



Hot, dry wind increases weed resistance to chemical.

Paper mulch

Paper mulch has been used with success comparable to grass herbicides. In southwestern Oregon and near the Willamette Valley, use a minimum of 3 square feet of paper mulch. On coastal areas and in western Washington, 2 square feet should be adequate. For mulch paper use fiber-reinforced laminated craft with asphalt core for adequate durability. Weight the mulch paper adequately on all four corners, or pin it to the ground. Clear plastic will not work. Black plastic will work, but is difficult to handle.

Nonchemical control methods have less effect on most serious forest weeds than herbicides do. Sprouting is difficult to control without repeated cutting. Evidence to date clearly points to the need to kill root systems to minimize competition. For growers whose goal is vigorous tree growth and minimum impact on soil and labor force, no alternatives to herbicides have been proven as safe or as effective.

Herbicides Used in Forest Environments

Virtually all brush and weed tree control on forest lands is done with 2,4-D, glyphosate (Roundup), imazapyr (Arsenal), picloram (Tordon), triclopyr (Garlon), sulfometuron (Oust), and MSMA, as dormant or foliage sprays, ground applications, injections, or cut surface applications. Atrazine and hexazinone (Velpar) are used for herbaceous weed control in plantations. These materials, singly or in combination, give broad-spectrum activity on forest species. The 2,4-D-type compounds are relatively noninjurious to Douglas-fir seedlings during the dormant season, but may injure ponderosa pine and noble fir. Picloram and dicamba (Banvel) are nearly always harmful when applied directly to conifers and should be used for site preparation only. Satisfactory reforestation brush control can be achieved with the proper formulation of these compounds applied at the proper season and with the right carrier. Soil-active herbicides are seldom suited for selective brush control in this region because of their tendency to injure conifers, but are useful for site preparation. Glyphosate is highly effective only on deciduous and herbaceous species. In fall it will selectively remove brush and herbs from conifers. In mid-summer glyphosate will damage conifers severely. Imazapyr is active on maple, alder, and other brush as a growth inhibitor. Imazapyr is especially adapted for trunk injection or spot treatments. Triclopyr is registered for site preparation and release. Either triclopyr formulation, (amine or ester) may be applied to cut surfaces. Note restrictions on the label when grazing treated areas. Triclopyr is highly injurious to two- and three-needle pines.

Hazards

The broadcast application of pesticides has received considerable attention in recent years in connection with the danger to animals and other forms of life. The known toxicity of the common brush killing compounds used on forest lands is rather low, as indicated in the section on manual properties of herbicides.

The pesticide applicator must consider numerous factors. Treatment of a forest often entails applying chemicals over large areas. It is sometimes difficult to delineate precisely which areas are being treated, and which areas, such as riparian areas, must be free of drift. The applicator must avoid unnecessary exposure to chemicals. Consult neighboring landowners before conducting a major spray job and take precautions to avoid trespass. The benefits from judicious and well-planned herbicide use can be enormous. Do not jeopardize them through poor public relations.

Application Methods

Selecting methods for applying herbicides in a brush control situation depends upon the species composition, proximity of crops, degree of control required, and available equipment. Method and season of application also influence degree of selectivity. In general, brush in which most stems are less than 2 inches in diameter, and grassy weed problems that cannot be reached with farm equipment, are best treated by aircraft. Spot brush control is best suited for hand or tractor-mounted ground rigs. Weed trees over 1.5 to 2 inches in diameter and conifers to be thinned are most economically treated by injection. Some of the other methods are useful in special circumstances, but the above usually give the best results per dollar. A description of the commonly used methods follows, with special emphasis on objectives, formulations, and equipment peculiar to each.

Note: Use the following application comments as general guidelines only. Consult the pesticide label for specific rates of application and techniques.

Foliage Application

Foliage spraying is an extensively used practice that, to some extent, lacks selectivity for conifers. Nonstocked brush fields that are to be converted to conifer stands are best suited to foliage spraying. Species such as vine maple may not be satisfactorily controlled by this method. Manzanita, ceanothus, and other persistent-leaved brush species lend themselves to satisfactory control with foliage treatments at any season from late dormancy until late mid-summer. The choice of season for these species is determined, within broader limits, by the availability of spray equipment and the presence or absence of susceptible crop trees. Alder and salmonberry are especially sensitive to foliage sprays, but timing is critical. Wait until foliage is at least at the two- to three-leaf stage for good control. Check product labels carefully because the optimum time of application will vary. For example, the preferred time for treating salmonberry and thimbleberry with glyphosate is in the fall. Spraying rapidly elongating stems will result in excessive sprouting, except in very sensitive species. The optimum season is usually mid-summer in terms of target species control, but that is when many conifers are most sensitive.

Chemical

2,4-D, dichlorprop, triclopyr, imazapyr, glyphosate, metsulfuron (Escort), dicamba, and picloram are the herbicides used for foliage applications. For rates of application refer to the product labels. 2,4-D, triclopyr ester, and glyphosate are by far the most helpful herbicides of this group. The others are used largely where these fall short. Picloram +2,4-D gives excellent control of mixed brush species. Picloram and dicamba are highly toxic to most conifers when applied directly, but seedlings planted 6 or more months after treatment are normally unaffected. Water is almost always used as a carrier; in late summer a small amount of diesel fuel (up to 5%) may be added to ester product mixtures.

Application

The choice of whether to spray foliage from the air or with ground equipment depends on the size of the job and the equipment available. For most small spray jobs, small equipment is the most satisfactory. Recent developments have shown that a backpack sprayer with adjustable cone nozzles can apply sprays at 5 to 20 gal/A quite uniformly when the applicator can move freely. This "waving wand" technique is much faster than the "spray-to-wet" procedure and much less wasteful of chemical. Aerial application involves 5 to 10 gal/A. While the ground equipment lends itself very well to small jobs, the labor requirement is excessive on jobs of more than 40 acres, and aerial application is preferred. On large jobs, aerial spraying becomes a much less expensive way to apply herbicides. The low dosages and volumes applied by aircraft may not produce quite as complete results as a soaking ground spray, but should prove adequate for most forestry purposes with much less herbicide waste.

Dormant Application

Applications are made during the season when buds are beginning to swell, but have not actually opened. Use dormant sprays where Douglas-fir or true firs are established and require release from brush that is susceptible at this season. In all cases, except where the brush species retain green foliage during the winter months, oil is the herbicide carrier. Emulsions may be as effective on the persistent-leaved brush. Pines are sensitive to dormant sprays after the end of January.

Chemical

Phenoxy herbicides and triclopyr ester are applied in low volumes by helicopter. Other types of ground apparatus are not well adapted to the requirements of this type of treatment. No substitutes are known for oil on deciduous brush. Water is appropriate on evergreen brush, but adding surfactant or 5% oil may improve results. You can treat most species in summer, except for vine maple. Vine maple is most sensitive to triclopyr during March and April. Glyphosate is also effective on vine maple in September, and may offer an effective substitute for the dormant spray. Imazapyr is especially effective on maple sprout clumps as a directed spray at low volumes.

Basal Application

Use this method of application where selective treatment of plants is desirable. It is also a means of extending spraying time for brush control, since basal applications are effective from February to November. When using basal treatments, mix the spray with oil and apply it to the lower 15 inches of a tree trunk or brush stem, soaking the trunk liberally to the ground line. Basal treatments usually control even larger hardwood trees with thick bark effectively.

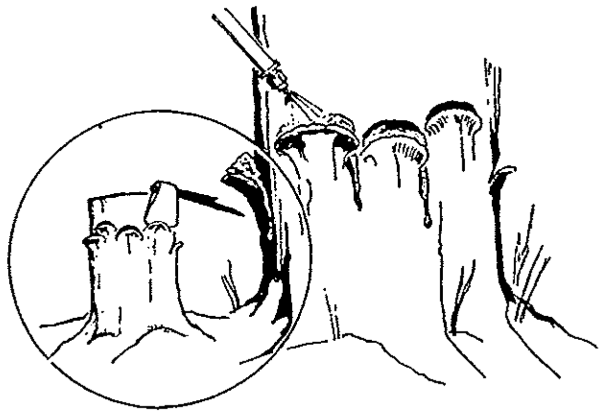
Chemical

You may use the low volatile ester form of 2,4-D, dichlorprop, triclopyr, and dicamba, singly or in combination, for basal spraying. Triclopyr is generally used when mixed brush species are involved; dicamba is excellent where residues will not harm conifers. Dichlorprop shows some utility for basal treatment of maples.

Application

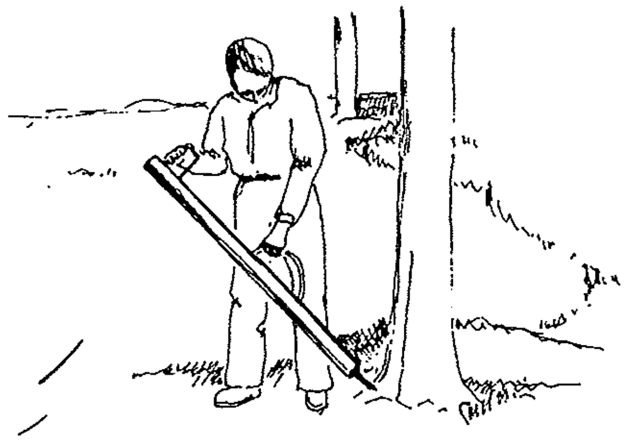
Herbicides for basal sprays are commonly applied with oil as a carrier, using either diesel or stove oil. Triclopyr, often with 2,4-D added, is the most commonly used herbicide. Use rates of 4 to 20 lb active ingredient of the herbicide (1 to 5 gallon of Garlon 4) to each 100 gal of oil. For successful results with basal sprays, soak and thoroughly cover the stems throughout the treatment area. The results from basal treatments do not become immediately apparent. Often the

Figure 3-10



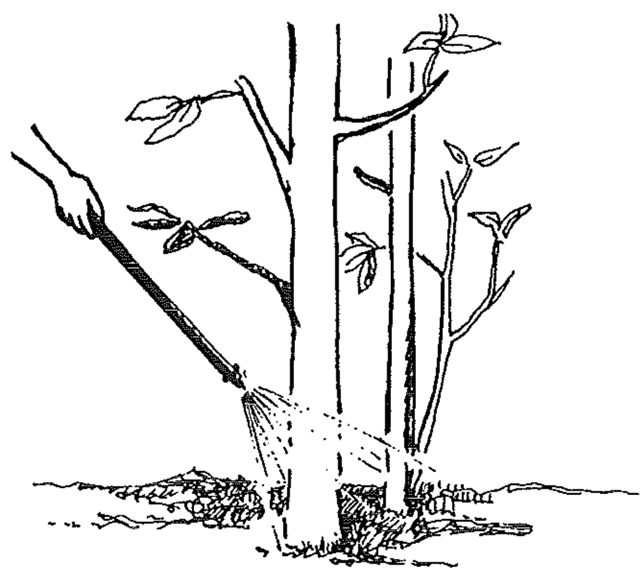
For best results apply through frills or notches.

Treat close-cut stumps with basal spray mixture.



Chemical application made through basal injection.

Pellet herbicides are used in treating base of plants.



In basal spraying herbicides are applied to stems and crowns.

tree will leaf out and die back 1 or 2 years before finally dying. Spring applications may produce best top kill, while summer and fall sprays may give better sprout control. Winter treatments may require a higher volume of spray with a higher concentration of chemical (Figure 3-10).

Modified Basal Application

This method combines the foliage and basal methods of application. It is quite effective on blackberries.

Chemical

Choose the same chemical mixtures that are effective in basal application.

Application

The spray mixture is 6 lb of the acid equivalent of the hormone chemicals in 10 to 15 gal of diesel oil, plus enough water to make 100 gal of total spray. For hard-to-kill brush, use straight oil carrier. Proper application requires careful wetting of the stem at the base, and at least 0.67 to 0.8 of the foliage of the plant. Apply during the growing season. High volumes of oil and chemical may prove excessively odorous for settled areas.

Cut Surface Application

In the frill treatment, hack or frill the trunk of the tree at intervals around the trunk at a convenient level. Cut through the bark, but leave the chips connected to the tree. Treat the cut frill any time during the year, but treat the cut section with the concentrated amine-formulated herbicide immediately after the frill is completed. Few species require complete frilling. Spaced axe cuts with one milliliter [ml] of herbicide per cut are usually adequate. Certain herbicides, including 2,4-D amine, act most effectively during the upward phase of sap movement, and others, including MSMA and dicamba, are best when sap is "moving down" in the fall. Season also affects root reserves of food for recovery. Two methods are effective for treating stumps. One method is essentially the same as for basal treatment. The only difference is that you remove the top and treat the stump to prevent regrowth and resprouting. Research with bigleaf maple and Oregon white oak indicates that best results require thoroughly soaking the stump around the ground line and cut surface with a basal spray solution at any time after cutting, but preferably before regrowth of sprouts. Far less costly is the application of undiluted herbicide to the perimeter of the freshly-cut stump surface. A teaspoonful is adequate for almost any stump when uniformly distributed around the perimeter of the live wood in a thin line. Stumps thus treated may sprout weakly in the second year if treated during the growing season or fall. Spring stump treatment has not been as successful. A delay between cutting and treatment of even an hour may reduce effectiveness unless esters are used.

Chemical

2,4-D amines, triclopyr amine, Imazapyr, picloram, dicamba, or MSMA, used singly or in combination, are most effective and easiest to apply for the frill and girdle method. Esters will not work as well except when applied to stumps cut 1 to 30 days before treatment. Most chemicals are used undiluted. Triclopyr may be diluted to half-strength with water for hardwoods other than maples. Triclopyr is very effective on many species. Imazapyr may be diluted also and will still be effective on most species. Glyphosate may be used at half to full strength.

Application

See *Chemical Control for Woody Plants, Stumps, and Trees,* S. Howard and R. Parker, WSU EB1551.

Special Considerations

Brush is not the only problem to anticipate in areas scheduled for reforestation. Brush is fine habitat for animals that feed on tree seedlings. Moreover, heavy stands of brush, dead or alive, provide substantial shade that weakens young trees and considerable debris capable of falling and crushing small planted seedlings. An ordinary effort to establish trees in such circumstances will surely result in failure.

Trees used for reforestation in the brush need to be substantially larger than those used for Christmas trees and old field plantings. They should also be repellent-treated, or, preferably, of a species unpalatable to animals. Finally, the seedlings should be able to persist in shade. Douglas-fir is attractive to animals and cannot tolerate heavy shade. Douglas-fir seedlings should be a minimum of 24 inches tall for such areas. Thirty inches is preferable. Normal 2- or 3-year-old nursery seedlings are inadequate because of susceptibility to animal damage and inability to stand up under litterfall.

Also suited to chemical site preparation are grand fir for areas that receive less than 60 inches of rainfall, and western hemlock for the moister areas. Both species are quite unattractive to animals even without repellents, and are capable of tolerating a substantial degree of reencroachment by brush. Seedlings 10 to 24 inches are adequate in size. Markets are improving rapidly for timber of these species, and they may well prove economically more attractive than Douglas-fir, for which planting success may be uncertain in brush. Both are inhibited by heavy competition and are not substitutes for weed control.

Experience is showing that two applications of herbicide or even more may be necessary for full establishment of plantations. Schedule applications so that most species are controlled immediately before planting. After planting, a maintenance spray is a good means of prolonging relief from brush with a minimum of damage to conifers. The spring dormant sprays are damaging to some pines, however, and release of these should be done during late summer. In general, the pines are poor bets in brushfields, and this will seldom be a consideration. Do not postpone release until trees are under the brush.

Special Registration for Forestry

Herbicide labels carry specific recommendations for a particular use. Forests are not included under noncrop labeling according to recent interpretation of labeling laws. Herbicide dealers and distributors are required under the Federal Pesticide Control Act of 1972 to ensure that their products are properly labeled and sold only for purposes described.

General Use Formulations

Some herbicides are registered for general woody species control for such areas as pastures, fence lines, and ditch banks. Some are nonselective in conifers, such as the dicamba (Banvel), imazapyr (Arsenal), and picloram (Tordon) formulations; others are nonselective only at certain times, such as glyphosate (Roundup), 2,4-D brushkiller, and other phenoxy formulations. These materials may be useful for site preparation or stand cleanup. Many of these products have been used traditionally on forest lands, but prospective users are warned to verify current label status and interpretation before proceeding.

Grass Control for Plantation or Christmas Tree Establishment

The practice of planting coniferous trees on fields supporting heavy stands of grass is usually beset by difficulty with plantation survival. A moderately dense stand of grass in an open field can remove virtually all available moisture in the surface foot (12") by the end of June. Removing a heavy stand of grass will make available to the seedlings much of the water that would be lost to transpiration by the grass. Use tillage to remove grass if mechanized equipment can operate on the terrain. If you decide to use herbicides, you will gain an added advantage. A single herbicide treatment gives complete weed control the first season, and may give partial weed control during subsequent seasons.

Chemicals

The most effective chemicals for grass removal have been the triazines-simazine, atrazine, and hexazinone (Velpar). The triazine-type chemicals provide relatively good weed control for an extended period at rates of 3 to 5 lb per acre of the 80% atrazine or simazine, and 1 to 2 lb of hexazinone. Atrazine alone or in combination with 2,4-D has produced the most consistently good results. Hexazinone is selective on many conifers and produces excellent control of some atrazine-resistant weeds. Glyphosate also will provide complete and selective control of many resistant weeds. At present, you can apply mixtures according to the rates of individual components registered for use in forestry. Some products are registered for preplanting application only. Sulfometuron (Oust) is used on plantations 1 to 4 years old to control grasses, forbs, ferns, and brambles.

Note: Use the following application comments as general guidelines only. Consult the pesticide label for specific rates of application and techniques.

Application Methods

The method of application should provide even coverage of herbicide for uniform weed control in the vicinity of planted seedlings. Tractor-mounted sprayers equipped to spray a strip of herbicide down the plantation row have provided some success. When following this practice, spray a wide enough strip on each side of the planted row so that lateral roots do not draw down moisture supply too rapidly. In most situations, a strip at least 4 feet wide should improve habitat for seedlings. The treatment of spots up to 3 feet in diameter generally has not proven very satisfactory. The most effective method of weed control for plantation establishment is broadcast application. While the initial cost may be somewhat greater in terms of money spent on chemicals, the net result in terms of cost per established tree should be somewhat lower with this method. Treatment costs for most herbicide applications represent a relatively small proportion of the total plantation establishment costs. The greater the number of seedlings that can be established on a treated site, the smaller the unit cost per established seedling; hence the advantages are greatest for broadcast treatments in high-density plantings. Hand application equipment or aircraft will be the only type of equipment suitable for application on rough terrain. It is estimated that 15% more chemical is needed for aerial treatments than when ground rigs are used, to compensate for evaporation of fine droplets and loss of dust. Helicopters are the preferred aerial application equipment. They should be equipped for large droplet sizes and minimum drift potential.

Planting Techniques

In any plantation, but particularly on difficult sites, select the choicest quality planting stock of large, vigorous seedlings. Machine planting and hand planting both have their advantages. The benefits to be derived from machine planting probably are more striking when coupled with the use of herbicides. It is even possible than an ingenious operator can rig spray application equipment right on the planting machine so that the whole job is accomplished in one operation. The removal of all grass in the vicinity of the planted trees exposes the soil to direct rays of the sun, resulting in surface temperatures high enough to cause extensive mortality in young Douglas-fir and true fir seedlings. On many south and southwest exposures and on flat land in valley bottoms, the soil surface temperature may be responsible for just as much mortality as drought damage. In cases where heat damage may occur, protect the seedling from direct contact with the hot soil at the ground surface. This may be done by placing protective materials immediately around the root collar, or by using stakes, shingles, or similar types of materials, which will shade the seedlings at the ground line. Ponderosa and lodgepole pine seedlings are more heat tolerant than other commonly used forest species. Large seedlings of any species are more heat-resistant than small trees, but give seedlings tender care to capitalize on weed control.

Table 3-1
Effectiveness of Major Forestry-Registered Herbicides During Seasons of Optimum Usage*

Species	Atrazine	Glyphosate (Roundup)	Picloram (Tordon)	2, 4-D
Conifers				
Pines	R	I-R	I-S	S-I
Douglas-fir	R	R	S	I-R
True firs	I-R	R	S	S-I
Hemlock	I-R	I	S	I-R
Woody Weed Species				
Alder	-	I	S	I-S
Big-leaf maple	-	I	I-R	R
Blackberry	-	S	S	R
Cascara	-	S	I	I
Ceanothus	-	I-R	-	S
Cherry	-	S	S	S
Chinquapin	-	I-R	-	I
Elderberry	-	S	S	R
Hazel	-	S	I	I
Madrone	-	I-R	-	I
Manzanita	-	R	S	S
Poison-oak	-	S	S	R
Salmonberry	-	S	I	R
Snowberry	-	S	-	I-S
Tanoak	-	R	S	I
Thimbleberry	-	S	I	I
Vine maple	-	S	I-S	R
Willow spp.	-	S	I-S	R-S
Herbs				
Annual grasses	S	S	R	R
Perennial grasses	S-R	S	R	R
Bracken fern	I	S	I	R
Broad-leaf herbs	I	S	S-I	S
Sword fern	R	I	R	R

Where R=resistant to highest rates; I=intermediate or variable; highest rates effective; S=sensitive, killed by medium or lower rates. Glyphosate (Roundup) has intermediate activity on chinquapin, ceanothus, and manzanita if applied after full leaf expansion but before wax development on leaves.

*Reference: 1993 *Pacific Northwest Weed Control Handbook*. R.D. William, R. Parker, R. Callihan, et al., eds.

Table 3-1 (continued)
Effectiveness of Major Forestry-Registered Herbicides During Seasons of Optimum Usage

Species	Hexazinone (Velpar)	Sulfometuron (Oust)	Metsulfuron (Escort)	Triclopyr (Garlon)	Imazapyr (Arsenal)
Conifers					
Pines	R	I-R	S	S	I
Douglas-fir	R	I-R	S	I	I
True firs	R	I-R	S	I	I
Hemlock	R	I-R	S	I	I
Woody Weed Species					
Alder	I	I-R	R	S	S
Big-leaf maple	-	R	R	I-R	S
Blackberry	I	I	S	S	I
Cascara	-	-	I	S	S
Ceanothus	-	-	I	S	S
Cherry	-	-	S	I	S
Chinquapin	-	-	I	S	-
Elderberry	-	-	S	S	S
Hazel	-	-	-	I	S
Madrone	-	-	I	S	S
Manzanita	-	-	I	-	I
Poison-oak	-	-	-	S	-
Salmonberry	-	S	S	I	I
Snowberry	-	-	-	I	-
Tanoak	-	R	I	I-S	-
Thimbleberry	-	I	S	I	I
Vine maple	-	R	R	I-S	S
Willow spp.	-	-	-	I-S	-
Herbs					
Annual grasses	S	S	R	R	S
Perennial grasses	S	S	R	R	S
Bracken fern	I	S	-	R	-
Broad-leaf herbs	S-I	S	S-R	S	S
Sword fern	R	S	-	R	-

Where: R = resistant to highest rates; I = intermediate or variable; highest rates effective; S = sensitive, killed by medium or lower rates.

*Reference: 1993 *Pacific Northwest Weed Control Handbook*. R.D. William, R. Parker, R. Callihan, et al., eds.

Donald Hanley and David Baumgartner are Washington State University Cooperative Extension Foresters, located in Seattle and Pullman, Washington, respectively.

This chapter is based on a compilation of the following publications: *Pacific Northwest Weed Control Handbook*, R.D. William, R. Parker, R. Callihan, et al., editors, PNW Extension Bulletin; *Weed Control on Rights-of-Way*, Swan, et.al., WSU EB0669; and *Chemical Control for Woody Plants, Stumps, and Trees*, S. Howard and R. Parker, WSU EB1551. All figures are from *Principles of Weed Control*, WSU EB0698.

Appendix 1

Forest Environment Pesticide Study Manual

Cooperative Extension
College of Agriculture & Home Economics
Washington State University
Pullman Washington
EB1551

Chemical Control for Woody Plants, Stumps and Trees

By Stott W. Howard and Robert Parker

Killing unwanted trees or preventing stumps from sprouting is a problem for many property owners. Various herbicides and application methods can kill unwanted stumps or trees. First, you must identify which tree is causing the problem. Once you are sure of the culprit, you can use the charts in this bulletin to match the tree to the appropriate herbicide and application.

Successfully controlling unwanted trees or brush also means considering the consequences of the herbicide and application method you select. Herbicides that control undesirable woody plants very in environmental stability, leachability, flashback potential, selectivity, and handling requirements. Control methods can damage surrounding vegetation and neighboring trees, contaminate groundwater, and prevent desirable vegetation from becoming established for several years.

Herbicide drift onto adjacent desirable plants has been a problem when using handheld equipment, especially when treating brush growing along fence rows. Apply only when there is little or no hazard from spray drift. Very small quantities of spray, which may not be visible, may seriously injure susceptible plants. Do not spray when wind is blowing toward susceptible crops or ornamental plants near enough to be injured. When treating trees and brush use a low pressure coarse spray and treat all sides of the plant. Drift often occurs when trying to spray the entire plant from only one side.

Read and follow herbicide label directions carefully. This bulletin suggests ways to avoid problems, but does not supersede product label instructions or cover first aid, or storage and disposal requirements. The herbicide label lists hazards that may make it unsuitable for use in certain situations. Read and follow requirements on the herbicide label closely.

Important Considerations

Consider the following factors carefully before choosing a control method. Each factor can affect the success of your project.

Suberization. Plants use this natural healing process to prevent insects or diseases from infesting tissues after cuts or wounds occur. The plants develop a layer of protective "corky" cells over the damaged tissue. Suberization can reduce herbicide effectiveness by preventing absorption. When you use frilling, cupping or cut stump methods of treatment, apply the herbicide immediately to achieve maximum absorption. Delaying application of water-soluble herbicide for as little time as one hour can reduce absorption and subsequent control of the undesirable woody plant.

Root Grafts. Sometimes the roots of different plants share vascular tissue through grafting. Root grafting occurs primarily within the same species, but may occur between plants within the same genus. This phenomenon can be of great importance. A herbicide can move (translocate) from a treated tree to an untreated desirable tree, killing or injuring it. Damage to desirable trees as a result of root grafting will occur from use of the following herbicides: amitrole, 2,4-D, dicamba, glyphosate, imazapyr, metsulfuron, picloram, and triclopyr.

Flashback. This term describes the passive loss of a herbicide from the roots of treated trees. Once the herbicide is released from one tree, it is available for uptake by another. The serious consequence of this is that a treated tree may release herbicide back into the environment, injuring other nearby trees and vegetation. This occurs with picloram, dicamba, and occasionally with 2,4-D.

Formulations. The herbicide formulation may affect its performance characteristics. Match the formulation and application method. For example, water-soluble amine formulations of 2,4-D and triclopyr are preferred for cut surface applications. Use oil-soluble ester formulations for best control on basal applications.

Other herbicide formulations include wettable powder, dry flowable, water dispersable granules, or flowables. These soil-applied formulations require moisture to move them into the soil and activate them. If you plan to use oil as the carrier or part of the carrier in the spray mix, use either diesel fuel or stove oil. Add an emulsifier when mixing fuel oil with water.

Stains and Dyes. Adding stains or dyes to the herbicide solution substantially increases applicator accuracy. Applicators use the dyes to monitor treated trees, so they are less likely to miss or respray targeted trees. Use of stains also will indicate personal exposure. The inexpensive, water-soluble stains wash off later.

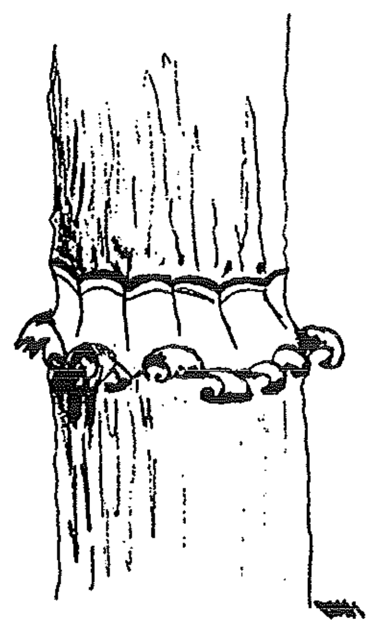
Dripline refers to the area directly underneath the spread of the tree limbs or canopy. Herbicide labels frequently caution against making applications within the dripline to avoid damaging desirable trees. Tree roots often extend well beyond the dripline. More appropriate is the rule-of-thumb that tree roots extend a distance equal to the height of a tree growing east of the Cascades, and equal to half of the height for a tree growing west of the Cascades. If the tree has been topped, increase the height estimate to more accurately gauge the drip line of the tree.

Heavily Pruned Trees. Some trees sprout prolifically, particularly after severe pruning. It is impossible to control the sprouts chemically without injuring the tree. Contact herbicides, such as paraquat (Gramoxone) and MSMA may be used to burn off these suckers. However, these non-selective herbicides will injure any plant incidentally sprayed. *CAUTION: do not use paraquat around homes, school, or recreational areas.*

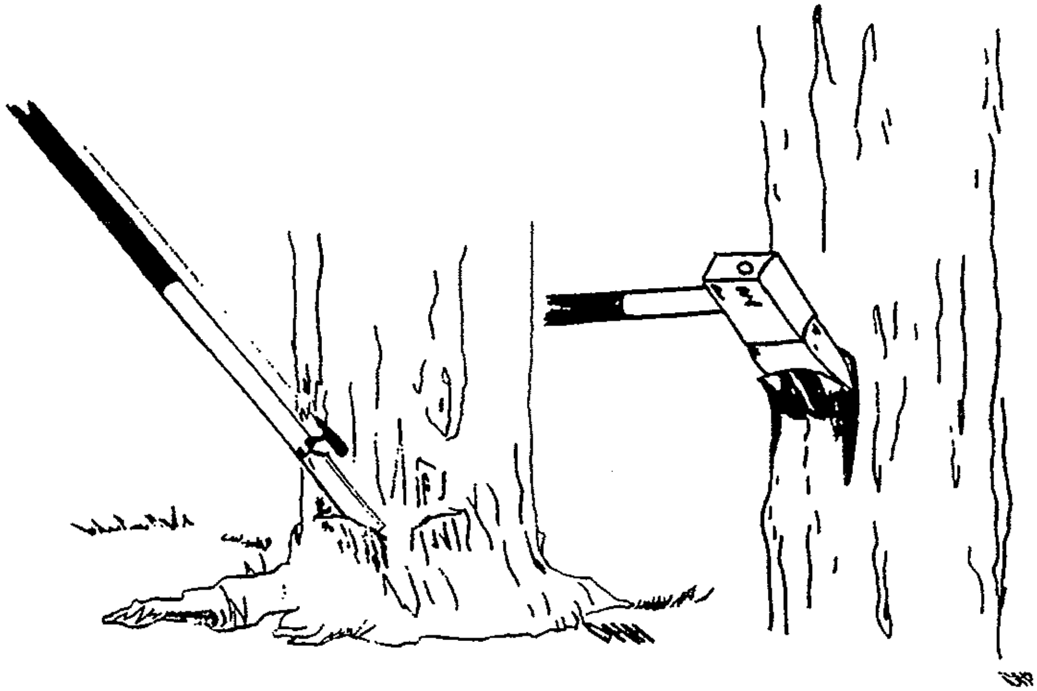
Methods of Application

Several methods exist for control of woody vegetation. Some treatments apply herbicide to a localized area on the tree. Directed applications can reduce impacts on adjacent nontarget vegetation from drift or overspray. Other methods require thorough herbicide coverage on foliage or soil. Review the herbicide labels for registered application methods and choose the best system for your needs. For the methods listed below, it is important to calibrate your application equipment and follow all of the herbicide label guidelines.

Cut Surface Treatments (frill, or cup treatments). Bark on larger trees (diameters larger than 5 inches) is often too thick for most water soluble sprays to penetrate. In this situation, it is necessary to provide a direct pathway for herbicide entry into the plant's vascular tissue. Do this by making a series of downward cuts through the bark, leaving the chip connected to the tree (frilling

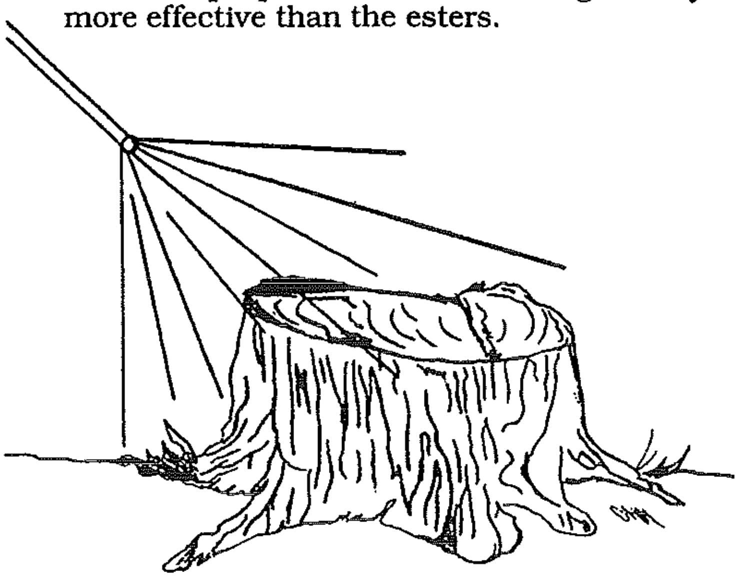


Make a series of downwards cuts, leaving the chip, and immediately apply herbicide into cuts.



Use special equipment to make injection applications. Injection cuts do not overlap as cut surface treatments do.

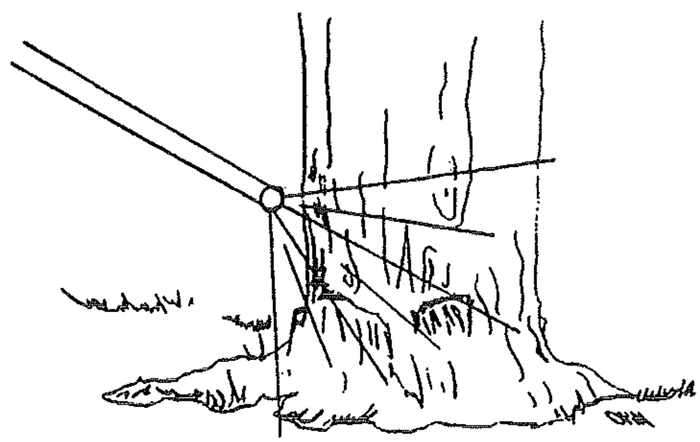
cuts overlay, and spaced-cut injection does not overlap). Make cuts around the entire circumference of the tree trunk with an axe or hatchet. Immediately apply the selected herbicide into the cuts. Avoid application during heavy upward sap flow in the spring, when sap flowing out of the wound will prevent good absorption. Apply herbicides registered for this use pattern undiluted or in dilution ratios of one-half to one-quarter strength. The amine formulations of picolinic acid (triclopyr and picloram) or phenoxy (2,4-D, dichlorprop, etc.) herbicides are generally more effective than the esters.



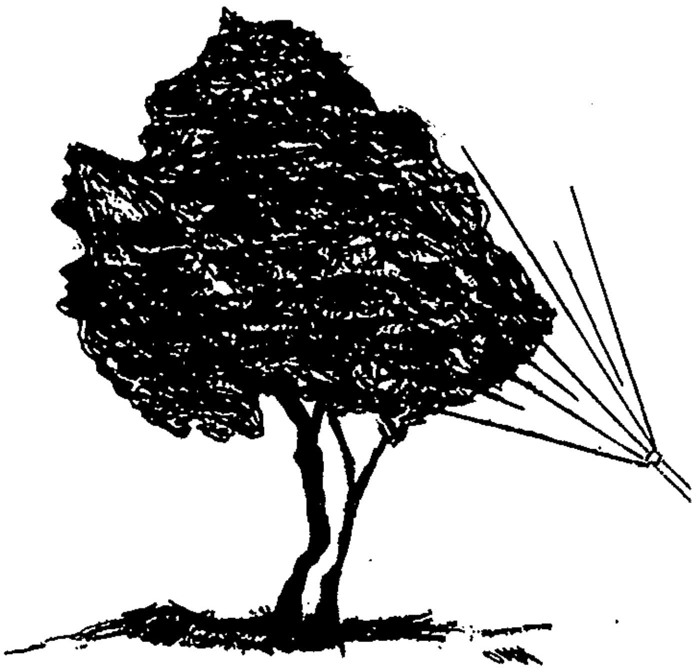
In treating stumps, apply herbicide to cut area immediately.

Injection is similar to cut surface treatments. Use specialized equipment to inject a specific amount of herbicide into the tree when the cut is made. Treatments are effective when injections are made every 2 to 6 inches around the tree. For best results, treat trees 1.5 inches or more diameter at chest height.

Stump Treatment involves cutting a tree down and treating the freshly cut surface with herbicide. Cut the top of the stump level to allow uniform herbicide coverage. Thoroughly wet the cambium layer next to the bark so the conducting tissue will carry the herbicide to the roots. On larger trees treat only the outer 2 to 3 inches of the stump (the internal heartwood of the tree is already dead). On trees 3 inches or less in diameter, treat the entire cut surface. Apply treatments immediately after cutting to achieve maximum effectiveness. If application is delayed after cutting, recut the stump and apply the herbicide to the live tissue. Delaying herbicide application to freshly cut trees can result in prolific sprouting from the tree collar and roots. Moisture stress may affect control during the summer and early fall. Applications during the spring upward



When treating basal bark, apply herbicide to the lower 12 to 18 inches of the tree trunk.



Foliage treatments are used for brush up to 15 feet tall. Treatments are least effective during very hot weather or when trees are water stressed.

sap flow are not as successful as late spring and early summer treatments. Undiluted water-soluble herbicide formulations are more effective than the esters.

Basal Bark Treatments. Apply the herbicide to the lower 12 to 18 inches of the tree trunk from early spring to mid-fall. Some species can be treated during winter. Use herbicide spray mixed with oil, until the bark is saturated. The low volatile ester formulations are the only oil soluble products registered for this use. This method is effective on trees of all sizes.

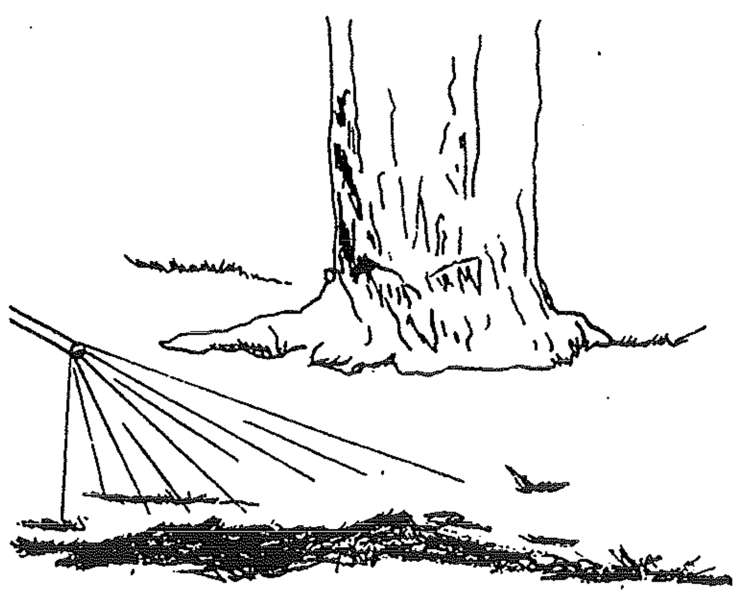
Foliage Treatment. Foliar spraying is a common method of applying herbicides to brush up to 15 feet tall. Make applications from early summer to late September, depending on choice of herbicide. Treatments are least effective during very hot weather and when trees are under severe water stress. Use 2,4-D, triclopyr, dicamba, and picloram in early summer, glyphosate in August and September, and imazapyr from June through September for best results. Fosamine and amitrole are additional choices. Except in very sensitive species, spraying plants with rapidly elongating stems will often result in excessive sprouting. Saturation of the tree is not necessary.

Soil Treatment. Herbicides applied evenly to the soil surface move into the root zone of the targeted plants with rainfall or overhead moisture. Common soil applied herbicide choices include: bromacil, hexazinone, and tebuthiuron. Hexazinone and tebuthiuron may be applied in narrow bands. Banding (also called lacing or streaking), applies concentrated solution to the soil in a line or band spaced every 2 to 4 feet. Use this type of application to kill large numbers of trees.

Herbicides for Woody Plant Control

Chemicals listed below are commercial packages and in some cases are restricted to licensed applicators. Materials described are not designed for homeowner use.

Amitrole (Amitrol-T). Apply as a foliar spray to susceptible woody plants from the full leaf stage until the onset of dormancy. Amitrole is most effective when all plant parts (leaves, stems, and suckers) are wet. Use only on noncropland and hardwood nurseries. Do not allow spray or drift to contaminate edible crops or water intended for irrigation, drinking, or domestic purposes. Do not allow livestock to graze or feed on treated areas.



Apply herbicides evenly to the soil above the root zone in soil treatments. Rainfall or overhead moisture carry the herbicide into the root zone.

Bromacil (Hyvar). Broadcast apply bromacil in the spring to control undesirable woody plants on noncropland. This herbicide may stay in the soil for several years. Avoid areas with standing water, irrigation ditches, rights-of-way or immediately adjacent areas with desirable trees, shrubs, or marketable timber. Do not use water from treated drainage ditches for irrigation or livestock. Do not contaminate water, food, or feed by improper application, storage, or disposal.

2,4-D (several trade names). Apply the ester formulations as a water-based foliar spray during periods of active growth or as an oil-based basal spray. Apply undiluted. The amine formulations are effective on many species as a stump, cut surface, or injection treatment. Apply undiluted. Use in pastures, rangeland, forest and noncrop areas. Thorough coverage is necessary; hard to control species may require retreatment. Do not allow spray to drift onto nontarget plants. Check additional label precautions regarding individual formulations.

Dichlorprop (2,4-DP, Weedone 2,4-DP). Use for control of mixed brush on highways, railroads, forests (limited uses), and utility rights-of-way. Apply as a foliage spray from full leaf stage until the start of dormancy. Thorough coverage is necessary, and hard to control species may require retreatment. Do not allow spray to drift onto cropland or nontarget plants.

Dicamba (Banvel). Use as a cut surface, basal, stump, or foliage treatment to control woody plants on pasture, rangeland, forest (limited uses), and noncropland. Do not treat areas where downward movement into the soil, or surface washing can bring dicamba into contact with roots of desirable plants. Conifers are particularly sensitive. Avoid applying when environmental conditions may favor drift to sensitive crops. Do not contaminate irrigation ditches or water used for domestic purposes. Dicamba can flashback to adjacent trees.

Fosamine (Krenite). Use to control brush in noncropland areas. Apply fosamine as a foliage treatment from full leaf in the spring to first fall coloration. Treatment does not immediately affect treated woody plants; they remain green for the remainder of the growing season. Treated susceptible plants fail to grow the next spring. A spray directed to only part of susceptible brush species will provide control of the portions sprayed, resulting in a trimming effect.

Glyphosate (Roundup). Apply glyphosate to actively growing trees with fully elongated and developed foliage, in late summer or early fall for best results. Treat early-maturing species such as poison oak by July. Repeat applications may be necessary. Wait 7 or more days after application before removing or tilling brush. For good control, do not treat plants under severe water stress; do not treat mowed or tilled brush until after a full season of regrowth. Vegetation damaged by mechanical or previous chemical treatments may be resistant to glyphosate. Do not allow drift to nontarget plants. Spray foliage thoroughly, but not to the point of runoff. Rainfall occurring within 6 hours of the application may reduce effectiveness.

Hexazinone (Velpar). To control undesirable vegetation in forests and noncropland primarily through soil uptake, make one foliar application in early spring, late fall, or winter. Fall applications generally give superior control in low rainfall areas. For best results, apply to brush seedlings or sprouts less than 18 inches tall. Use as a lace or streak application, but not on gravelly or rocky soils, on soils with greater than 85% sand, or on soils with less than 1% organic matter. Do not use in irrigation ditches or next to areas having desirable trees or shrubs.

Imazapyr (Arsenal). Use to control brush in forest and noncropland areas, such as conifer plantations, rights-of-way, fence rows, and storage areas. Use as a foliage, frill, or stump treatment. Do not use on food or feed crops, contaminate irrigation water (as injury to crops may occur), or use on lawns, walks, driveways, tennis courts, or similar areas. This herbicide may persist in the soil for several years.

Metsulfuron (Escort). Use as a foliar spray or soil treatment to control brush on noncroplant. For best control, apply as soon as the brush is fully leafed out. Do not use on food or feed crops, or apply where roots of desirable trees may extend into the treated zone. Do not allow drift to contact nontarget plants. This herbicide may persist in the soil for several years.

MSMA. For forestry and noncropland use, apply as a cut surface or injection treatment. Do not feed clippings to livestock or graze treated areas for one growing season.

Picloram (Tordon). Use as an all-season broadcast, stump, frill, or injection treatment to control woody plants in forest and noncropland areas such as fence rows or rights-of-way. Do not treat frozen soil. Do not contaminate cropland, water, or irrigation ditches. Avoid areas where downward movement into the soil or surface washing may cause picloram to reach the roots of desirable plants. This product can flashback, and may persist in the soil for several years. Do not use in western Washington where shallow water tables occur.

Tebuthiuron (Spike). Use as an all-season broadcast, lacing, or spot treatment to control undesirable broadleaved or woody vegetation on noncrop areas only. Apply just before the wet season in dry regions. Do not apply to frozen or saturated oil, sidewalks, driveways, tennis courts, streets, lawns, patios, under asphalt or concrete pavement where future landscraping is planned, or to any area where desirable roots extend. Injury symptoms appear slowly and may depend on moisture and soil conditions. this herbicide may persist in the soil for several years. Do not use in western Washington where shallow water tables occur.

Triclopyr (Garlon 3A, Garlon 4, Crossbow). Crossbow is a combination of triclopyr and 2,4-D. Use Garlon to control woody plants in forests and noncropland. Use Crossbow to control woody plants in noncropland, pasture, and rangeland. Best results are obtained during early summer. Do not permit spray or drift to contact desirable plants, as severe injury may occur. Do not apply to irrigation ditches or allow lactating animals to graze treated areas for 1 year following application.

Plant Susceptibility

Plant susceptibility depends on a number of factors: time of year; stage of plant growth; type of application and spray carrier; soil moisture before, during, and after application; precipitation (rain or snow); and temperatures of soil and air before, at, and immediately after the application. The addition of oil and/or a surfactant will enhance control of some species.

The susceptibility charts are complied from several sources. Use these charts only as a guide when planning control operations. Consult research reports, product labels, and knowledgeable personnel for additional information.

Label Clearances for Herbicides

Herbicide	Type of Application					
	Foliar	Soil	Frill	Stump	Basal	Inject
Amitrole	X					
Bromacil	X	X				
2,4-D*	X		X	X	X	X
Dicamba	X		X	X	X	
Dichlorprop (2,4-DP)	X					
Fosamine	X					
Glyphosate	X		X	X		X
Hexazinone	X	X				
Imazapyr	X		X	X	X	
Metsulfuron	X	X				
Picloram*	X		X	X		X
Tebuthiuron		X				
Triclopyr	X		X	X	X	X

*All formulations of these herbicides are not suitable for all the uses undicated. Check manufacturer's label for uses and additional precautions. *FOLLOW LABEL INSTRUCTIONS.*

Susceptibility to Cut Surface, Injection, and Stump Treatments

Plant	Herbicide						
	2,4-D	Dicamba	Picloram plus 2,4-D	MSMA	Triclopyr	Imazapyr	Glyphosate
Alder	G	G	G	P	G	G	G
Ash	P	F	F	F	G	G	G
Aspen, quaking	F	G	G	F	G	G	G
Cherry	G-F	G	G	G	G	G	G
Cottonwood	G	G	G	G	G	G	G
Douglas Fir	P		G	G	G		
Elm	F	G-F	G	G-F	G-F	G	G
Locust	G-F	G-F	G	G-F	G	G	F
Madrone	G	G	G	G	G	G	F
Maple, Bigleaf	P	P	F	F	G	G	F
Oak	G	G	G	G	G	G	
Pines	F		G-F	G			
Russian-olive	F	F	F		F	G	G
Willow	F	G	G	P	G	G	F

G = Good control
F = Fair control, likely to need retreatment
P = Poor control

Susceptibility to Foliage Treatments

Plant	Herbicide								
	2,4-D	Dicamba	Glyphosate	Picloram plus 2,4-D	Triclopyr	Imazapyr	Amitrole	Metsulfuron	Fosamine
Alder	G	G	G	G	G	G	P		G
Ash	P	G	G	P	F		G	G	
Aspen, quaking	F-P	F	G	G-P	G	G		G	G
Barberry	P	F	P	F	F	G	F		
Blackberry	P	F-P	G-F	F	G-F	G-F	G	G	G
Cherry	F	F	G	G-F	G-F	G	F	G	
Chokecherry	G	F-P	G	G	G				
Cottonwood	F-P	G	G	F	G	G		G	G
Douglas Fir	F-P	G	G-P	G	G-P	G-F	G-P		
Elderberry	F	G	G	G	G-F	G	G		
Elm	F-P	F-P	G	G	G-F	G		G	
Gorse	F-P		G-P	G-F	G-F			G	
Hazel	F	F-P	G	F	F	G	F		
Hemlock	F-P	G	F-P	F-P	G-P	G-F	F		
Locust	G-F	G	F	G	G		G		G
Madrone	G			G	G-F	G	P		
Manzanita	G	F	P	G	F	G-P			
Maple, Bigleaf	P	P	F	F-P	F-P	G	P		
Oak	G-F	G	G	G	G	G		G	
Pine	G	G	P	G	G	F	P		
Poison Oak	P	P	G-F	P	F-P		G		
Rose Multiflora		G	G	G	G			G	
Russian-olive	F	G	G	G	F	G			
Sagebrush	G	G	F	G	G				
Salmonberry	F-P	P	G	P	F	F	G	G	G
Scotchbroom	G-F	G-F	G-F	G-F	G-F	G			
Snowberry	P	P	G	G-P	F	G		G	
Sumac	G-F	G-F	G		G	G			G
Willow	G-P	G-P	G-F	G-F	G-P	G			

G = Good control
F = Fair control, likely to need retreatment.
P = Poor control

Susceptibility to Basal Bark Treatment with Oil

Plant	Herbicide	
	2,4-D	Triclopyr
Alder	G-F	G
Ash	P	
Aspen, quaking	G-F	
Blackberry	P	G
Broom, Scotch	G-F	G
Cherry	F-P	G
Chokecherry	G-F	G
Cottonwood	G	G
Elderberry	G-F	G
Elm	G-F	G-F
Gorse	G-F	G
Hazel	F	G
Locust	F	F
Madrone	G	G
Manzanita	G	G
Maple, Bigleaf	P	G
Oak	F	G
Poison Oak		P
Sagebrush	G	
Salmonberry	P	P
Snowberry	F-P	F-P
Sumac	P	
Willow	G-F	G-F

G = Good control
F = Fair control, likely to need retreatment.
P = Poor control

Susceptibility to Basal Bark Treatment

Plant	Herbicide			
	Bromacil	Haxazinone	Picloram	Tabuthiuron
Alder	G	G	G	G
Ash	G	G		G
Aspen, quaking		G	G	
Barberry	G			
Blackberry	G	G	G	G-F
Cherry	G-F		G	G
Chokecherry	G			G
Cottonwood	G			G
Douglas Fir	G	P	G	G
Elderberry	G			
Elm	G	G		G
Gorse				
Hazel	G			
Hemlock	F	P	G	
Locust	G	G	G	F
Madrone			G	
Manzanita				F
Maple, Bigleaf				F
Maple, Vine	P		F	F
Oak	G-F	G	G-F	G
Pine	G	P	G	G
Poison Oak				
Rose Multiflora		G		G
Russian-olive		G		G
Sagebrush				G
Salmonberry		G-F	P	
Scotchbroom	G			
Snowberry	G			
Sumac	G	G	G	G
Willow	G	G		G-F

G = Good control
F = Fair control, likely to need retreatment.
P = Poor control

COOPERATIVE EXTENSION
Washington State University

By Stott W. Howard, Ph.D., former Washington State University Extension Weed Scientist, WSU Mount Vernon, and Robert Parker, Ph.D., WSU Extension Weed Scientist, WSU Prosser. Illustrations by Dianna M. Miller.

▲Use pesticides with care. Apply them only to plants, animals, or sites listed on the label. When mixing and applying pesticides, follow all label precautions to protect yourself and others around you. It is a violation of the law to disregard label directions. If pesticides are spilled on skin or clothing, remove clothing and wash skin thoroughly. Store pesticides in their original containers and keep them out of the reach of children, pets, and livestock.

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EB1551

Helping You Put Knowledge To Work

Chapter Four

Insect Pests of Trees

Robert I. Gara

Appendix 2

Chapter Four

Insect Pests of Trees

Robert I. Gara

Introduction

As timber harvesting on federal and state lands become more limited, forest management will become an intensive and innovative enterprise. This means that forest rotations will shorten and maximum value will have to be obtained from every stem of the resource. Enhanced values will come about through intensive management practices that routinely will include thinning and pruning operations. These operations will be coupled with breakthroughs in fiber utilization technologies and attendant milling techniques. Intensive forestry and revolutions in the wood processing industry will be costly. For this reason, the role of forest protection (i.e., forest entomology and pathology) will be to protect capital investments against losses to forest growth, raw materials, and finished products.

As the Pacific Northwest becomes more urbanized, a demand will arise for protection of environments found in the forest-urban interface. Often insects and diseases that affect forests also damage the aesthetics of urban landscapes. Reasons for protecting urban trees include profit motives as well as other values, such as:

1) prevention of costly tree replacements, especially since this involves complicated economic, social and legal issues;

2) maintenance of vigorous nurseries; and

3) maintenance of urban plant communities that form the bases of particular public experiences, e.g., urban park environments, wetland communities, arboreta, and zoological gardens.

Pest management of both forest and urban plants involves a working knowledge of plant identification, forest and urban plant ecology, principles of entomology, plant pathology and the social sciences.

General Entomology

Insects belong to the Phylum Arthropoda, which means, "organisms with jointed appendages." Characteristics of the arthropods: jointed appendages, bilateral symmetry, body composed of linear series of rings called somites, body with exoskeleton and dorsal heart and ventral nervous system. The arthropods are divided into two groups, based on evolution of their mouth parts, the Chelicerata and the Mandibulata (Figure 4-1). The Chelicerata contains several Classes, including the Scorpionida (scorpions), Merostomata (horseshoe crabs) and Arachnida (ticks, spiders, and spider-mites). The Mandibulata consist of the Insecta (insects), Crustacea (shrimps, crabs, lobsters, pill bugs, etc.), Chilopoda (centipedes) and Diplopoda (millipedes). The Class, Insecta, is recognized by having three body regions (head, thorax and abdomen), one pair of antennae, three pair of legs, and the adults generally have wings (see Appendix II for more details).

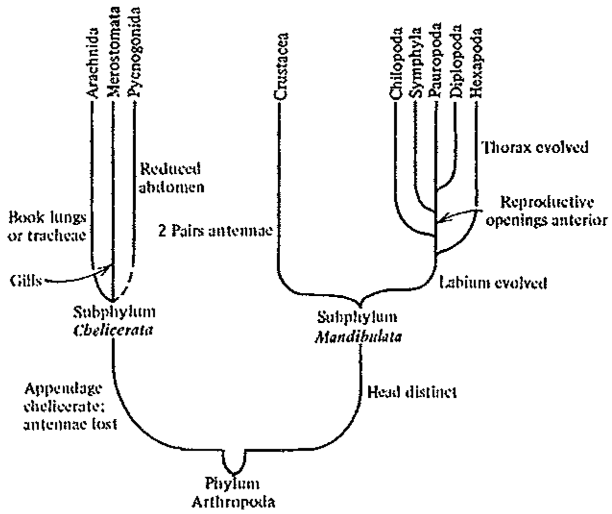


Figure 4-1. Modified from figure 2-5, page 33 and reprinted with permission from Ross, H.H., C.A. Ross, and June R. P. Ross. A Textbook of Entomology, 4th Edition. Copyright © 1982 by John Wiley and Sons, New York. Phylogenetic tree of the Phylum, Arthropoda: Arachnida (ticks, mites, spiders); Merostomata (horseshoe crabs); Pycnogonida (sea spiders); Crustacea (shrimps, lobsters, pill bugs, crabs); Chilopoda (centipedes); Diplopoda (millipedes), and; Hexapoda or Insecta (the insects).

The fact that insects have exoskeletons has given these organisms a tremendous opportunity for innovative means of survival and evolution. The exoskeleton serves as an impermeable and hard suit of armor; it provides for development of appendages capable of huge mechanical advantages. Most of all, the exoskeleton has led to the development of complete metamorphosis.

Metamorphosis

Metamorphosis means "change in form"(see Appendix II). Groups with gradual metamorphosis (see list) emerge from eggs as tiny wingless individuals which begin to feed and grow. As they come to the limits of their exoskeleton they molt and replace the new exoskeleton with a larger one. As the nymphs (the term for immature insects that have gradual metamorphosis) go through this process of feeding, growing, and molting, each new stage (called an instar) takes on the characteristics of the adult stage. Finally, the definitive adult is generally winged and sexually mature, and no further growth occurs.

Complete metamorphosis is perhaps the ultimate evolutionary advance of the Insecta. In complete metamorphosis, the larvae (also called caterpillars, maggots, and grubs) emerge from eggs and begin to feed, grow, and molt. Unlike gradual metamorphosis, each instar does not gradually take on adult characteristics. Rather each stage is ever more specialized for feeding, metabolism, growth and survival. The adult insect is totally unlike the larva. Usually adults feed on different food than larvae (in some groups, adults do not feed). Adults are winged and dedicated to dispersal, host selection, and reproduction. The stage that bridges the gap between the larvae and adults is the pupa. The pupal stage actually reallocates the tissues and energy budget of the larvae and converts these products into the adult insect. Complete metamorphosis means that, within one insect species, the young is specialized for food selection; processing of nutrients; defense against host-produced-defensive compounds; and juvenile growth. The adult disperses the gene pool, reproduces, selects new food and breeding sites and does not compete in any sense with its offspring. Moreover, the bridging role of the pupa allows for separate selection pressures to act on the immature and adult, thus permitting separate evolutionary pathways for both stages.

Insects have intricate mouth parts, consisting of the labrum, mandibles, maxillae and maxillary palps, and the labium with labial palps. These basic mouth parts have evolved into a variety of specialized feeding structures that govern the mode of life for the various insect groups. The way insects feed, the type of metamorphosis, and the kind of wings they have delineate the insect Orders (Table 4-1 and Figure 4-2).

Insects have simple digestive, breathing, and reproductive systems (Figure 4-3). The digestive system, which is modified depending on food material, has these basic components: foregut (composed of mouth-larynx, esophagus, crop, gastric cecae (blind tubes that harbor micro-organisms which produce essential vitamins); midgut (containing epithelial cells that produce digestive enzymes), malpighian tubules

Table 4-1. Examples of insect orders and suborders with their feeding and flying specializations. Heteroptera and Homoptera are part of Hemiptera.

Order	Common Name	Feeding	Wings	Metamorphosis
Orthoptera	grasshoppers, crickets	chewing	4-straight	gradual
Dictyoptera	roaches, mantids	chewing	4-flat	gradual
Thysanoptera	thrips	rasping-sucking	4-fringed	gradual
Hemiptera	bugs	piercing-sucking	2-half wings/ 2-membranous	gradual
Homoptera	cicadas, scales, aphids	piercing-sucking	4-membranous/ no wings	gradual
Coleoptera	beetles	chewing	1 pair elytra/ 1 pair membranous	complete
Neuroptera	lace wings, ant lions	chewing-piercing	4-membranous	complete
Lepidoptera	moths and butterflies	siphoning	4-scaly wings	complete
Hymenoptera	sawflies, horn tails, wasps, ants, bees	chewing	4-membranous	complete
Diptera	flies	variable	2-membranous 2-halteres	complete

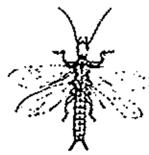
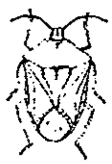
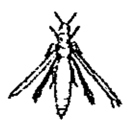
(excretory organs), and hindgut and rectum. Food that is ingested moves to storage in the crop where it is metered out to the midgut and digested. The nutrients are then transported out of the walls of the midgut, where they are conveyed by the blood to metabolizing cells and tissues. Uric acid, the main excretory byproduct, enters the malpighian tubules via active transport. There the material is flushed into the hindgut for excretion. Solid waste, fecal matter, is moved through the hindgut where the moisture is extracted by specialized cells (rectal papillae) in the rectum. Because of this water conservation adaptation, the waste product from chewing insects is dry and pelletlike.

The breathing mechanism of insects consists of paired longitudinal tubes (called longitudinal trachea) which subdivide into smaller and smaller tracheoles. Oxygen enters the longitudinal trachea through tiny openings (spiracles) along the sides of insects. As metabolizing tissues consume oxygen, a gas pressure gradient is established between the atmosphere and the oxygen-using tissues. This diffusion pressure gradient causes atmospheric oxygen to enter the insects, where it eventually reaches the living cells. Accordingly, insects utilize atmospheric oxygen, and for this reason, insectan blood does not need hemoglobin. Hence the blood of insects is often green or yellow rather than the red of hemoglobin.

Male insects have paired testes where the spermatozoa are produced. Females have paired ovaries, and eggs are produced by ovarioles within the ovaries. Mature eggs move down the oviduct and past the spermatheca where stored sperm emerge to fertilize the eggs. Eggshell materials and other egg-protecting structures are produced by accessory glands. Insecta reproduction may be as follows:

Reproduction Type	Description
Oviparous	Eggs are laid and the young emerge from these eggs.
Ovoviparous	Eggs hatch within females and larvae are laid.
Paedogenesis	Immatures produce other immature insects.
Parthenogenesis	Females reproduce without mating—can be cyclic as with many aphids, sporadic as in Hymenoptera, or continuous.

Figure 4-2. Adapted from Insect Biology by Howard E. Evans. Copyright © 1984 by Addison-Wesley Publishing Company. Reading, MA. Reprinted by permission. Modified from Table 2-3, pages 46-49.Examples of some major insect Orders.

Order	Common Name	Example	Front Wings	Hind Wings
Ephemeroptera	Mayflies		Triangular, membranous; many veins and cross-veins	Smaller, rounded (may be absent)
Odonata	Dragonflies, damselflies		Long, slender, membranous; many veins and cross-veins	Similar to front wings
Plecoptera	Stoneflies		Slender, membranous, with numerous veins	Usually wider than front wings; vannus present
Embioptera	Webspinners		Slender, membranous but often smoky; few veins present	Very similar to front wings
Dictyoptera	Cockroaches, mantids, termites		Elongate, often thickened; usually with many veins	Wider than front wings and with vannus (except in most termites)
Orthoptera	Grasshoppers, crickets, katydids, walking sticks		Long and slender, thickened, with many veins (may be absent)	Wider than front wings, membranous, with vannus (may be absent)
Dermaptera	Earwigs		Very short, padlike, leathery (may be absent)	Large, membranous, folding fanlike under front wings (may be absent)
Psocoptera	Barklice, booklice		Membranous, with few veins (may be absent)	Similar to but somewhat smaller than front wings (may be absent)
Hemiptera	True bugs, cicadas, leafhoppers, aphids, etc.		Membranous or thickened, with few veins (may be absent)	Membranous, shorter but often somewhat wider than front wings (may be absent)
Thysanoptera	Thrips		Very slender, with a wide fringe of hairs, few veins or none (may be absent)	Same as front wings
Phthiraptera	Lice		None	None

Selected Forest Insects

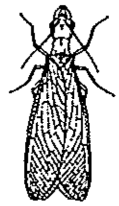
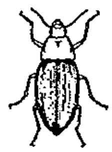
(see Appendix)

The insects significant to foresters can occur in any setting. They are discussed under the category with which they are most often or most significantly associated.

Insects of the Forest-Urban Interface

• BALSAM WOOLLY ADELGID (*Adelges piceae* (Ratzberg)) (BWA): The worst pest of true firs, genus *Abies,* is the introduced homopteran (family, Homopterai Phylloxeridae). The

Figure 4-2 continued

Order	Common Name	Example	Front Wings	Hind Wings
Megaloptera	Dobsonflies, snakeflies		Elongate, membranous, with numerous veins and cross-veins	Similar to or somewhat wider than front wings
Neuroptera	Lacewings, ant lions		Similar to Megaloptera but often with much branching near margin	Similar to front wings but sometimes slightly smaller
Coleoptera	Beetles		Hardened, protective "elytra," which meet in a straight line on back	Membranous, fold complexly beneath front wings (may be absent)
Mecoptera	Scorpionflies		Membranous, slender (especially basally), with numerous cross-veins	Similar to front wings (both pairs may be absent or reduced and modified)
Trichoptera	Caddisflies		Elongate, with few cross-veins, covered with hairs	Similar to front wings but broader and slightly shorter
Lepidoptera	Moths, butterflies		Slender to rather broad, clothed with scales; relatively few cross-veins	Similar to front wings but usually shorter, broader, and more rounded; often attached to front wings
Diptera	Flies, gnats, midges		Membranous, with relatively few veins and cross-veins (may be absent)	Absent as functional wings; forming small, knobbed "halteres"
Siphonaptera	Fleas		Absent	Absent
Hymenoptera	Sawflies, wasps, ants, bees		Membranous, with relatively few veins but usually several cross-veins (may be absent)	Smaller than front wings and capable of attachment to them by a series of hooklets

parthenogenic balsam woolly aphid was first reported in North America from balsam fir growing at Mt. Monadnock, New Hampshire. Since that time, the BWA has spread over large areas within the Canadian Maritime Provinces and the northeastern United States. From there it has spread south along the Appalachians and Great Smoky Mountains, where it currently is destroying thousands of Fraser fir stands. During the 1930s BWA infestations were commonly found in grand fir stands of Willamette Valley, Oregon. In 1954 BWA infestations were reported causing serious damage to Pacific silver fir (*Abies amabilis*) stands in southwestern Washington and in subalpine fir (*Abies lasiocarpa*) stands in Washington and Oregon. Presently the BWA is common throughout the Puget Sound Trough, the Cascade and Olympic mountains, and on Vancouver Island, B.C. The BWAs have gradual metamorphosis and three nymphal instars. Eggs are attached to the bark of true firs in clusters with white cottony tufts by sessile (immobile and

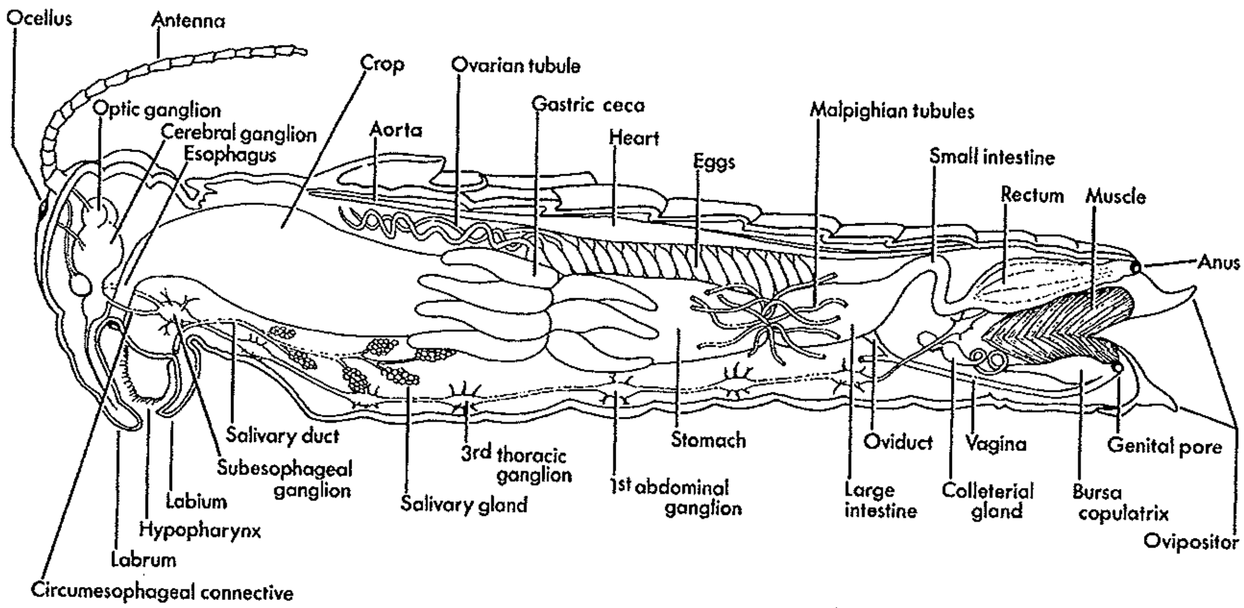


Figure 4-3. Reprinted with the permission of Macmillan College Publishing Company from INVERTEBRATE ZOOLOGY by Robert W. Hegner and Joseph G. Engerman. Copyright © 1969 by Macmillan College Publishing Company, Inc. Figure 11-8, page 478. Internal organs of a female grasshopper showing: ventral nervous system; digestive tract; aorta or "insect heart"; reproductive system and excretory system (malpighian tubules).

legless) females. Each egg is 0.4 mm long and amber colored. As development progresses, the color changes to purplish-brown, and the red ocelli (simple eyes) and dark stylets (piercing-sucking mouth parts) can be seen beneath the corion (eggshell). Upon emergence the 1st instar (first nymphal stage) is light purplish brown with red ocelli. After stylet insertion the insect gradually darkens and produces a fringe of wax threads that cover the body. The 2nd instar is more convex dorsally and is about 0.5 mm long and purplish black; the wax threads become longer and curly. The antennae and legs become shorter as they begin to atrophy. The body of the 3rd instar is extremely convex and colored purplish brown. The curly wax threads begin to form a waxy mat. Finally, the adult is about 0.7 to 0.86 mm long and the body is almost hemispherical in shape but longer than wide. The antennae and legs are almost completely disintegrated.

The BWA spends the winter as a 1st instar (the insect immediately after hatching from the egg). These tiny individuals already have inserted their stylets (long tubelike piercing-sucking mouthparts) through the bark and into parenchyma tissues. The first signs of activity in spring are a swelling of the body and appearance of honeydew. The adelgids then quickly feed, molt twice more, and reaching the adult stage in 4 weeks. These adults begin egg laying and deposit several hundred eggs over a 30-day period within the waxy filaments. Eggs incubate for about 2 weeks. Characteristically, the egg mass of each adult will consist of freshly laid eggs, incubated eggs, and 1st instars crawling over broken eggshells. These crawlers disperse over the bark and insert their stylets into living cells. The adelgid from that point on is sessile for the rest of its life. Shortly after stylet insertion, the 1st instar enters a period of rest (called diapause) for 1 or 2 months. With resumption of activity, development progresses rapidly and egg-laying females are present in the fall.

The symptoms of crown attack by the BWA are known as the gout disease. At the point of stylet penetration abnormal growth of bark and wood occurs. This is a hypertrophic distortion resulting from a salivary enzyme the adelgids introduce into the tree. The most conspicuous gouting occurs at the base of shoots, particularly in the leaders and uppermost branches. Because water movement is eventually interrupted by the abnormal growth, the trees die from the top down and large crown areas are defoliated.

The hosts most susceptible to BWA damage are subalpine fir, and then Pacific silver fir. The best way to avoid problems is not to transplant small subalpine firs from the forests into yards. Established firs also are subject to BWA attack. [Reference: *Balsam Woolly Adelgid A Pest of True Fir Species*, WSU EB1456.]

• APHIDS OF TRUE FIRS: The bow-legged aphid (*Cinara curvipes*) as well as the balsam twig aphid (*Mindarus abietinus*) produce large populations on fir trees. The resulting amount of honeydew causes growth of unsightly sooty mold. The honeydew also sticks the foliage together. If large trees are infested the sugary exudate covers cars, patios, lawn furniture, and walkways. Accordingly, besides debilitating fir trees, these aphids present a considerable nuisance.

Bow-legged fir aphids (*C. curvipes*) feed on twigs, branches and even roots of firs, Englemann spruce and deodar cedar. The aphids feed gregariously, and heavy infestations cause yellowing of the foliage and poor tree growth, especially on small ornamental trees. There are several generations of *Cinara* per year. They overwinter as eggs on needles and bark. In summer several generations of wingless females give birth to living young.

The balsam twig aphid (BTA) is a major pest of Christmas trees, and can be serious on forest and ornamental firs. It has a complicated life cycle. Overwintering eggs hatch in spring and become wingless, parthenogenic females (called stem mothers), which shortly produce living young (a type of reproduction called vivipary). This new generation of wingless females clusters in a colony around the bluish gray parent. All these forms feed in unison on old needles and developing buds. The next generation of wingless females are one of two forms: one group, called the sexuparae, are covered with powdery wax and feed on new growth. Eventually, around mid-June, these sexuparae produce the sexual forms, i.e. males and females, which mate and deposit the overwintering eggs. The other group, called the viviparae, are wingless viviparous females that produce several generations of viviparae through mid-June; these too produce males and females which lay overwintering eggs.

Feeding by these aphids cause needles to twist and become distorted and the excessive honeydew may mat the foliage with a sugary coating. In fact the affected foliage remains distorted for the life of the needles. These aphids are subjected to intensive natural control by a complex of coccinelid and syrphid predators. Thus, before chemical control is applied, determine if 1) the live adelgids are present and 2) if there is an active predator population already bringing this under control.

• EUROPEAN PINE SHOOT MOTH *(Rhyacionia buoliana):* This shoot moth belongs to the family of the Olethreutidae. As the common name implies, the insect was introduced from Europe and was discovered infesting pine shoots in New York State in 1914. In the Northeast it has since become a major forest and ornamental pest. It deforms trees and drastically slows their height growth by affecting buds and reducing shoot elongation. This pest became established in the Pacific Northwest through nursery stock movement. In spite of an eradication campaign in the early 1970s the EPSM occurs from British Columbia to northern California.

The EPSM infests terminal shoots of essentially all the hardpines, those with two or three needles. Common hosts are Mugho, Scotch, Japanese red, black, lodgepole and other ornamental hard pines.

Females oviposit yellowish, "Frisbee™-shaped" eggs in midsummer on twigs, buds and needles. The 1st instars mine the base of needles and later the larvae bore into buds. This activity causes formation of small globules of encrusted, dried pitch at the base of buds. Larvae consume one bud then move to another. The partially-grown, dark brown larvae overwinter either in the affected buds or under the pitch. In spring, the larvae enter other buds and eventually bore down through the base of elongating shoots, killing them. The pupa forms in the mined shoot. It wiggles its way out of the pitch mass, and the delicate adults emerge from these pupae from late May through July. The adults fly at dusk, and are recognizable by their orange-brown forewings marked with fine and wavy silver lines. Control is aimed at the adults. Spraying new buds and needles with currently registered insecticides such as dimethoate every 2 weeks until mid-July

(See current year *PNW Insect Control Handbook*).

Prevent aesthetic damage to pines by timely pruning of infested shoots and branches before adults emerge. Prune only after the larvae are well within their mines and not during the time larvae are migrating from their overwintering sites. Make sure to destroy material pruned in May to prevent adults from emerging from the prunings.

• PINE NEEDLE SCALE (PNS): This Coccidea (the scale super family) is a serious and, unfortunately, ubiquitous pest of ornamental pines across North America. The most heavily damaged hosts are Mugho, Scotch, Monterey, red, Austrian and ponderosa pines. These scales belong to the armored scale family Diaspididae. The adult males are winged, but the females are wingless (apterous). The females cause the damage and are the form usually seen. Their bodies lie between a thin, delicate lower scale and a tough, hard white upper scale. The PNS is distributed with planting stock, but it also disperses with the wind during the crawler stage. Eggs are brownish and overwinter beneath the female. These eggs hatch in spring when reddish crawlers seek new sites in which to sink their piercing-sucking mouthparts. Through the subsequent molts, the legs of those nymphs destined to be females atrophy, and the females begin to take on the appearance of an immobile scale. Those that will become males eventually develop wings, fly to the female, and mate.

Control serious PNS infestations before new growth begins by spraying the overwintering females in spring with summer-weight oil sprays; lime sulfer sprays also can be used. At this time, malathion 57% EC, diazinon 25% or possibly insecticidal soaps can be used to control crawlers. Apparently, two generations of PNS occur in western Washington, so from mid-June through October, treat infestations again with malathion, diazinon, or Sevin (always keeping in mind that this pesticide is dangerous to bees).

• SILVER SPOTTED TIGER MOTH (*Halisidota argent*): The principal hosts of this defoliating Arctiidae are Douglas-fir and hard pines. The SSTM also is found in the Puget Sound Region on western hemlock, grand fir, Sitka spruce and other conifers.

The adult SSTM is a robust, hairy, yellow-brown moth. The forewings have rows of distinct silvery spots. Adults fly in late summer (July through August) and deposit clusters of small, round greenish eggs on twigs and needles. Eggs hatch in 3 weeks, and clumps of gregarious larvae feed on foliage of later branches. These larvae protect themselves from wind and rain by creating tightly woven silken tents. These larvae feed until fall and proceed to overwinter in their tents. In the Puget Sound area, the larvae will feed in winter during unusual warm periods. In spring, the larvae enlarge their tents and voraciously feed on the foliage. It is at this time during heavy infestations that entire branches can be stripped of foliage. During their last instar, the large (40 mm) hairy caterpillars disperse and feed individually before spinning silken cocoons. In July the new adults commence flying. The larvae often are found wandering prior to pupating. The hairs (which cause alergic reactions in may people) are incorporated into the cocoon which looks reddish brown.

Generally, SSTM infestations are not serious; control would be simple removal of the tents. In more serious situations, *Bacillus thuringiensis* can be used or Orthene as a second choice. During the second year of SSTM outbreaks, the population is heavily controlled by a tachinid fly and ichoreumon wasps that lays their eggs directly on or in the SSTM larvae.

• HEMLOCK WOOLLY ADELGID (HWA): This phylloxerid (family Phylloxeridae), introduced from Europe in 1927, appears as white cottony tufts on the bark, twigs, and foliage of western hemlock. These parthenogenic insects multiply rapidly. Many small sucking insects feeding at the same time often greatly weaken the host. This activity causes needle drop and gives the tree a sickly general appearance. In severe cases, small ornamental western hemlocks are killed. The eastern hemlock is much more sensitive to HWA infestations, and ornamental plantations are severely threatened.

The life cycle of HWA is poorly known. The cycle probably is as follows: a) overwintering adults (under the white fluff) lay brownish orange eggs in late winter-early spring; b) eggs hatch and reddish brown crawlers disperse all over the foliage, twigs and upper stem area in March through May; aerial dispersal by ballooning or bird transport is also probable; c) the crawlers settle down, often on twigs or needle bases, and a fringe of woolly material is seen around the periphery of their bodies; d) these crawlers begin to cover themselves entirely with the whitish, woolly material, and after a few molts they become parthenogenic, viviparous females; e) during summer there are probably three generations of these females; f) whether or not the HWA have alternate hosts is unknown; whether the North American populations have males is similarly unknown; and g) in October only females are found overwintering. Inspect carefully for HWA adults or crawlers before designing a control strategy. The cottony material remains even though the insect has been brought under bio-control.

Treat heavy infestations with Sevimol 4, one tablespoon, 50% emulsifiable concentrate (EC) per gallon of water. Summer-weight oils also can be used before budbreak (See *PNW Insect Control Handbook*).

• SPRUCE APHID: The spruce aphid is of European origin. It has been introduced throughout the world where spruce occurs naturally or as an exotic species. The spruce aphid is a serious problem since heavily infested trees lose the majority of their old needles. Repeated heavy attacks not only make trees unsightly but also can seriously weaken or kill them.

The spruce aphid is active in late winter and early spring. This habit, together with the insect's cryptic coloration, makes it hard to detect. Often serious damage to the old foliage has been done before the presence of the aphid is known. The overall life cycle of the spruce aphid is poorly understood. Although a portion of the population stays on the host during the year, the majority of the insects disappear by March; they probably fly to an unknown alternate host.

The spruce aphid is controlled in February or early March at the latest. After this time, even though damage is still not noticeable, the population has built up to damaging proportions, and the old needles will begin to drop by April. Insecticidal soaps do not work well for control of this pest in western Washington. Summer-weight oils applied in January and even up to March have been used successfully. Seriously infested trees have to be treated with recommended insecticides in fall and again in late winter to assure adequate control; in fact, several applications may be necessary. The presence and concentration of the aphids is sampled by tapping a branch over a sheet of white cardboard. These aphids are heavily parasitized, so a qualitative appraisal on the amount of "aphid mummies" may be used as a way to judge if chemical treatment is necessary.

• COOLEY SPRUCE GALL ADELGID: This adelgid is responsible for the formation of cone-shaped galls on terminal, twigs of blue, Engelmann, Sitka, and Norway spruce in western North America. The galls are from 1 to 2 inches long, light green to dark purple, and are formed as the basal portion of the needles swell, forming chambers between the base of the needles and the stem. These chambers, which are not communicating, usually contain from three to 30 small wingless adelgids covered with a white waxy covering. Later the galls turn brown and dry on the tree after the insects have left.

As with many aphid and adelgid species the insect has an alternate host, in this case, Douglas-fir. On Douglas-fir these adelgids appear as cottony tufts on the underside of the needles. Their feeding punctures cause formation of chlorotic spots and some deformation of the needles. Sometimes the damage is severe, causing the affected hosts to prematurely drop their needles.

The life cycle of the Cooley spruce gall adelgid is complicated. The form found on Douglas-fir needles during winter is hibernating females. These lay eggs early in spring, and the young, which settle on the tender foliage and feed, later mature into winged and wingless females. The wingless forms deposit eggs within tufts of white cottony wax. The eggs hatch later into females that will hibernate, while the winged females migrate to the spruce and lay eggs at the base of needles. The young hatching from these eggs feed at the base of the needles and inject salivary enzymes that trigger hypertrophic growth and formation of galls. About mid-summer the forms in the galls become full-grown, winged migrants, which return to Douglas-fir to lay eggs that also produce hibernating females. Altogether these adelgids appear in five stages or forms over the course of the year.

Apply recommended insecticides when new growth is unfolding in spring. Once galls are beginning to form, it is too late to consider chemical control. Aesthetic damage caused by these insects can be ameliorated by pruning out the galls before they turn brown and the aphids leave; moreover, this would serve as a means to lower the adelgid population as the galls contain significant quantities of immature individuals. Be sure to destroy galls that are pruned.

• SPRUCE SPIDER MITE: Spruce spider mites attack spruce, arborvitae, juniper, hemlock, pine, Douglas-fir, and possibly other conifers. These mites build up to damaging populations during the moderately warm spring and fall weather. Hot, dry weather stops their development but may increase the visibility of damage. As these mites feed, they rasp the epidermal tissues of scales and needles, causing formation of elongated chlorotic patches. At first this chlorosis is evident at the base of the foliage, then the damage spreads out. In severe outbreaks the foliage browns and falls off.

As mite activity can be confused with chemical or pollution damage, tapping branches while holding a sheet of paper under the foliage is a way to find the presence of the tiny organisms. Any dust that walks away is likely a mite. However, also check for the presence of predator mites (Drawings of predator mites in the special section on mites of the *PNW Insect Control Handbook.*)

These mites, readily moved from place to place by the wind and birds, are primarily a problem in spring and fall. Overwintering eggs of the mites are placed under bud scales, in the axils of needles, or under webbing on the stem or branches. Development of larvae (the 1st instars of mites and ticks are called larvae as they only have six legs) and nymphs (eight legged young) requires about three molts. The adults, about 0.5 mm long, are brownish green in color. Three or more generations develop per year, with successive generations produced at intervals of 2 to 3 weeks. All active forms feed on foliage, preferring the older needles or scales.

Severe spider mite outbreaks are controlled with Kelthane, an acaricide (a miticide which is secific to mites). Give thorough coverage of the foliage in early spring using a miticide procedure; additional applications may be necessary after sampling the population by beating foliage over a sheet of paper.

• LARCH CASE BEARER: The larch case bearer belongs to a family of tiny moths, the Coleophoridae. These case bearers appeared in Massachusetts in 1886 as they flew from ballast piles to eastern larch trees. Case bearers soon spread to larch forests throughout the northeastern United States and the Canadian Maritime provinces, and by the early 1900s outbreaks were occurring in tamarack forests of Minnesota and western Ontario. In 1957 an outbreak was discovered in western larch growing in the area of St. Anthony, Idaho. When this outbreak was pinpointed, other heavily defoliated larch forests were discovered in northern Idaho and eastern Washington; the insect is now found throughout Washington State.

Moths of the larch case bearer emerge from pupae during May through June and mate on the hosts which contained their pupae. Each female lays singly about 50 eggs on the underside of needles. Upon hatching, in about 2 weeks, the 1st instars drill through the bottom of their eggs and into the needles. They feed as leaf miners for 2 months. The third instars hollow out needles, line the inside with silk, and unfasten the needle base from the short-shoot (the rounded projection on the stem which gives rise to the needles). Then the insects live within these cases and drag them around from needle to needle. They feed by fastening their cases firmly to a needle with a pad of silk, and then they hollow out the needle. The larch case bearer overwinters as a 3rd instar inside its case. During fall each larvae drags its case to a short-shoot and attaches itself to this structure before it begins to hibernate. Because the larch drops its needles in winter, the cases can be seen. In spring the larvae resume feeding and by April, the 4th instars are rapidly devouring the new needles. Pupation takes place within the case, and new adults begin to emerge by the end of April or early May. Damage results chiefly by the 4th instar feeding activity. In heavy infestations the needles are destroyed as soon as they appear. Fortunately, larch can produce two needle crops. A European parasitic wasp, *Agathis pumila,* of the larch case bearer was introduced during the 1970s. From a timber management perspective the introduction was successful as the parasite is firmly established in the forests, and the pest is under natural control. In urban situations it may be necessary to spray the emerging moths.

• CYPRESS TIP MOTH (CTM): The cypress tip moth infests cypress, juniper, arborvitae, and occasionally redwoods. In the Puget Sound area the tiny, silvery colored moths emerge from infested hosts from early May to mid-July. Peak activity occurs during the latter half of May. Eggs are laid on green tips of twiglets. Upon hatching, larvae tunnel into leaf scales and mine within the foliage until late winter or spring of the following year. Little foliage discoloration is caused by the first two instars. Beginning in late winter, however, a yellowing and then a browning of the infested tips is apparent. The dead tips can be broken readily because they are dry and hollow. After feeding is complete, the larvae leave their mines, and each spins a white paperlike cocoon usually in the axils of the leaflets. Several weeks later moths emerge, mate and lay eggs.

The CTM is heavily parasitized by small braconid wasps. Accordingly, a year of severe CTM damage often is followed by a year of minimal damage as the braconids begin to regulate the population. However, if damage is unusually heavy, and natural controls are overwhelmed, a pesticide can be applied (see *PNW Insect Control Handbook*). Spraying with a systemic chemical is usually recommended.

• PINE NEEDLE SHEATH MINER: The pine needle sheath miner attacks and defoliates several species of two and three needle pines. The tiny moth lays eggs singly on the current year's needles in midsummer; the first instar larvae overwinter as needle miners in the needle on which the egg was laid. In spring, larvae start to feed on the tender tissues within the sheath of newly developing needles. The needles are severed within the needle-sheath and webbing is present around the needle bases. Each larva needs about 10 fascicles for development, and under high populations nearly every new needle at the tip of each branch may be killed.

During late summer and fall, when the larvae are needle miners, they are difficult to detect. The only evidence of their presence is a threadlike mine along the edge of needles. During infestations, the first obvious symptom is fine silken webbing around the new needles. Then the new growth begins to fade and eventually turn brown. Larvae can be found within the webbing. Needles are attacked throughout their elongation period.

A number of natural controls exist for this moth. However, if pines become unsightly, moths can be controlled by spraying at the time new growth begins.

Important Forest Insects

BARK BEETLES: Bark beetles belong to the order Coleoptera and the family Scolytidae-insects which normally attack weakened, drought-stressed trees or downed timber. However, when populations of these insects build up, outbreaks can occur. For example, outbreaks of the mountain pine beetle (*Dendroctonus ponderosae*) can kill thousands of acres of ponderosa and lodgepole stands. Bark beetles have common traits and habits. They all excavate egg galleries in fresh phloem. The larvae feed away, at right angles from the egg gallery, and feed in the succulent phloem tissues. Patterns formed by both the original egg galleries and the larval mines is characteristic for each bark beetle species. Examples of some common bark beetles follow:

• DOUGLAS-FIR BEETLE (*Dendroctonus pseudotsugae*) (DFB): During years with normal amounts of fallen logs, emerging beetles will fly and disperse with the prevailing wind. In time, certain females will find their preferred host material, downed-logs. They will bore into the phloem and release a potent pheromone (chemical attractant) that will guide the dispersing population to the newly-found food material (host-selection behavior). The insects will then mate and each female will cut egg galleries within the phloem and lay about 30 to 50 eggs. These broods will develop within the logs and emerge the following spring as new adults.

In a year with large amounts of blow-down material there will be vastly more food material to colonize than during normal years. When surplus food and minimal host selection flight occur, the population will magnify dramatically. The year following the blowdown event, and assuming no additional major blowdowns, the increased DFB population would further multiply, and reattack the first-year's brood material, scattered stems which fell in winter, and possibly living trees.

During the third year, and assuming no major new blowdowns occur to absorb the now-immense DFB population, attacks on living trees are probable. In addition, if stands are under drought stress, a major DFB outbreak can occur. This scenario has been the historical pattern. As seen in Figure 4-4 below, previous large and unsalvaged-blowdowns were followed by large DFB outbreaks. Note the exception in the 1962 Columbus Day storm, when over 40,000 acres of western Washington timber was blown down, but timely salvage operations prevented subsequent bark beetle infestations.

Maintenance of stand vigor and prompt salvage of downed logs will prevent DFB outbreaks.

• MOUNTAIN PINE BEETLE (*D. ponderosae*) (MPB): During outbreaks, the MPB kills millions of cubic feet of timber annually. Although the beetles primarily invade weakened trees during periods of low population density, attacks on healthy trees are common during outbreaks. The beetles typically kill trees in groups.

Group killing of lodgepole pine occurs as follows. After initial host selection (as discussed with the Douglas-fir beetle), the attacking female beetles release an aggregating pheromone, a chemical that attracts other females as well as males to the selected tree. The selected host thereby serves as a focus tree. As the focus tree is mass-attacked, incoming beetles switch from attacking this focus tree to attacking adjacent, recipient trees. A mass-attacked recipient tree then becomes a focus tree and again incoming beetles may switch from attacking this new focus

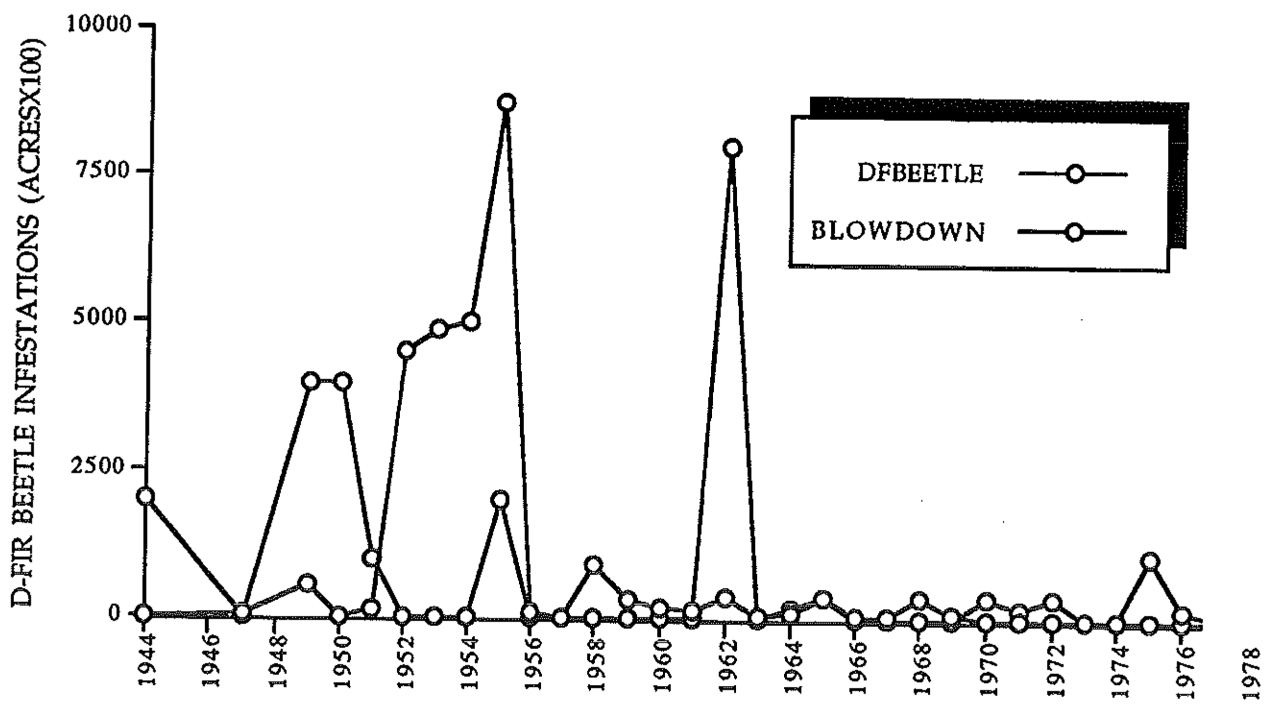


Figure 4-4. Relationship between blowdown of Douglas-fir stands and incidence of Douglas-fir beetle outbreaks.

tree to attacking new recipient trees. This switching mechanism is caused by a sequential functioning of aggregating pheromones attracting beetles to the focus tree, then anti-aggregating pheromones. Antiaggregants, produced by male beetles at the time of mating, prevent incoming beetles from attacking the already fully attacked tree. These hoards of repelled beetles then attack nearby trees at a precipitous rate. During switching (*i.e.*, beetles switching hosts from focus trees to recipient trees), beetles select a recipient tree by virtue of its diameter and distance from the focus tree. The largest-diameter lodgepole pines suffer the greatest mortality as the distance over which switching occurs is related to stand diameter, Figure 4-5. In lodgepole pine, therefore, if trees are spaced far enough apart, the switching of beetle attacks from tree to tree will not occur-the switching mechanism will be disrupted.

Thinning prescriptions to prevent the spread of MPB outbreaks and even to prevent widespread attack can be based on a regression equation as seen in Figure 4-5. For example, if the average stand diameter is about 25 cm (9.8 inches), the stand could be thinned so that the average distance between stems is about 7.5 m (24 feet). Actual thinning prescriptions must be based on empirical results from a variety of stand cuttings and beetle population densities.

The MPB also attacks 80- to 120-year-old stands of ponderosa pine in eastern Washington and Oregon. During 1988, for example, and following 2 years of drought, MPB populations increased steeply in Washington. By 1989-90, large areas of pine mortality were noted in the densest, most exposed sites. These were relatively pure 75- to 80-year-old ponderosa pine stands supporting mixtures of Douglas-fir and grand fir. The fire-protected stands developed soon after the original forests were harvested in the early 1900s. The stands are normally dense, differentiating, and stressed, where MPB outbreaks behave as follows: a) The sequence of attack in unthinned stands is not the discrete tree to tree selection (known as switching) common to lodgepole pine forests. Instead, the outbreak resembles a wavelike movement, in which trees are simultaneously attacked, progressing outward from the initially attacked focus trees and; b)

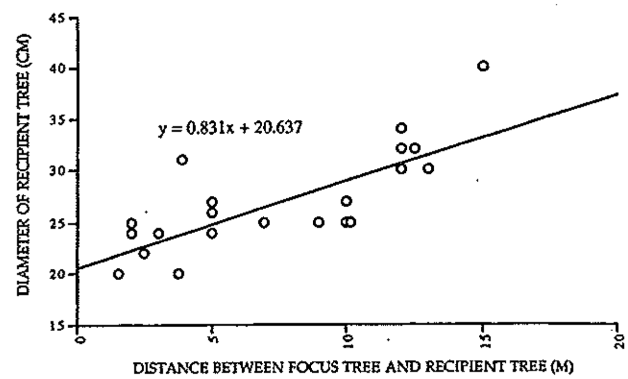


Figure 4-5. Relationship between diameter of recipient trees and distance over which MPB switch attacks from focus tree to recipient tree.

spacing control is effective in interrupting the wavelike movement of the outbreak. From thinning trials, it was established that 4-m, 6-m, or 8-m spacing treatments are effective in preventing the spread of localized outbreaks. In fact, most tree mortality only occurred in dense, unthinned control plots.

• PINE ENGRAVER BEETLE (*Ips pini*) (PEB): The PEB typically attacks logging slash, blowdowns and recently dead or dying pine trees. In spring, emerging populations disperse throughout the forest in search of new hosts. Eventually a male PEB finds a suitable host, and as he constructs a nuptial chamber within the phloem, he releases an aggregating pheromone. This chemical messenger attracts females and other males to the selected host-for example, a log within a slash pile. Each male upon completion of its nuptial chamber attracts several females into the chamber. After mating, each female constructs an egg gallery and lays eggs in notches cut into the margins of the galleries. Larvae mine in the phloem and eventually dig pupal cells and emerge as new adults. Depending on the area, two or more generations of *I. pini* may occur per season. When large quantities of slash or stands of severely weakened pines are present, (e.g., after a forest fire), PEB populations can increase and attack standing trees. Prevention of PEB problems can be easily accomplished by attending to slash removal and thinning of unthrifty trees before droughts.

DEFOLIATORS:

Insect defoliation of the forest can be recognized by the thinning or absence of foliage and the raining of frass (insect fecal matter and bits of foliage). Many larvae feed only on the softer parts of leaves, leaving a skeletal network of leaf veins. These insects are the skeletonizers. Leafminers, by contrast, bore inside and eat the tissues between the upper and lower epidermal walls of the foliage. The most damaging defoliators consume the foliage entirely. Some, such as the western spruce budworm (*Choristoneura occidentalis*) specialize on new growth, while others, (for instance the Douglas-fir tussock moth *Orgyia pseudotsugata*), consume new and old foliage. When defoliation is severe, frequent, or continuous, tree mortality can occur. Partial or less frequent defoliation always results in growth loss. Growth loss seriously affects management plans by lengthening rotations. From a commodity production viewpoint, this is the major impact of defoliation. Examples of common defoliators follow.

• WESTERN SPRUCE BUDWORM (*C. occidentalis*) (WSBW): This moth is the most important defoliator of true firs and Douglas-fir in western North America. The life cycle is as follows:

1) Eggs are laid in a shinglelike fashion on the underside of needles in late summer. They hatch in less than 2 weeks. 2) The tiny larvae spin silken hibernacula (silken shelters in which to overwinter) among lichen and under bark scales. 3) Next spring, as the buds of their host trees (either true firs or Douglas-fir) begin to swell, the larvae may either mine into old needles if the weather is cold and inhospitable, or spin silken threads and balloon with the wind as a means of dispersal. 4) Upon landing on a new host (or the original host), the larvae web together the expanding new needles and begin to feed on this tender new foliage. They also feed in developing cones and staminate flowers. 5) By July the new foliage is consumed and the last instars begin to pupate on the foliage to emerge as new adults. Female WSBWs call the males by means of a sex pheromone. After mating, egg laying begins again.

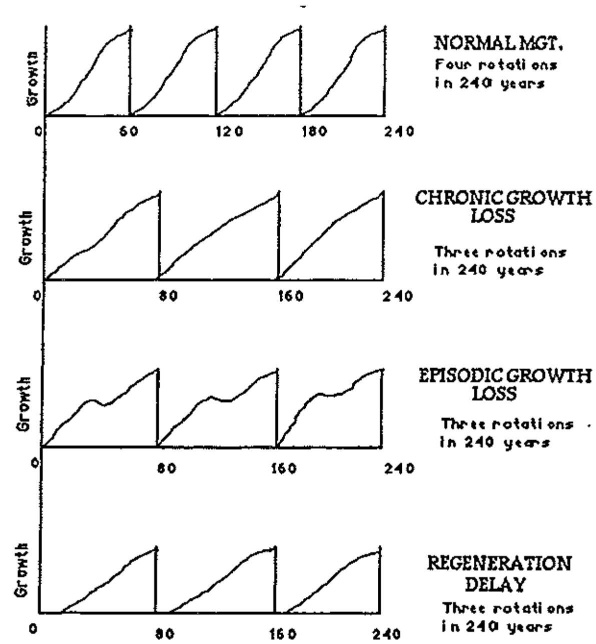


Figure 4-6. Impact of western spruce budworm outbreaks on management of fir and Douglas-fir forests.

The main problem with WSBW outbreaks is that they last for several years. Each year of the outbreak, the new foliage is cropped off and a substantial amount of the cone crop is lost. Accordingly, the stands grow more slowly and anticipated harvesting cycles are not met (Figure 4-6). In areas where timber management goals are important, long standing outbreaks have been treated successfully with *Bacillus thuringiensis.*

Generally, the most susceptible stands are uneven aged, multistoried stands with shade tolerant firs predominating in a dense understory. This stand condition is brought about by excessive attention to wildfire suppression. Late successional species are most susceptible as their buds break in synchrony with WSBW emergence. Mature host stands suffer more damage than younger stands because 1) at maturity, trees devote less energy to production of defensive foliar chemicals; 2) more overwintering sites exist for construction of hibernacula; 3) cone crops are more abundant (developing cones and staminate flowers produce the most nutritious WSBW food) and; 4) trees tend to be taller and more capable of intercepting windblown larvae. Consequently, WSBW damage is reduced by precommercial and commercial thinnings and by application of silvicultural techniques that favor pioneering species and nonhosts (ponderosa pine). Intermediate operations should include prescribed under-burnings.

• DOUGLAS FIR TUSSOCK MOTH (*O. pseudotsugata*) (DFTM): The DFTM are periodically severe defoliators of Douglas-fir, grand fir, and white fir. During extreme outbreak conditions, all conifers are defoliated. The DFTM belongs to a family of Lepidoptera called the hairy moths, the Lymantriidae, which includes the gypsy moth (*Lymantria dispar*). Adult DFTM emerge from loosely wound cocoons from late July through early September. The male is a robust, hairy moth with a wingspan of about 2.5 cm. The wingless female depends on a powerful sex pheromone to attract the male. Each female lays about 100 to 350 eggs per mass, which are covered with hairs from its body. The population overwinters within the egg masses. In spring, at budbreak of their host, the small larvae emerge and balloon with the prevailing winds. At first the larvae feed on the underside of new foliage, causing the needles to turn brown and curl. The larvae grow slowly at first, but during their 5th to 7th instars they grow progressively faster and consume both new and old foliage. In early July, the 7th instar larvae construct cocoons and emerge as new adults in 10 to 18 days. Populations of DFTM increase dramatically during population buildup. In the third year of an outbreak, large areas of host trees are defoliated, but by the fourth year an epizootic neucleopolyhedrosis virus occurs, and populations collapse.

Outbreaks have a 9-year cycle. By the 10th year, a major outbreak occurs somewhere in the host range of the moth. Apparently, this cycle depends on DFTM-virus interactions as well as on climatic cycles. As severe outbreaks are episodic, they can lengthen forest rotations as shown for the western spruce budworm in Figure 4-6. Unless stands are under intensive forest management regimes, applied control is unnecessary as the viral epizootic will control the problem. The following silvicultural prescriptions, however, are applicable: 1) where possible, manage stands for ponderosa pine, and 2) thrifty host stands recover growth faster than suppressed stands.

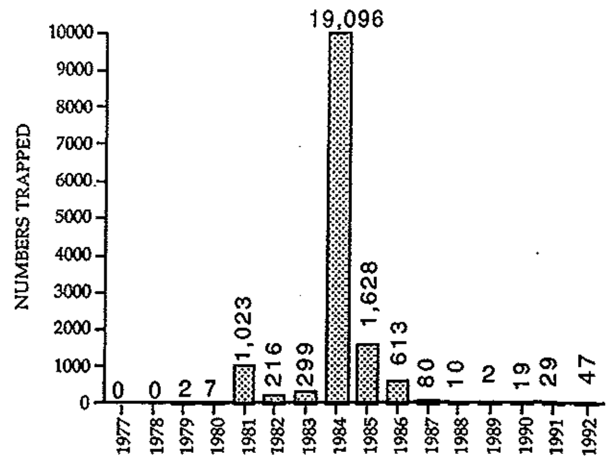


Figure 4-7. Annual number of gypsy moths trapped in Oregon.

• GYPSY MOTH *(Lymantria dispar(=porthetria))*: This as an introduced pest. Its native range is from northern Africa, throughout Europe and east through far eastern Russia and possibly other Asian countries and Japan. The gypsy moth was introduced into Medford, Massachusetts in 1869 by Leopold Trouvelot. He was raising silkworms and crossbreeding them with other moths to obtain hardy varieties. The moths escaped, and over the past century gypsy moths have spread through the hardwood forest of North America from Maine and the Canadian Maritime Provinces to the Lake States and south to North Carolina and Alabama. In 1973 spot infestations occurred in California. As gypsy moth egg masses attach to virtually any substrate, and as North Americans over the years have become increasingly mobile, the moths have been transported all over western U.S. and Canada. For example, the Pacific Northwestern states have had a long-standing program of sampling incoming L. dispar populations by means of pheromone traps (Figure 4-7). When local infestations are identified, control measures are initiated by regulatory agencies.

The gypsy moth has an extremely varied and flexible diet of over 400 hosts. During population buildup nearly all plants can be fed upon; during latent phases typical food would include oak, alder, apple, poplar, and other hardwoods. In eastern North America and far eastern Russia they also feed on larch. The life cycle of *L. dispar* follows.

1) Females of the European variety of the gypsy moth do not fly, but the far eastern Russian variety does fly over 30 km and is attracted to light. In North America, the flightless females lay egg masses with up to 300 eggs per mass between early July and late August depending on to the region. 2) The population overwinters in the egg stage, and new larvae hatch the following May or June. The larvae begin to feed at once. If the population is high, many will disperse with the wind. This is an effective way to disperse the population. 3) Larval feeding continues for 2 to 3 months. The last instar is the most voracious feeder. During this latter period the caterpillars devour 60% to 70% of the foliage they will eat in their lifetime. 4) Mature caterpillars find a sheltered area anywhere, and weave a dark cocoon of silk and larval hairs. Emergence of adults begins some 10 to 17 days later.

Several strategies are used to control of local populations: trapping out the males with pheromone traps, confusing males by saturating an area with synthetic pheromone, placing burlap barriers around the boles of trees in home or parks (early larval stages hide during daylight hours beneath these barriers), or by using insecticides. The most common products used are bacterial formulations of *Bacillus thuringiensis*. During 1992, the states of Oregon and Washington, as well as the Province of British Columbia, successfully eradicated introductions of the Asian gypsy moth by judiciously applied *B. thuringiensis* sprays. This eradication program was especially beneficial because if the Asian variety of the moth had established, it would have been difficult to halt its advance. Asian gypsy moth is very similar to the European species, except that females can fly for 20-30 miles. This can increase the rate of dispersal to adjacent forest areas. The larvae also feed on a greater variety of host plants than their European counterparts (e.g., larch is a favored host). The population is adapted to cold climates, and larval emergence is precocious and unpredictable.

• OTHER DEFOLIATORS The pine butterfly (*Neophasia menapia*) is an occasional, important pest of ponderosa pine. Under ordinary conditions, larvae feed only on older needles, but under outbreaks they eat both new and old needles. Early larval stages feed gregariously on single needles at first, but later instars feed individually. Mature larvae migrate to bark crevices, limbs, or twigs, or they may lower themselves on silken threads to other vegetation, where they pupate.

Another defoliator of ponderosa pine is the large and gaudy Pandora moth (*Coloradia pandora*). Outbreaks generally occur in areas with soils loose enough for the mature larvae to bury themselves prior to pupation-for example, the pumice soils of Oregon and decomposed granite soils of the Rocky Mountain States. Epidemics seem to occur every 20 to 30 years, but once established an outbreak can continue for 5 to 8 years.

Adults are large, heavy-bodied moths with wing spans of 90 mm or more; the males have feathery antennae, and females have slender antennae. Egg laying occurs in late summer, when hundreds of pearl-like eggs are placed on foliage and on bark. The young larvae feed gregariously during August and early fall on new needles. These immature caterpillars spend the first winter in clusters at the base of needles. They resume feeding the following spring, and the larvae reach full growth by the end of June. At that time they crawl down the trees and enter the soil where they form pupal cells and pupate. They stay as pupae for an entire year before transforming into adults.

The western hemlock looper (*Lambdina fiscellaria fiscellaria*) is periodically destructive in coastal western hemlock forests. It also feeds on associated Sitka spruce, Pacific silver fir, and Douglas-fir during outbreaks. Heaviest losses of timber occur in old-growth stands. However, outbreaks can occur in healthy 80- to 100-year-old stands. Thus, this defoliator may pose a threat to new and innovative forest management plans.

The delicate brownish moths fly, mate, and lay eggs in fall through October. The tiny, bluish eggs are attached to moss and lichens on boles and limbs of host trees. The winter is passed in the egg stage, and the eggs hatch the following spring. The young larvae are banded with a white and gray color. They crawl to the foliage and begin feeding from May through the early part of July; buds and new growth are most vulnerable to damage at this time. From July to early fall heavily infested forests become chlorotic. The foliage looks thin as the later instars devour not only needles but also small twigs. At maturity the buff colored caterpillars drop to the ground on silken threads. They pupate in sheltered sites such as moss or bark crevices or under debris on the ground and there transform themselves into mottled, greenish pupae, about 12 mm long.

Outbreaks of the WHL last about 3 years. They are brought under control by complexes of parasites, predators and a viral disease. Heavy rains during the flight period also have historically served to lessen the impact of WHL population buildups. In the past, heavy loss of timber has been averted through aerially spraying insecticides. If future aerial control is deemed necessary to mitigate losses, undoubtedly *Bacillus thuringiensis* will be tried or possibly formulations of the pests' nucleopolyhedrosis virus.

Sawflies are another group of defoliators that belong to the order Hymenoptera. The adults differ from other members of the Hymenoptera in that the abdomen is broadly joined to the thorax. The name sawfly is associated with the sawlike ovipositor which females use to cut slits in foliage to lay their eggs. Sawfly larvae can be separated from those of the moths and butterflies by presence of seven or more abdominal false-legs (prolegs), most lepidopteran larvae have five or fewer prolegs. Also, sawfly larvae have two simple eyes, caterpillars have many more. Sawfly larvae, e.g., the hemlock sawfly, *Neodiprion tsugae,* which feeds on needles of western hemlock and Douglas-fir, characteristically feed gregariously. Pupation occurs in tightly wound cocoons in the duff or soil. Although forest defoliations caused by sawflies have impacted growth in the eastern and southern United States, their effects on growth of western forests, as yet, have not been a problem.

Regeneration Pests

Intensive forest management assumes that new stands will develop in normal fashion when forests are opened after harvesting or other silvicultural operations. Since establishment of genetically selected seedlings (i.e., growing stock selected for fast growth and good form) is a major financial commitment, damage to seedlings and small trees cannot be tolerated. The following serve as examples of these pests.

Cone and Seed Insects

Seed loss due to insect herbivory is a major concern in seed orchards of the Pacific Northwest; losses commonly range from 10% to 60% of the annual crop. Factors that determine the severity of insect damage are complex. Fluctuations in seed crops, insect population levels, overwintering losses of pest species, and general abiotic factors are all important; moreover, insect problems differ from one locale to another, and from one year to the next. Examples of cone and seed insects follow.

• The Douglas-fir seed chalcid, a tiny wasp *(Megastigmus spermotrophus),* feeds within Douglas-fir seeds and devours their contents. After feeding, the small, grublike larvae remain within the seed coat. No external evidence of damage appears until the miniscule adult wasp emerges, after which a clearly defined hole is evident in the seed. Prior to adult emergence, insect damage can be detected and quantified by destructively sampling seeds or by x-ray techniques.

Adults emerge from infested seeds in late spring. The females insert their ovipositors into young cones and deposit an egg into each seed selected. A larva spends its entire life within one seed while feeding during June and July. Larvae overwinter within seeds and pupate in spring.

• Douglas-fir cone moths, *Barbara colfaxiana,* at first damage developing seeds as larvae feed on scale tissues; more mature larvae feed on the seeds. Although infested cones are often attacked only by one larva, multiple infestations are common. A single larva will destroy about 65% of the seed in a cone; three or more will destroy all the seeds.

The moth emerges when host flowers open for pollination, the latter half of April to early May. The moth flies at dusk and is active when the temperature is above 15°C. The female lays its eggs, usually singly, on the outer surface of cone bracts. When the egg hatches, the young larva tunnels into a cone scale and feeds there on seeds for several weeks, gradually moving towards the cone axis. It pupates in a tough pitch-coated cocoon during the last half of July. The insect overwinters as a pupa in the cone, which usually remains on the tree.

• The fir coneworm, *Dioryctria abietivorella*, feeds on cone tissues and seeds of Douglas-fir, spruce, and ponderosa pine. The larvae feed voraciously and tunnel indiscriminately through scales and seeds. Tunneling larvae leave holes and considerable amounts of coarse frass on cone surfaces; infested cones are completely destroyed. The life history of this pest is variable and only partially understood. Some larvae pupate in cocoons on the ground during July, August and September; these emerge in late summer or fall and lay eggs on foliage. The population then overwinters as eggs. Another segment of the population overwinters as prepupae in cocoons in the litter, pupates in March and April, emerges as adult moths in May and June and then lays eggs on cone scales.

• The Douglas-fir cone midge, *Contarinia oregonensis*, is a fly whose maggots produce an expanding gall on the cone scale. The developing gall fuses with the developing ovule and causes its collapse. The gall then turns into an apartmentlike shelter for up to 30 tiny maggots per gall. Severe infestations will destroy all seeds in a cone. Under severe conditions cone scales will die prematurely and turn reddish by July or August. This provides the only external evidence of damage by this midge.

Adult midges emerge from puparia (cocoonlike structures) in the litter during April when Douglas-fir flower buds are opening. The midges deposit eggs near the base of the cone scales in the newly opened flower at the time of pollination. When the eggs hatch, orange larvae tunnel into the young cone scales and form galls near the ovules. After the maggots mature, they fall to the ground during the first autumnal rains. These larvae often select old male cones on the ground in which to overwinter. Pupation occurs from February through March.

• The cone bug, *Leptoglossus occidentalis*, sucks the contents of conifer seeds while standing on the outer surface of the cone. Adults overwinter in protected places, including buildings. They break winter stupor in early summer and commence to feed by inserting their tubelike mouth parts into developing seeds. As adults, they lay eggs on the foliage.

Since establishment, maintenance and seed harvest are an expensive undertaking, maximum seed yield is essential. Accordingly, it often is necessary to protect crops with insecticides. Generally, because of the variation in cone crops and insect abundance, it is not necessary to control pests yearly. Information on the condition of the cone crop the previous year aids in deciding if and when to apply insecticides. If the previous cone crop was large and heavily infested, then it is likely that cone and seed insects will attack the current crop. The greatest problem arises if the current cone crop is smaller than last season's; in this case, insects may destroy the entire current year's crop. Generally, a decision to spray depends on a working cone and seed sampling system. Timing of sprays is determined in early spring by sampling for insect eggs. In Douglas-fir, this sampling takes place when the young cones are closing and turning down.

Nursery Insect Pests

Seedlings in forest nurseries, whether grown in containers or as bare root stock, are susceptible to insects that attack roots, stems, and foliage. These insects are able to cause more injury at this stage than later when the trees have well developed roots, stems, and crowns. Nurseries, like seed orchards, are capital intensive operations. They too can have pest problems, but damage can be prevented or minimized through monitoring, vigilence, and the application of chemical and cultural controls.

The major groups of insects infesting seedlings are weevils, white grubs, cutworms, wireworms, aphids, scales, sod webworms, thrips, hemipterans (bugs), and mites. Some of these pests are also forest insects, while others are agricultural-related insects adapting themselves to the nursery environment. These pest problems vary between nurseries and from year to year. Therefore, it is important to maintain a computerized journal of the problems and the control techniques applied.

Some preventive measures such as soil fumigation or treating soil with insecticides are done periodically for soil inhabiting insects and pathogenic fungi. Plowing beds and planting them to cover crops or allowing them to remain fallow for a year also reduces pest problems.

• WHITE PINE or SITKA SPRUCE WEEVIL(*Pissodes strobi*) Sitka spruce is one of the fastest growing and most desired tree species in coastal forests of the Pacific Northwest. This shade tolerant species has excellent pulping qualities, is resistant to animal browse, and tolerates most herbicides. Its light wood, having excellent mechanical properties, is highly prized on the export market. However, successful establishment of Sitka spruce is frustrated by attacks of the Sitka spruce tip weevil. These weevils lay their eggs in cortical tissues of the previous year's terminal. The eggs hatch, and larvae mine downward in the cortex. This results in death of both the previous year's leader and the current year's leader. The following year, an apical bud takes dominance and a new shoot is established; in about 3 years this terminal growth is again susceptible to tip weevil attack.

Weevils oviposit in spring; 90% of the oviposition is completed by the second week in May. The greatest concentration of egg punctures is located on the northwest side of the previous year's terminal. Leaders over 40 cm (16 inches) long and over 0.7 cm (0.3 inches) in diameter are preferred for oviposition. One or two eggs are inserted in each ovipositional puncture. Eggs hatch within 2 weeks, and the larvae mine the cortex. Larvae require between 2 to 3 months to develop, depending on weather conditions. Weevil pupation occurs in August or September for 2 weeks within chip-cocoons inside the pith. Adults emerge in early fall. The adults remain hidden in the foliage during winter. The males are sexually mature, and the females have undeveloped ovaries. The next spring, females disperse to other terminals and feed in the phloem of these terminals to mature their ovaries. Then they produce an attractant to bring in males. After mating, the gravid (sexually mature and mated) females seek out for oviposition the fastest growing terminals in which to oviposit.

Sitka spruce damage can be mitigated by the following silvicultural means:

1) Sitka spruce growing within 1.6 to 3.2 km (1 to 2 miles) of the Washington State coast are not infested by weevils. Therefore, Sitka spruce generally can be planted within this coastal strip. 2) Moderate weevil damage occurs within 3.2 to 32.2 km (2 to 20 miles) of the coast. Locate these moderate-damage areas (i.e., areas with 5% to 8% damage) by surveying and quantifying the present weevil damage of potential planting sites. The Sitka spruce tip weevils prefer to mate and oviposit in direct sunlight and under warm conditions. Cool conditions such as occur in coastal forests, which prevent the presence of weevils, can be attained by planting spruce under a cover crop such as red alder. The shade tolerant spruce will continue to grow under the red alder until the spruce overtop them in about 30 to 40 years. Then these Sitka spruce can be released without worry of subsequent weevil damage, as the tip weevil mostly attacks trees under 9 m tall (30 feet). 3) Another approach to tip weevil management is to establish spruce in discrete stands, where each stand is separated from its neighbor by about 2.5 km (1.6 miles). Then the young stands are treated with an insecticide. As tip weevils do not disperse over long distances, the treated stands will not accrue a new and damaging weevil population for about 5 to 8 years. Then a decision to apply controls can be made again. However, by then at least one basal log will be clear of weevil damage.

• REPRODUCTION WEEVILS and BARK BEETLES: A complex of weevils (*Pissodes fasciatus* and *Steremnius carinatus*) and bark beetles *(Hylastes nigrinus)* can impact the development of young plantations. As intensive forest management will depend on healthy plantations, any organism affecting the stocking and health of these stands will become important, especially since plantations represent an early financial investment that will be carried for 45 to 50 years. These insects develop in the roots of recently created stumps and dead and dying trees. Both weevil species, upon emerging from their brood material, feed on subcortical tissues of young trees or seedlings. Large populations of the weevils can kill newly planted seedlings. However, the biggest threat posed by this beetle-weevil complex is that the pests all are potential vectors of the black stain root disease (*Ceratocystis wagneri*). For example, when Douglas-fir stands are thinned before these insects disperse (*S. carinatus* does not fly) the disease is transmitted to the new stumps after dispersal occurs. The worst time to thin is in winter. It has been shown in one study of winter thinning in Oregon, that 15-year-old dense stands, thinned to 300 stems/acre (600 stems/ha), developed black stain root disease in an additional 15% of the leave trees during the next 6 years. As intensively managed forest plantations are new to the Pacific Northwest, managers must become aware of the potential damage caused by these insects.

Wood Products Insects

Important pests of buildings and other wood products in the Pacific Northwest are the powder post beetles, termites, carpenter ants, horn tail wasps, ambrosia beetles, and wood borers.

• POWDER POST BEETLES: Three important beetle families are included in this group of damaging insects-the Anobiidae, Lyctidae and Bostrichidae. Anobiids and bostrichids frequently infest dried coniferous wood, while lyctids are mostly found in hardwoods. The most damaging powder post beetle (Anobiidae) of this region is the Pacific powderpost beetle, *Hadrobregmus gibbicollis*. These beetles attack the under portions of older buildings as well as structural timbers and subflooring. The adults lay eggs in cracks and fissures of construction timbers. The larvae feed in the dry sapwood of this material and render the substrate to a fine powder. They pupate within the wood. New adults then reenter the timbers and lay eggs in sound wood. The new crop of larvae proceeds to mine and feed in the sapwood. The only sure way to control the problem is to replace seriously damaged wood and fumigate the entire structure or dwelling.

• TERMITES: Two termite species thrive in the Pacific Northwest, the Pacific dampwood termite (*Zootermopsis angusticollis*), and the western subterranean termite (*Reticulitermes hesperus*). In autumn, winged forms of the dampwood termites issue from their colonies and swarm. The sexes pair off, fall to the ground and remove their wings. After mating, the female constructs a small cavity in damp, rotting wood. She lays a few eggs in the cavity. After hatching, the nymphs begin to tunnel in the wood and feed the queen by regurgitating the digested wood. Eventually the expanding colony contains working nymphs, soldiers with large heads armed with a pair of long, black, toothed mandibles, and winged reproductives. These termites frequently colonize houses and other wooden structures that have a moisture problem, such as leaking downspouts, leaky pipes, leaking roofs, and so forth. When this material begins to rot, dispersing reproductives find the spot and begin their colony. The most effective way to solve *Z. angusticollis* problems is to solve the moisture problem and replace the infested material.

Colonies of the western subterranean termites include workers, reproductives and soldiers. These indivduals are much smaller and darker than the dampwood termites. Following the first rains of autumn, winged reproductives emerge in a swarm, mate, shed their wings, and find a rotting, buried piece of wood. After establishing a colony in this material, the queen continues to lay eggs until, after a few years, a typical colony may have a couple of hundred thousand individuals. These termites frequently build earthen tubes over concrete foundations to get to new sources of wood above their colony. Once the tunnels are complete and contact is maintained with their buried colony, the termites can rapidly cause serious structural damage. Damage can best be prevented by a combination of structural and chemical means, including eliminating situations where wood is in contact with the soil, removing wood in crawl spaces and wood left on foundation forms.

• CARPENTER ANTS: These large black ants, *Camponotus* sp., are largely beneficial as they contribute to forest recycling by increasing the surface area for establishment of decay organisms in stumps, fallen logs, and other large woody debris. However, they also can establish satellite colonies in human dwellings and structures that are close to their primary nests.

Similar to the dampwood termites, carpenter ants frequently begin their initial colonies in rotting wood. After initial establishment, they tunnel into sound wood. Unlike termites, carpenter ants do not feed on wood, rather they construct their brood tunnels in the wooden substrate. These ants are scavengers and predators that bring numerous insects into their tunnels to feed the colony. Carpenter ants can be difficult to control. Ant colonies in more secluded areas of human structures must be located and destroyed by chemical means. Location of the parent colony, correcting moisture problems, treating both parent and satellite colonies, and removal of vegetation or wood piles against the structure are all methods to be used in concert.

• HORN TAIL WASPS: These generally large, often colorful wasps are called horn tails because the ovipositor is prolonged into a piercing, awl-like appendage. Larvae also have a spikelike prolongation at the dorsal tip of the abdomen. Females lay their eggs through the ovipositor, which is thrust through the bark of dead and dying trees and into the sapwood for a depth of a 2.0 to 6.4 cm or more (1.0 to 1.75 inches). Often the females are attracted by infrared emissions from recently fire-scorched trees and logs. Eggs deposited in the sapwood hatch, and the larvae bore through the wood. When this material is salvaged and manufactured into air-dried lumber, the horn tail larvae complete their life cycle, and sometimes emerge within houses. Generally, other than a nuisance, these insects do not affect the mechanical integrity of lumber. In any case, kiln drying the lumber would prevent this problem.

• THE AMBROSIA BEETLES: Ambrosia beetles are farmers. They emerge in spring from brood cells cut in the wood, called cradles, and disperse through the forest. Eventually, dispersing females (or males, depending on the species) sense tiny amounts of ethyl alcohol produced by fermenting sugars within the phloem of fallen trees. These insects then land on the logs and send out a pheromone that guides the flying population to the newly found hosts. After mating, each female bores deep into the wood, cuts cradles at right angles to these tunnels, and lays eggs in the cradles. Then, she sows spores from a special structure near her head and propagules of ambrosia fungi in the cradles and tunnels. The fungi grow and provide food for developing larvae.

The myriad of small, black-stained holes punched into logs by heavy ambrosia beetle attacks severely degrade logs and drastically lower lumber grades. This problem is exacerbated in the log and lumber export market, as buyers often will not accept material with ambrosia beetle holes. As in the case of the Douglas-fir beetle, ambrosia beetle populations build up geometrically the year following a blowdown event. Downed logs are riddled with attacks and white frass (boring debris from the wood) the invading females push out of the logs.

• FLAT HEADED AND ROUND HEADED WOOD BORERS: Females of these two families of beetles (the Buprestidae and Cerambycidae, respectively) deposit eggs within or on the outer bark of logs. The larvae bore through the bark and into the fresh phloem. Months later, as the succulent phloem eventually ferments and degrades, the larvae bore straight into the wood and continue enlarging their feeding galleries as they grow. Additional attacks the following year by an increased population serve to decimate the logs and drastically lower their value as sawlogs.

In a beneficial sense, wood borers serve to increase the surface area of the wood; this action hastens decay of the material.

Robert I. Gara is a Professor in the College of Forest Resources, University of Washington, in Seattle, Washington

Appendix 2

Forest Environment Pesticide Study Manual

APPENDIX 2; Part A:

Important Forest Insects of the Pacific Northwest and their Hosts

Insect Species	Common Host	Occasional Host
Bark Beetles		
Douglas-fir beetle (*Dendroctonus pseudotsugae*)	Douglas-fir	western larch, western hemlock, western redcedar
western pine beetle (*Dendroctonus brevicomis*)	ponderosa and coulter pine	all other pines
mountain pine beetle (*Dendroctonus ponderosae*)	all pines	———
spruce beetle (*Dendroctonus rufipennis* [kby. 1])	Englemann spruce	all spruces
red turpentine beetle (*Dendroctonus valens*)	ponderosa pine	all other pines, spruce, larch and other conifers
pine engraver (*Ips pini*) and other species	ponderosa, Jeffrey, and lodgepole pines	all other pines
silver fir beetles (*Pseudohylesinus* spp.)	pacific silver fir	true firs, Douglas-fir, and hemlock
Douglas-fir pole beetle (*Pseudohylesinus nebulosus*)	Douglas-fir	———
Douglas-fir engraver (*Scolytus unispinosus*)	Douglas-fir	true firs, hemlock
fir engraver (*Scolytus ventralis*)	true firs	Douglas-fir, hemlock and spruce
pitch moths, two species:		
sequoia pitch moth (*Vespamina sequoiae*)	pines	Douglas-fir
Douglas-fir pitch moth (*Vespamina novaroensis*)	Douglas-fir	spruce, pines
bud, shoot, and twig insects		
weevils:		
Englemann spruce weevil* (*Pissodes strobi*)	sitka spruce	other species of spruce and all pine
other species of *Pissodes* and *Cylindrocopturus*	other conifers	———
twig beetles:		
various species	all trees	———
shoot moths:		
various species	all trees	———
Root insects		
various species of white grubs, weevils, wireworms, and symphylids	all trees	———
Cone and seed insects		
various species of moths, beetles, weevils, midges, and wasps	all trees	———
Wood borers		
Flatheads:		
California flatheaded borer (*Melanophila californica*)	all pines	———
flatheaded fir borer (*Melanophila drummondi*)	Douglas-fir	true firs, hemlock and larch
sculptured pine borer (*Chalcophora angulicollis*)	pines, firs, Douglas-fir	———

*Now includes the sitka spruce weevil and white pine weevil.

APPENDIX 2; Part A (continued)

Insect Species	Common Host	Occasional Host
Wood borers (continued)		
golden buprestid (*Buprestis aurulenta*)	all conifers, ponderosa pine, and Douglas-fir	spruce and fir
western cedar borer (*Trachykele blondeli*)	western red cedar	other cedar, juniper, cypress
Roundheads:		
ponderous borer (*Ergates spiculatus*)	Douglas-fir, pines	other conifers, other pines, true fir, redwood
California prionus (*Prionus californicus*)	Hardwoods and softwoods	———
sawyers (*Monochamus* spp.)	pines, firs, Douglas-fir, spruce	———
Ambrosia beetles		
Wilson's wide-headed ambrosia beetle (*Platypus wilsoni*)	true firs, western hemlock, Douglas-fir	other conifers
(*Gnathotrichus* spp.)	all conifers	hardwoods
(*Trypodendron* spp.)	all conifers	hardwoods
(*Xyleborus* spp.)	hardwoods	softwoods
Termites		
dampwood termite (*Zootermopsis angusticollis*)	all damp decaying wood	———
western subterranean termite (*Reticulitermes hesperus*)	all wood	———
Arid land termite (*Reticulitermes tibialis*)	all wood	———
Carpenter ants		
(*Camponotus* spp.)	all wood	———
Defoliators		
western spruce budworm (*Choristoneura occidentalis*)	Douglas-fir and true firs	larch
spruce budworm (*Choristoneura fumiferana*)	true fir, spruce	———
western black-headed budworm (*Acleris gloverana*)	true firs, hemlock, spruce	Douglas-fir
Douglas-fir tussock moth (*Orgyia pseudotsugata*)	Douglas-fir, true firs	ponderosa pine, lodgepole pine
pandora moth (*Coloradia pandora*)	ponderosa pine, lodgepole pine	other pines
pine butterfly (*Neophasia menapia*)	ponderosa pine	all pine, Douglas-fir
western hemlock looper (*Lambdina fiscellaria lugubrosa*)	western hemlock	sitka spruce, pacific silver fir, Douglas-fir, hardwoods
tent caterpillars (*Malacosoma* spp.)	most hardwoods	———
fall webworm (*Hyphantria cunea*)	most hardwoods	———
western oak looper (*Lambdina fiscellaria somniaria*)	oaks	———
silver-spotted tiger moth (*Halisidota argentata*)	Douglas-fir, pine	other conifers
larch sawfly (*Pristiphora erichsonii*)	western larch	other larch
sawflies: (*Neodiprion* spp.)	pines, true firs, hemlock	Douglas-fir
needle miners (*Coleotechnites* spp.)	ponderosa pine, lodgepole pine	fir, juniper, spruce, cypress
cone and needle midges (*Contarinia* spp.)	Douglas-fir	———
alder flea beetle (*Altica ambiens*)	alder, poplar, willow	other hardwoods (by other species)
Sapsucking insects		
aphids:		
spruce aphid (*Elatobium abietnum*)	spruces	pine, Douglas-fir
other aphids		
(*Pineus* spp.)	spruce	true fir, pine
(*Cinara* spp.)	conifers	———

APPENDIX 2; Part A (continued)

Insect Species	Common Host	Occasional Host
Adelgids		
balsam woolly adelgid (*Adelges piceae*)	true firs	———
Cooley spruce gall adelgid (*Adelges cooleyi*)	Douglas-fir, spruces	———
hemlock woolly adelgid (*Adelges tsugae*)	western hemlock	———
Scale insects:		
pine needle scale (*Chionaspis pinifoliae*)	ponderosa pine, lodgepole pine	other pines, Douglas-fir, spruce, cedar
black pineleaf scale (*Nuculaspis californica*)	ponderosa pine, lodgepole pine	other pines, Douglas-fir
mites	all trees	———

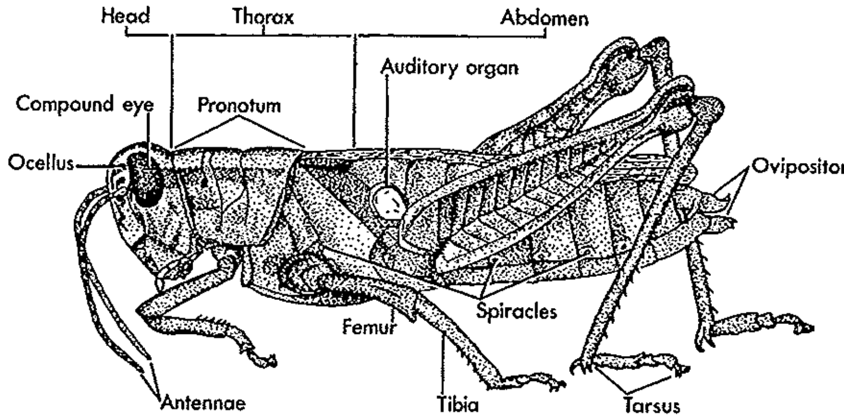


Figure 4-8. Reprinted with the permission of Macmillan College Publishing Company from INVERTEBRATE ZOOLOGY by Robert W. Hegner and Joseph G. Engerman. Copyright © 1969 by Macmillan College Publishing Company, Inc. Figure 11-1, page 472. A female grasshopper showing the main characteristics of the arthropod class Insecta: 1) three body regions: head, thorax, and abdomen, 2) one pair of antennae, 3) three pair of legs, and 4) wings.

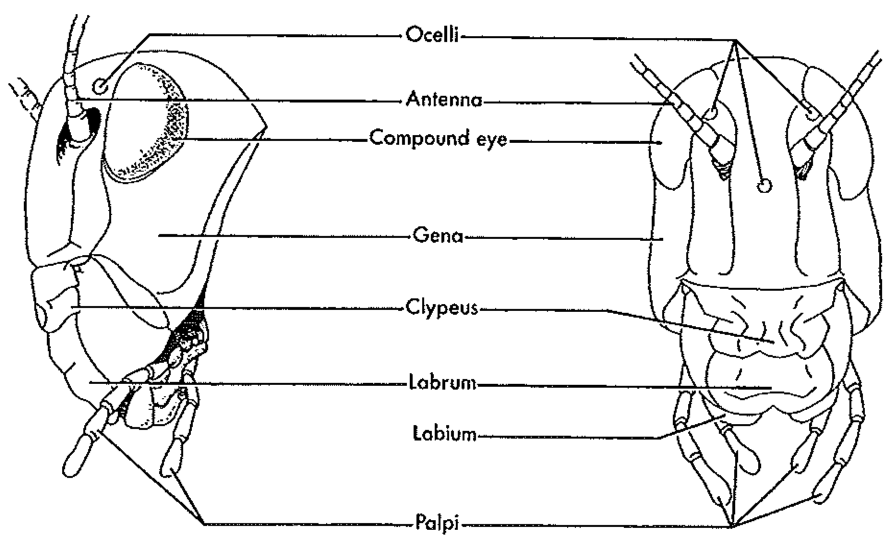


Figure 4-9. Reprinted with the permission of Macmillan College Publishing Company from INVERTEBRATE ZOOLOGY by Robert W. Hegner and Joseph G. Engerman. Copyright © 1969 by Macmillan College Publishing Company, Inc. Figure 11-2, page 472. The head of a grasshopper showing arrangement of antennae, eyes (simple and compound), and mouthparts.

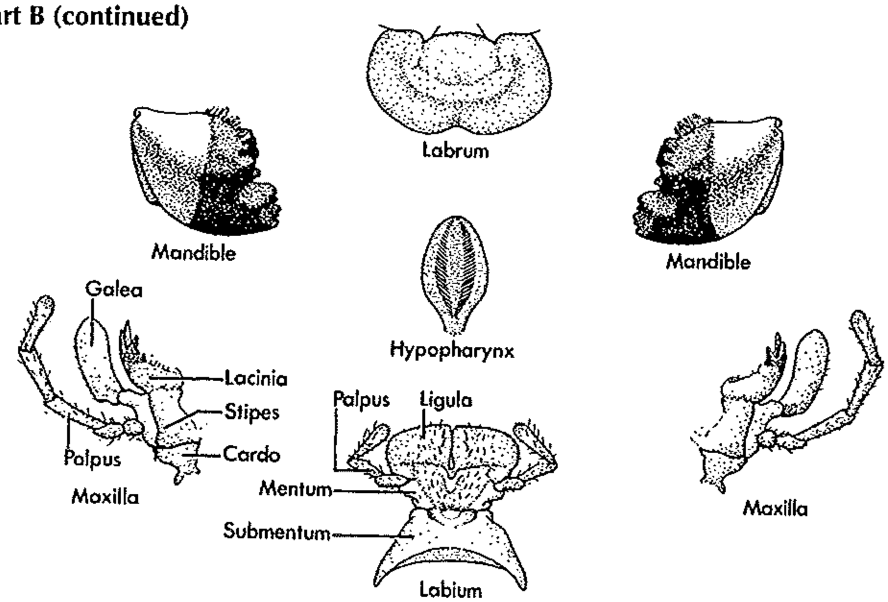


Figure 4-10. Reprinted with the permission of Macmillan College Publishing Company from INVERTEBRATE ZOOLOGY by Robert W. Hegner and Joseph G. Engerman. Copyright © 1969 by Macmillan College Publishing Company, Inc. Figure 11-3, page 473. Individual mouthparts of a grasshopper, typical for insects that chew their food. Note the massive mandibles used in grinding and tearing while the maxillary and labial palps serve to poke food into the mouth.

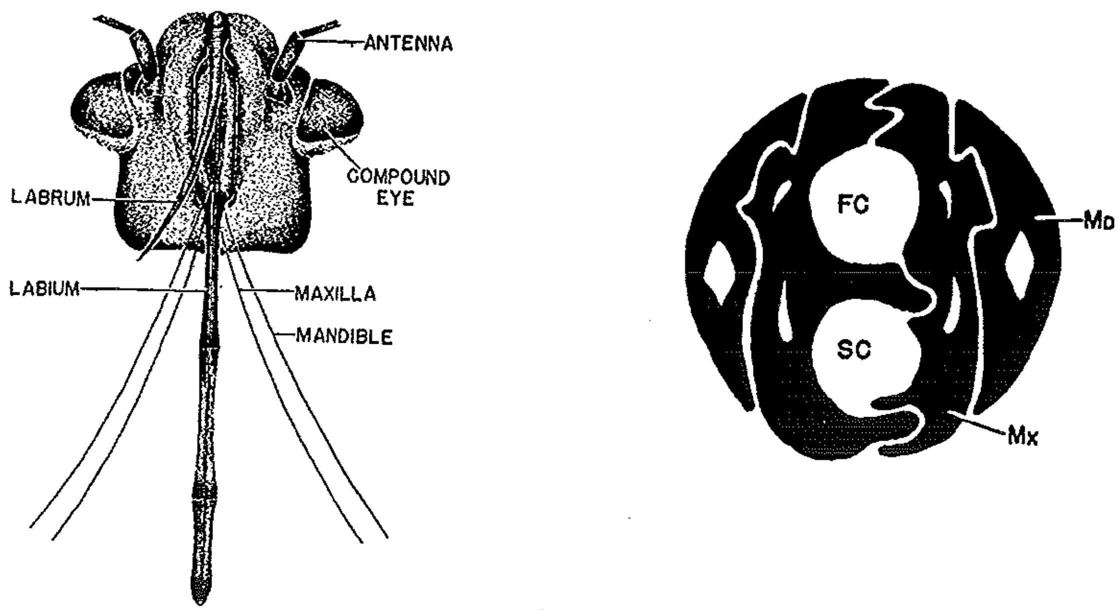


Figure 4-11. Figure 31, page 44; figure 32, page 45 from GENERAL AND APPLIED ENTOMOLOGY by V. A. LITTLE. Copyright © 1957 by Harper & Brothers. Copyright © renewed 1985 by V. A. Little. Reprinted by permission of HarperCollins Publishers, Inc. Mouthparts of insects with piercing-sucking mouthparts such as stink bugs, seed bugs, aphids, scales, leafhoppers (left). A cross section of the mandibles and maxillae when these parts (called stylets) are held together forming a feeding tube. When the double-grooved maxillae (MX) are held together they form a food canal (FC) and a salivary canal (SC). The outside pair of stylets are the mandibles (MD). The MD are forced into plant tissues until they produce a puncture. The MX then are forced into the puncture and plant sap comes up the FC, while insect saliva with enzymes moves down into the plant tissues along the SC.

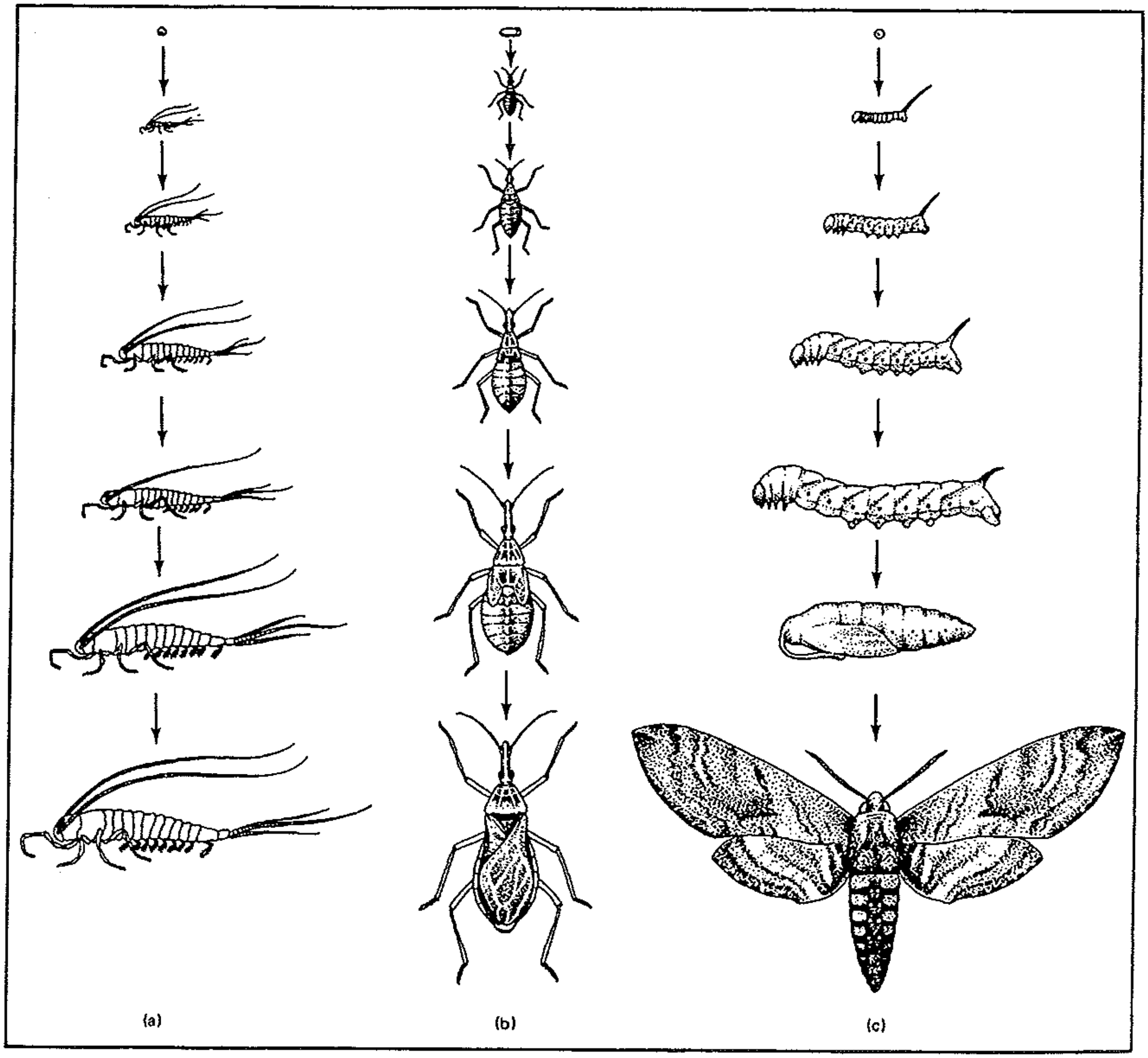


Figure 4-12. Adapted from Insect Biology by Howard E. Evans. Copyright © 1984 by Addison-Wesley Publishing Company. Reading, MA. Reprinted by permission. Figure 4-2, page 96. The three principal kinds of metamorphosis found in the Class Insecta: a) no metamorphosis (e.g., silverfish); b) gradual metamorphosis (e.g., assassin bug); and c) complex metamorphosis (e.g., sphinx moth).

Chapter Five

Maintaining Good Forest Health: Forest Diseases

Kenelm Russell

Appendix 3

Chapter Five

Maintaining Good Forest Health: Forest Diseases

Kenelm Russell

This chapter describes factors that reduce forest health, but emphasizes actions that produce and maintain healthy forests and forest ecosystems. Forests contain a diverse mix of organisms, which almost always include some level of disease and injury. As part of the diversity, disease and damage should not materially detract from acceptable growth and production of the forest.

The desired state of Forest Health then, is a condition where biotic and abiotic influences on the forest (pests, silvicultural treatments, and harvesting practices) do not threaten management resource objectives now or in the future. This concept of Forest Health applies whether it is a backyard woodlot, a timber-producing forest, a wildlife area, a park, or even a wilderness area.

Before discussing the agents of change which affect forests, it is necessary to understand terminology and concepts used to describe forest diseases.

Terminology and Concepts used in Forest Diseases

Stress, injury, disease, and damage

Injury and disease can be separated by the duration of stress factors upon the tree. Injury is the result of a single damaging event (stress) such as a spring frost, which kills new foliage within a matter of hours, or a winter freeze, that kills foliage during the following growing season. Disease is different in that the stress factor must cause a sustained adverse effect on the trees. The adversity may cause death or only growth loss.

Forest damage occurs as economic or otherwise unacceptable loss. For example, a healthy unit of forest produces a certain timber volume over a rotation commensurate with normal site factors. A disease condition on the unit reduces volume, and the resulting shrinkage (damage) is an economic loss. This loss can be expressed as a percentage of the healthy volume condition. Similarly, a nontimber forest could have its function altered significantly by a disease. A few disease-killed trees could improve forage habitat in a wildlife refuge and at the same time provide snags for birds and other wildlife. This mortality would not be considered damage.

Abiotic versus biotic stress

While many diseases are caused by biological (living) agents, abiotic (nonliving) or adverse environmental stresses cause a great many tree maladies. Adverse weather events, including early winter freeze, ice, dry east winds with winter sun, spring frost, and summer drought cause considerable damage each year to

Washington forests. Nutritional deficiencies, changes in water table, flooding, airborne or water borne pollutants are also abiotic agents. Abiotic stresses can occur in almost an infinite number of combinations causing subtle changes in their effects on trees.

Biotic stress agents include fungi, bacteria, dwarf mistletoes, possibly viruses, intraspecific competition, and even weeds, which sap soil nutrients and cause growth loss. Other agents such as animals, birds, algae will be addressed in other sections of this book.

Causes of biotic diseases are transmittable from plant to plant

They can transfer to other hosts by spores or other mechanisms, or by direct contact invasion, such as through roots in the case of root diseases.

Causes of abiotic diseases are nontransmittable

Remember this distinction to separate the two types of diseases. Abiotic disease, however, can weaken a host tree sufficiently to allow attack by biotic agents such as root or foliage diseases. Because insects are also common invaders following abiotic damage to trees, people become confused as to which agent arrived first.

Symptoms and signs

These two terms in plant pathology are helpful in describing the conditions found on a diseased tree. Symptoms describe the condition of the host tree, such as yellow foliage (chlorosis), burned leaf margins (drought) reduced leader growth (root disease) and brooming (rusts, dwarf mistletoes). Signs provide actual evidence of a causal agent, such as fungus mycelium under the bark, fruiting sporocarps such as decay conks on bark and pustules on needles, microscopic spores, and other parts of the invading agent. Symptoms are found on trees with both abiotic and biotic damage. Signs may be secondary, yet provide valuable clues as to the causal agent identity.

Factors involved in disease development.

A biotic plant disease results from the interaction of a causal agent (the pathogen) with a susceptible host plant. This interaction must take place under favorable conditions for the disease to occur. Thus, three components must be present for a disease to develop: (1) a host plant must be susceptible to disease; (2) a causal agent must be present; (3) the environment must be favorable for disease to develop.

Each of these ingredients is variable, and the interrelationships are variable and complex. To illustrate this concept, each of the three ingredients can be represented by a circle, free to move in any direction (Figure 5-1a). Disease occurs when all three circles overlap to form the black portion in the center (Figure 5-1b,c).

The disease situation is mild when only a small portion of each circle overlaps (Figure 5-1b). This represents mostly native endemic diseases that occur at relatively low levels in plant populations. Severe disease outbreaks occur when the circles almost merge (Figure 5-1c). This represents a very severe disease situation (epidemic) in which a dramatic flare-up of a disease occurs in a plant population. The epidemic may eventually subside, or it may

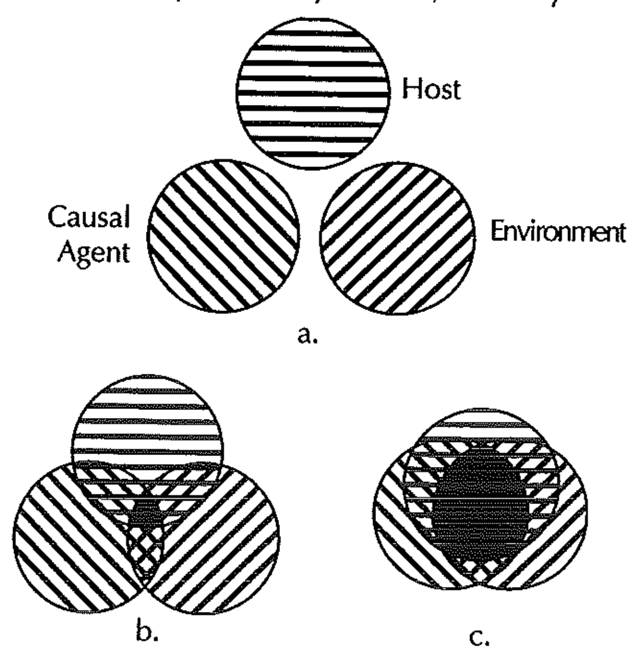


Figure 5-1. By Otis C. Maloy, former Washington State University Cooperative Extension Plant Pathologist

continue until the affected host plants are essentially eliminated. If one or more of the components is not present under otherwise favorable circumstances, the circles will not overlap, and no disease occurs (Figure 5-1a).

Endemic = predictable and ± constant.

Epidemic = unpredictable or sporadic.

The development of abiotic disease is a similar process but involves only two of the circles (host and environment) because the causal agent circle is missing. The pattern of merging the circles for mild or severe damage is the same. An abiotic disease may develop suddenly following sharp early winter freeze, or it may take longer after prolonged summer drought.

This concept also illustrates the basic principles of plant disease control, since eliminating any one of the three components (biotic) or two ingredients (abiotic) will prevent disease development. The ingredients may be eliminated in several ways: using nonsusceptible species or resistant varieties; eliminating the causal agent with chemicals or other protective barriers, or modifying the environment so that it is less conducive to disease development.

Control of a biotic plant disease involves the application of practices devised to reduce the damage or loss from disease. Control measures are placed in one of four categories, each of which embodies a general principle of control or reduction. Two of these-Exclusion, and Reduction to a Nonthreatening Level-are directed primarily at the disease causing agent, independent of the host plant. The other two-Protection and Resistance-are directed at the still healthy host plant and assume that the pathogen remains present in the vicinity of the host.

Principles of Disease Control

Exclusion

Exclusion is perhaps the first line of defense. Its aim is to keep the cause of a disease out of an area where it does not exist. Exclusion usually depends for success on natural barriers, such as oceans, deserts and mountain ranges. Continental shores may be the best barrier. Exclusion is accomplished by

- intercepting plant shipments and rejecting them,
- eliminating infected material from shipments by sorting or disinfection,
- isolating (quarantine) possible disease carriers for a prescribed period of time accompanied by periodic inspection, and
- prohibiting importation of possible disease carriers.

Embargoes may be placed against the introduction of certain plants, a single plant species or unprocessed plant parts. This is frequently called a quarantine, but "quarantine" refers to the holding of plants (or animals or other possible carriers of a pest) for a period of time (literal translation is "40 days"). These measures are generally imposed and enforced by government agencies at both federal and state or local levels.

The forest industry may impose a voluntary restriction on movement of planting stock, seed, breeding material, or products such as foreign logs or pulp chips to prevent disease introduction. Unfortunately, people often recognize the magnitude of the potential hazard too late. It is important to critically evaluate the potential for establishment of pathogens for all introductions of exotic material.

The first U.S. plant quarantine was established in 1912 to prevent introduction of white pine blister rust fungus into the valuable white and sugar pine stands of the western United States. The need for such a quarantine followed the discovery of chestnut blight in 1904. This devastating disease swept through vast stands of American chestnut in the eastern United States. Within a few decades, this magnificent and valuable tree was eliminated as an economic species.

The white pine quarantine followed the discovery of blister rust on the *Ribes* genus alternate host in New York in 1906 and restricted the importation of five-needle pines into the United States west of the Mississippi River. However, it later appeared that the fungus was carried on pine seedlings shipped from France to

Vancouver, B.C. in 1910. By 1930, the disease was generally distributed in the Pacific Northwest. This attempt at quarantine failed.

A more recent occurrence dramatizes the difficulty of containing plant pathogens, especially on a single land area. In 1974, Dutch elm disease, lethal to the picturesque American elm, was found in northeastern Oregon and later in Walla Walla, Washington. This came as no great surprise after its appearance a few years earlier in southern Idaho. The fungus causing this disease, like chestnut blight and white pine blister rust, was introduced from Europe (on imported logs) into a tree population with no exposure to the pathogen. American elms were very susceptible. By the time the disease was discovered, it was well established in the area.

Several potentially serious forest diseases are now recognized that do not yet occur in the United States. Every effort should be made to prevent their introduction and subsequent damage. The fact that most plant pathogens are microscopic, and to the untrained or nonspecialized observer are often indistinguishable from their less dangerous relatives, means that absolute exclusion is virtually impossible. Mobility by millions of airline travelers, and global markets and trade add monumentally to the task of preventing accidental pathogen introduction or importation.

Quarantines have proven almost impossible to enforce for extended periods of time. Most have eventually failed. They do buy time, however, to prepare for invasion of an unwanted pest.

Reduction to a Nonthreatening Level

Reduction to a Nonthreatening Level involves those measures to minimize pathogen inoculum impact in an area where it is not well established. This method of disease control has traditionally been called eradication. Eradication can have the aim of total elimination of an established organism, for example, the Mediterranean fruit fly from California and the screwworm. To be sure, neither is totally eliminated, but that is the aim. Realistically, eradication of a plant pathogen is not successful. Reduction to a nonthreatening level is a more practical and achievable approach. These measures may include:

- Mechanical removal such as pruning, pulling, cutting, excising, removal of alternate host, etc.
- Starvation of the pathogen
- Chemical disinfection (fumigation)
- Biological control to encourage natural enemies such as competing fungi

Pathogen reduction programs may be area-wide action or local treatments. Early detection and diagnosis is important to the success of area-wide programs, less so in local treatments.

The extensive *Ribes* (currants and gooseberries) eradication programs which attempted to break the white pine blister rust disease cycle in selected white pine stands illustrate some of the requisite features of an area-wide action program. At the time the programs were initiated (ca. 1930), the disease was widely but recently established in Washington, Oregon, and Idaho. The fungus causing the disease cannot spread from pine to pine (the economic host). The spores of the fungus that are carried from the alternate host-currants and gooseberries-to the pine are fragile and were believed to be able to travel less than a quarter of a mile, even under the best of conditions. This suggested that, if currant and gooseberry bushes were eliminated from within and adjacent to white pine stands, the disease would be eradicated from that area. Many thousands of hours were expended in this endeavor.

Unfortunately, some information about the disease was lacking, and in time the *Ribes* eradication program was abandoned. Such items as the amount of alternate host that could safely remain in the treatment area, the actual distance spores could survive, regeneration of alternate hosts, and detection and progress of disease in pines were linked to the failure of the program.

An event that probably contributed to halting the alternate host eradication program was the implementation of a treatment for individual crop trees with an antibiotic. The chemical, Acti-dione, was a successful treatment when directly applied to blister rust cankers. The treatment did not work well in field applications. The practice that finally evolved was to spray the chemical on the lower tree bole. It was believed that the chemical was taken up and translocated in the phloem, thereby acting as a systemic eradicant. Adequate tests had not been conducted. Eventually it was recognized that the Acti-dione basal stem treatment was not effective. The program was abandoned.

Total pathogen eradication programs sound good in concept, but in reality, they are generally impractical and unsuccessful. Using holistic concepts of Forest Health practice, it is usually more effective to use a combination of factors that prove unfavorable to the pathogen. Establish susceptible host trees with proper seed and low hazard location, and extend management well into the next rotation to manipulate the forest habitat and host in such a way that pathogens do not establish well.

Examples

1. For example, use of this approach has proved to be the best way to grow western white pine. Many factors, beginning with rust resistant seed, proper nursery stock with few low branches, low rust hazard in the planting site, planting away from wetlands, and early low stem pruning and spacing all serve to bring a high proportion of trees to rotation age with minimal loss from blister rust.

2. A long history of successful chemical disinfection (fumigation) has worked in forest nurseries to control soil diseases. Soil fumigation is a relatively costly measure that is used largely in crops of high value. In forestry it is restricted primarily to nurseries, but has potential for spot treatment in establishing high value trees in seed orchards and experimental plots. Recently, stump fumigation has been approved to eliminate laminated root rot infected centers.

Nurseries are especially favorable for the buildup of fungus root pathogens and nematodes because they have constant high populations of single tree species in disease susceptible stages. Frequent irrigation and cultivation promote rapid spread of pathogens. Nursery soils are frequently light, sandy soils that favor an extensive system of fine rootlets that serve as a prime substrate for disease organisms.

Fumigation consists of applying a chemical to the soil, usually as liquid or granules, and compacting or sealing the soil surface to delay escape of the fumigant gas. Some of the gas goes into solution in the water film around the soil particles. The main factors influencing success of fumigation are temperature, moisture and aeration. The basic principle of fumigation is to retain the gas in the soil long enough to kill the target organism, but to have it leave the soil completely before the crop is planted.

Fumigation as it is known today may become limited in the near future. Methyl bromide, perhaps the most common soil fumigant, is being removed from use due to the belief that it causes upper atmosphere ozone depletion. Several other soil fumigants that have a long history of use have also been removed for a variety of reasons.

3. An example of starving the pathogen in lieu of fumigation is to simply fallow nursery soils for a season before replanting with trees. Without suitable hosts to feed on, many pathogens move into a low population cycle during a fallow period. In some nurseries fallowing might provide better disease control than the more traditional planting of cover crops. The entire area of nursery soil pathogen control is being reevaluated using natural and chemical methods of disease control.

4. Another pathogen starvation technique that is gaining acceptance is stump removal to reduce root disease inoculum. A primary source of infection of young stands for laminated and armillaria root rots occurs where roots of young stands contact infected roots of the previous stand. Stump removal is recommended in root rot centers when planting disease tolerant species is not feasible, and the economics of the operation is acceptable. The technique, called push-over logging, is used in southeastern British Columbia.

A large excavator (40,000 lbs, minimum 200 HP) with a moderate sized bucket and attached thumb is used to push trees down, levering the stumps free of the ground. The stump with attached tree is then grasped by the bucket and thumb, shaken free of soil and pushed into a windrow. A sweeping pass by the bucket over the stump hole smooths the surface before the machine shifts to the next tree. A bucker follows later and cuts the stump off at or below the ground line. Substantial gains in volume can be made by harvesting a larger portion of the stumpwood. The logs are skidded in normal fashion. The stumps are left above ground to air dry where they cannot cause new infection.

Logging and site preparation are accomplished in one operation. The unit may be replanted with root rot susceptible Douglas-fir or ponderosa pine the following season. A side benefit of site preparation is removal of competing brush. Experimental trials east and west of the Cascades show that regeneration does well. Soil compaction is not a factor because the low ground pressure excavator normally makes only one pass. Bulldozing stumps out was the original method of extraction, but site disturbance and possible soil compaction are excessive.

5. A mechanical disease removal method that works is special thinning to reduce dwarf mistletoe in conifer stands. Control is based on the fact that spread from infected residual overstory trees to understory trees is generally less than 50 feet, and that lateral spread through a one-story stand is less than 1.5 feet per year. Thus, the elimination of infected residual trees (culls, seed trees) will prevent infection of the new stand, or at least greatly reduce speed and severity of infection.

A low level of dwarf mistletoe is allowed to remain. Large, dense brooms can be left in specially designated stands or in places where there is little danger of infecting nearby healthy understory trees. Small birds, spotted owls, grouse, other small animals, and butterfly larvae make use of dwarf mistletoe brooms for roosting, nesting, or food.

Successful reduction of dwarf mistletoe from a stand works best when done in the following order: 1) select areas for control with moderate, but not excessive dwarf mistletoe; 2) delineate control areas; 3) reduce overstory infections by marking infected trees to cut according to the six class Hawksworth mistletoe rating guide; 4) reduce infections in the understory using the same system; 5) periodically check the control areas; 6) protect new reproduction, or in some cases consider alternate immune species regeneration.

6. Biological control is basically a form of pathogen reduction but seldom is of practical value in the control of forest diseases. Biological control is variously defined, but to most it means the development of organisms competing with or antagonistic to the pathogen. Early attempts to promote the development and spread of *Tuberculina maxima*, a fungus parasite on the white pine blister rust fungus, were unsuccessful. However, several examples exist where biological control is effective in preventing infection by root and stem invading organisms.

Annosus root disease, *Heterobasidion annosum*, an important disease of western hemlock, true firs, and ponderosa pine in Washington State invades freshly cut stumps and healthy trees via root grafts. When other fungi colonize the stumps first, the weakly competing *annosus* fungus cannot gain entry. Therefore, inoculation of freshly cut stumps with spores of fungi, such as *Trichoderma viride* or *Phlebiopsis gigantea* deprives *annosus* of its entry pathway to infect new trees. Sodium tetraborate has been applied to fresh stumps for years to prevent entry by *annosus*. Current disfavor of using chemicals in the forest has renewed interest in inoculating stumps with competing fungi, a technique developed in the 1960s, but never used in widespread operational logging in the United States.

Crown gall is a disease of the roots and stem of woody plants caused by the bacterium, *Agrobacterium tumefaciens*. The pathogen gains entry through wounds and galls commonly occurring at the graft union. Stone fruit seedlings with injured roots and crowns and grafting wood are protected from crown gall infection by dipping the young trees in a culture of a nonpathogenic crown gall bacterium. Spray grafting wood to run-off for best results.

Chestnut blight virtually eliminated the American chestnut from the eastern United States. Recent work in Europe and the United States has shown the existence of hypovirulent (less pathogenic) strains of the chestnut blight fungus. When these hypovirulent strains are established on existing chestnut blight cankers, severe blight infection from the original fungus is suppressed. Hypovirulence is a form of biological control that may reduce the impact of chestnut blight in the future. Active research is being conducted in the eastern United States.

Protection

Protection involves establishing a barrier between the pathogen and host plant. It may be a mechanical or chemical barrier. The prevalent concept of protection involves spraying or dusting a fungicidal chemical onto the plant surface to protect against infection. In the United States few forest diseases are controlled by chemical protectants. Managers are more likely to use such protectants in nurseries, windbreaks, Christmas trees, seed trees, or high value trees in recreation areas.

Managers must apply protective chemicals before infection is established, and time of application is a critical factor. Most of the chemical applied is wasted for several reasons. The target covered by the chemical may not be inoculated, or the chemical may be washed away by rain or decomposed by sunlight. Timing of inoculation by a pathogen is not easy to predict, and forest managers must base prescriptive application of protective chemicals on a general knowledge of the disease cycle. The microscopic nature of most plant pathogens makes the development of the pathogen unsuitable as a cue for timing the application. Most spray schedules are tied to weather conditions, primarily temperature and moisture, or to development of the host. Time of initial flush with dropped bud scales and one inch of elongation is a typical spray window.

Mechanical barriers are of various types. They are rarely thought of as disease control measures alone, yet combinations of mechanical barriers, which include temporal, spatial and environmental factors will reduce many plant diseases. Some general techniques employed include: modification of the natural environment to increase resistance of the host or to decrease the population and aggressiveness of the pathogen; interposing barriers to inoculation or infection; separating host and pathogen; eliminating inoculating and disseminating agents; and removing hosts.

Some specific measures of establishing mechanical barriers are increasing or decreasing density of crown canopy; spacing of seedlings or transplants; shading, exposing or mulching seedbeds; altering soil drainage; controlling seed germination by time, method, and depth of seeding; planting of windbreaks; interplanting with nonsusceptible species; preventing logging, fire or climatic injuries; pruning dead branches; trenching around diseased trees; following pathological marking rules; enforcing sanitation clauses in timber-sales contracts; using pathological rotation age and diameter limits.

Many forest disease control methods that illustrate use of mechanical barriers. White pine blister rust can serve as an example here. Some sites are more disposed to pine infection than others. Microclimatic factors that determine intensity and distribution of the blister rust fungus include air circulation during favorable infection periods, temperature, relative humidity, rain, fog, and dew. Foresters should avoid planting white pine on some sites. On other sites white pine can be planted with good chances of escaping infection or severe disease loss. In some regions topographic features and tree cover have been used to predict high hazard sites. Rust infection is favored in narrow valleys, depressions, bases of slopes, small openings in the forest canopy, areas with high elevations, and other places into which cool air will drain and accumulate at night.

Streams and wetland areas pose particularly high infection potential to pines because this is the favored habitat of *Ribes* species. To reduce this hazard, plant white pine more than 200 feet from these areas.

Pruning lower boles further reduces infection potential of western white pine. The barrier in this case is the absence of needles. Spores traveling from the *Ribes* plants to the pines must land on needles, germinate, and enter through stomates. Approximately 90% of rust cankers occur within 6 feet of the ground. Pruning can begin as early as 3 or 4 years after planting. Later pruning can be done when trees are precommercially thinned.

Resistance

Resistance (or immunization) uses natural or acquired resistance to infection or immunity to the disease. Immunity is an absolute characteristic; immune plants are never infected. Resistance is a relative value. Individual plants within a population may vary greatly in their resistance (or susceptibility) to disease. Nonhost species are immune to the white pine blister rust, which affects only the five-needle pines. Eastern white pine is less susceptible (more resistant) than white-bark pine to blister rust. Tree breeding for disease resistance is a long and complicated program that can span the working careers of more than one generation of geneticists. The pay-off in success may take so long that demand for the product diminishes. This almost happened with western white pine and even with American chestnuts resistant to the blight. Foresters and arborists simply used other species for replanting. Fortunately, demand is now high, almost insatiable, for rust resistant western white pine, and interest is growing for planting American chestnut in Washington cities.

Western white pine is one of the three best conifer species to plant in laminated root rot centers because of its tolerance to this devastating Douglas-fir disease. Western redcedar and western hemlock are the other two species commonly used.

Certain types of pathogens are more successfully controlled by the development of resistant varieties. Prominent among these are pathogens that can survive only on living tissue, i.e., are very specific or selective. Rusts and viruses are prime examples. However, development of resistant varieties does not mean the end of the disease problem, because the pathogen can undergo genetic changes. A prime example of this is the constant changing of the wheat rust fungus. Plant breeders stay ahead of the problem by constantly breeding new rust resistant varieties.

In the case of white pine blister rust the proliferation of pathogenic races or strains would occur on the alternate host (currants and gooseberries). It would help to eliminate these alternate hosts from and around seed orchards and nurseries where seed from resistant pines is produced or seedlings grown. This would greatly reduce the probability of new races of the fungus becoming established.

Although virus diseases are not presently known to constitute serious problems in forest trees, they do illustrate a method of inducing resistance vaccination in trees. Many viruses consist of strains that differ in the severity of the disease they cause. If a mild strain is established in a plant, that plant cannot be infected by a more severe strain. This is called crossprotection. Even though it has had limited application, it is worthy of note for possible future use. Tristeza disease of citrus is now being controlled by crossprotection in South America.

Selection and use of naturally resistant seed sources and careful choice of planting sites can avoid many diseases. Douglas-fir has great individual variation in susceptibility to Rhabdocline needle blight. In some areas the fungus is adapted to late bud opening. A good general rule for minimizing problems with *Rhabdocline* is to use the best local seed sources. Christmas tree growers who brought superior quality Douglas-fir seedlings from Corvallis, Oregon, to Olympia had severe *Rhabdocline* and frost damage problems. Local trees were unaffected. This rule applies to Swiss needle cast *Phaeocryptopus gaeumannii* as well. Seed sources can safely be brought from the north to most southern locations, but not the reverse. Also, do not take Douglas-fir seed from the intermountain region to land west of the Cascade Mountains.

A final and perhaps more effective means of controlling devastating forest diseases is to convert stands to nonhost species. These species may not be as desirable or as well adapted as the susceptible tree, but do offer a practical alternative. In areas of north Idaho, where white pine blister rust was severe, attempts were made to establish ponderosa pine. In many instances the seed sources were from completely different ecotypes, such as the Black Hills of South Dakota. These plantations have stagnated at an early age and are ravaged by other problems, including Armillaria root rot, bark beetles, and needle diseases. These plantations stand as mute testimony to the hazards of off-site planting. Proper seed source is key to plantation success.

Diagnosing Abiotic Problems in Young Conifer Plantations

Adverse weather (an abiotic problem) causes most problems in artificial regeneration. Diseases, insects, and animals cause troubles too, but by far the biggest cause of difficulty or failure in new regeneration is weather that stresses new seedlings beyond their recovery ability. Such injuries are nontransferrable, which is a good clue to their diagnosis. Fungus disease agents are progressive, sometimes leaving evidence (fruiting bodies, spores), and may be transmitted to other seedlings. Insects and animals leave evidence too. When the weather does a tree in, it is often a mystery that involves some careful sleuthing.

Newly planted trees have their greatest difficulty in the first five years, the toughest time being the first season. It is of utmost importance that species and seed source are correct for the site. Variations in harvesting the previous crop or manipulation of existing or future vegetation may make the difference in the success of a planting.

1985 Freeze damages plantations

A sharp fall freeze before trees are fully dormant can take a serious toll of young plantation trees. The 16-day freeze in November, 1985, that plunged to zero degrees in Olympia on the 23rd was the earliest deep cold snap since the similar November, 1955 freeze. Considerable vegetation was damaged or killed in the famous 1955 freeze mainly due to strong desiccating winds. In 1985 damage was not as widespread, but locally severe injury and mortality occurred.

Plantation trees up to 7 or 8 years old were damaged before they became dormant. Trees planted in depressions with little or no air drainage had the worst injury. Four- to six-foot-tall Douglas-fir planted near Olympia had severe to complete needle loss and more than 30% mortality. The injury was first apparent as early as March, 1986. Examination of the plantation in mid-June showed the same injury extending about 10 feet up the natural Douglas-fir stands surrounding the plantation. The pattern of damage in the plantation coincided with the highest contours of the depressions.

To diagnose fall freeze injury and predict the next spring mortality, check the buds on the newest leaders and shoots first. Slice the buds lengthwise with a sharp blade. The pith in the center of the tiny twig inside the bud may be slightly brown, but freeze killed buds will be soft and brown throughout.

Sometimes, only the foliage will be killed and if the buds flush successfully they will gradually refoliate the tree. Damaged one-year-old foliage often ranges from partially pale red to full red needles with little or no distortion or bending. Close examination of a freeze-dried needle will show sunken tissue on either side of the midrib.

On injured stems, peel away the bark and look for dark colored dead inner bark and a sharp boundary between healthy and damaged tissue. Small fungus pustules may be present and are usually secondary (Table 5-1).

Combinations of tall tree edges and surrounding hills or ridges may create a cold air "lake" with no outlet, leaving a frost hole. Shaping harvest units to allow proper air drainage can prevent some of this problem. Planted Douglas-fir may freeze back for 10 years or more until they slowly build enough bulk and height to escape the frost line. When faced with reforesting chronic frost areas, try red alder or the frost resistant pines.

A heavy cover of grass in a plantation may enhance this kind of cold damage. The grass insulates and slows heat released from the earth that could provide protection. Removal of the insulating grass may temper but not completely solve the problem.

Summer drought can kill plantations.

For example, gravelly soils may be too droughty for the Douglas-fir. Such soils may appear to support Douglas-fir, but tree-killing summer droughts may occur as often as three times in a decade. Gravelly alluvial (water washed) soils in valley bottoms sometimes cannot hold enough moisture to sustain young Douglas-fir, even though fir was removed from the site. Remember

Table 5-1—Seasonal weather injury descriptions for conifers

PROBLEM	DESCRIPTION
Summer	
Heat defoliation; leaf or needle scorch	Needles shrunken, distorted, all brown or brown on margins only. Needle color light brown vs. the deep red brown of winter desiccation.
Heat canker; sunscald	Swollen at root collar. Killed reddish bark.
Drought	Light brown to red foliage late summer.
Early yellowing of earliest foliage	Occurs when fall rains are delayed. First fall winds remove the foliage.
Fall	
Fall freeze	Early cold snap causes red brown foliage. Buds may be killed. Similar to winter desiccation.
Winter	
Winter desiccation	Needles deep red, undistorted or absent. Needles may have reddish margins or red entire outer portions. Slice buds, observe green or brown tissue.
Stem canker	Cambium killed in patches. Sharp line between healthy and killed tissue.
Frozen roots	Strip roots with fingernail; tissue dead.
Spring	
Spring frost	Emerging shoots discolor and wilt. Wilted shoots often persist for a season or more.
Hail	Scars top or side of shoots-late summer.
Excess moisture	Thickened root phloem tissue, chlorosis.
Wounding	Not serious if wound heals.

that it probably took nature 75 years to regenerate the Douglas-fir in the previous stand compared with the current single time planting effort. Seedlings planted on the deep loamy soils of the adjoining slopes may grow perfectly because those soils have much better moisture holding capacity.

Douglas-fir grew on the alluvium before, but after the site was clearcut, temperatures were too high and moisture deficit was common in the rocky soil. Planted Douglas-fir may even grow normally for 5 or more years, only to be killed by a prolonged summer drought. Try a shelterwood for the alluvial rocky soils. Then replant with Douglas-fir. If the area was clearcut, try a drought resistant species such as lodgepole pine or rust resistant western white pine. These pines usually do well on droughty soils.

Regenerate the unit slowly back into Douglas-fir as the pine builds a little cover to nurse the fir along. Eventually the fir will overtop the lodgepole, but white pine, although a slow starter, usually surpasses fir if the soil is poor. This technique, using lodgepole pine to nurse a crop of noble fir) was used to replant some of the high ridges in the Mount St. Helens eruption blast zone.

Microsite planting improves survival

Be especially observant of macro and micro environment that will influence your new seedlings. Look from the hills and ridges surrounding your unit, which might indicate frost pocket potential right down to the tiny microsite within a few inches of the seedlings.

Instruct tree planters to use microsites to their fullest advantage to protect new seedlings. Show planters the difference in temperature (when there is sunshine) between the north and south facing slopes of a small mound by simply placing your hands on the two slopes. The north facing one will be noticeably cooler. Planting the tree on the cooler minislope may make the difference between a drought killed tree and one that will survive.

A rock, log, stump, and even slash absorb daytime heat and reradiate it at night to protect a seedling from frost damage. By day these may provide just enough shade to prevent drought damage or mortality. Sometimes these valuable heatsinks are lost during site preparation. Units that are "too clean" may suffer from poor survival. It may be possible to provide some protection in a potential frost pocket by using other vegetation.

Forest Disease Control with Chemicals

Five distinct groups of living organisms may cause plant diseases: fungi, bacteria, viruses, nematodes and seed producing plants. Fungi cause the greatest number of parasitic forest diseases. Next in importance are the dwarf mistletoes, which are seed producing plants. The abiotic diseases explained at the beginning of this chapter as nontransmittable are important in that they need to be identified to avoid confusing them with biotic, living plant diseases.

Chemicals used to control diseases of plants, including forest trees, are collectively lumped with all pesticides. A chemical that is used to kill or control fungi is called a fungicide. Fumigants are chemicals that may be used to kill several kinds of pests including fungi, animals, insects, nematodes, and weeds. Fumigants are normally used as soil applications, or whenever deep penetration of a chemical is needed to reach a target organism. Logs being shipped to other countries are often fumigated to kill potential pathogens, insects, and nematodes.

Controlling plant diseases is frequently likened to the control of insects or weeds. However, there are basic differences in the principles governing control of most diseases and those for controlling insects and weeds. The causal organism must be controlled to keep the disease from developing. Insects and weeds are visible to the naked eye; most causes of diseases are not. Managers must correctly identify the cause of disease to correctly prescribe control measures, especially chemicals. This frequently requires specialized knowledge and equipment. A close look at the organismal cause of disease requires a microscope.

Another major difference lies in the absolute necessity of applying most disease-control chemicals before the disease develops. Waiting until the disease flares up and then applying chemicals does not work. Timing of applications is usually the single most critical factor in obtaining adequate disease control. Managers must understand how the disease cycle works. They must apply the appropriate chemical at a point in the cycle when the infective material (inoculum) is most vulnerable. It is not always possible or practical to observe microscopic plant disease organisms directly. Application of the chemical often coincides with climatic conditions, especially temperature and moisture, or with annual development of the plant itself.

A third difference is the need to assure that the chemical (fungicide) reaches the target and protects the host tree or plant from disease. Insects moving over the surface of the plant may encounter the pesticides directed at their control. Similarly, a weed will absorb herbicides even though only a portion of the plant is sprayed. However, nearly all plant pathogens are nonmotile. Their movement depends on wind, water and other forces. A fungus spore landing on a plant surface may, if conditions are favorable, penetrate the plant surface at that point. Thus, fungicide deposits near but not at that point will not kill the spore.

The use of chemicals to control diseases of forest trees has been extremely limited, most being applied in nurseries, windbreaks or shelterbelts, plantations (especially Christmas trees or ornamentals), or on high value trees such as those in parks or seed orchards. Present public opinion does not favor use of forest chemicals in any form. Topography, mixture of species, phenology of individual trees, cost of application, difficulty of assessing results, and incomplete knowledge about pathogen activity are additional factors that tend to discourage spraying for disease control over extensive areas.

In a number of disease categories, chemicals are used in a quasi-forest situation.

Nursery Diseases

Soil fumigation is a common practice in forest nurseries to control soil borne fungi and nematodes. Continuous cropping of the same species in concentrated populations allows buildup of pathogens or nematodes. Various formulations of methyl bromide, or similar related fumigants, are the most effective soil treating pesticides used in forest nurseries. Methyl bromide and many other fumigants will not be available in the future due to possible upper atmosphere ozone depletion by the bromine ion in the fumigant. This valuable fumigant will be phased out entirely by 2000. Few chemical alternatives can take its place. Solar heating of soil and fallow fields are two alternatives being examined as substitutes for fumigation.

In nurseries it may be feasible to spray for certain foliar diseases to increase growth, vigor and survival of the plants. *Lophodermium* needle cast of pines may be prevented in nurseries by applications of maneb or chlorothalonil. A careful schedule of selected fungicides is necessary in the first year to protect nursery seedlings against disease complexes that include *Botrytis, Pythium, Fusarium, Phoma,* and several other species. Managers should alternate several fungicides carefully to minimize chances of pathogens developing resistance to a single fungicide.

Careful attention to watering schedules can, under some conditions, actually help reduce or prevent disease incidence. Nursery seedlings usually have better tolerance to pathogenic fungi when they are deep watered on a less frequent schedule than when watered frequently and lightly.

Plantation Diseases

It is generally accepted that pure forest stands are more vulnerable to disease than are mixed stands. Not only do pure stands offer a greater mass of susceptible tissue, but spread from one plant to another is not impeded by the presence of immune species. The vulnerability of pure stands is countered somewhat by the opportunity to apply chemicals over an area of similar characteristics.

The use of chemicals for disease control in plantations is normally limited to Christmas trees, windbreaks, shelterbelts, natural seed production areas, and intensively managed seed orchards. Fungicide use on Christmas tree foliage diseases is very common in Washington.

Cone and seed diseases of conifers have become much more important in recent years due to major changes in the way tree seed is produced. A large portion of the forest industry now produces tree seed in intensively managed seed orchards of genetically superior material. Although cones are still collected from wild stands, the time is approaching when almost all tree seed will be produced in seed orchards.

The oldest seed orchards in the United States are in the South. Cone rusts of slash and loblolly pines were first controlled using fungicides. The rust can be prevented by spraying the developing strobili with the fungicide ferbam. In the Pacific Northwest and British Columbia the inland and coastal spruce cone rusts attack several conifers. Western gall rust found in lodgepole and ponderosa pine has the potential to damage cones and seed.

Other damaging fungi are found in conifer tree seed. The seed or cold fungus takes its name from the fact that it spreads on the seed during the cold storage stratification period and later when seed is sown in cold soil. Sirococcus blight is found on Sitka spruce, Engelmann spruce and white spruce seed. The disease affects young shoots and seedlings in the nursery during mild temperatures, high humidity, and low light intensities typically experienced by Pacific Northwest nurseries.

Abiotic problems such as frost, drought, and physiological abnormalities from nutrient deficiencies or excesses also affect cone production. Fortunately, in seed orchards under intensive management, some of these problems can be prevented. Keeping seed orchards away from toxic chemical areas, frost holes, and within the species range reduces the threat from these kinds of problems. It also may be possible to locate a seed orchard within a local area where a certain disease is not known. Locating a seed orchard in a nearby area with hotter, drier summer weather will suppress some diseases.

Keeping good inventories and making routine surveys of cone and seed diseases are the first step in dealing with these pests. Carefully develop an integrated approach to controlling these pests. Eliminate the suronding area of natural trees (200-300 meters) that may host common pests. Maintain a sanitary facility by continuously removing all diseased plant material. Fungicides may need to be applied occasionally or routinely. Systemic fungicides may be more applicable in seed orchards.

In the Pacific Northwest Rhabdocline and Swiss needle casts can cause sufficient damage in Christmas tree plantations to ruin harvestable trees for market. Certain Douglas-fir seed sources are more prone to infection. The rule for prevention is to use the best local seed source available. Bringing planting stock north from southern parts of the Douglas-fir range usually means higher disease incidence as well as above normal frost damage.

Fortunately, well developed fungicide schedules for Swiss needle cast also work fairly well on Rhabdocline. A single application of chlorothalonil just after bud elongation (about June 1) produces nearly disease free foliage. Two or more applications may be necessary to give suitable control for Rhabdocline. Give careful attention to the weather to allow a sufficient number of hours for the fungicide to dry. It is better to spray as weather is clearing rather than prior to rain.

Lophodermium needle cast of pines used to be a limiting factor in producing good quality Scotch pine Christmas trees in Washington. This disease can now be controlled with two to five applications of either chlorothalonil or maneb. The first spray generally commences with bud elongation and is repeated at approximately monthly intervals.

Diseases in Natural Forests

Very few chemicals have been used to control diseases in natural forests.

Heterobasidion annosum root disease occurs in natural forests throughout the world but it is most destructive, or at least causes greatest concern, in plantations. In the Pacific Northwest this disease is important in natural stands of western hemlock, true firs, and ponderosa pine. In western hemlock and true fir it causes significant butt decay, but rarely kills trees outright. Disease weakened root systems often accelerate blowdown. Annosus root disease does not commonly kill ponderosa pine in Washington, but mortality is readily apparent in southern Oregon and northern California.

The fungus gains entrance to trees by first invading freshly cut stumps of adjacent trees, growing down through their roots, passing through root grafts and becoming established in the trees of the residual stand. Stumps can be protected against *annosus* invasion by applying Timbor, a product containing boron. Dry borax (sodium tetraborate) has been used for years, but current difficulty with the label may prevent its use. Refer to the numbered principles of disease control in this chapter for an explanation of using competing fungi to keep annosus out of stumps.

The white pine blister rust story is an excellent example of a devastating disease that was introduced into a region (North America) where susceptible host species were abundant and valuable, and where much time, effort and money went into 1) trying to exclude the fungus from the western United States, 2) eradicating the disease from valuable pine stands, and 3) developing white pines resistant to the disease.

The first of these failed, the second was tried for nearly 30 years then abandoned, and the third also took more than 30 years. In the late 1950s an immediate short-term control measure was needed until resistant pines were available for outplanting. Preliminary results with Acti-dione and, to a lesser extent, another antibiotic, Phytoactin, appeared to provide acceptable control and would buy the time needed to develop more permanent controls. Unfortunately wide scale field applications of Acti-dione were begun before adequate testing was completed. Within a few years, the effectiveness of Acti-dione treatment was seriously questioned, and eventually the entire spray program was abandoned.

Present concepts of natural stand forest management do not favor the use of chemical pesticides. These concepts are deep rooted even though many stands are not entirely natural. They have been harvested once or twice and at least one of the crops was probably artificially planted. Forest diseases may on occasion need to be controlled with a fungicide, but the first line of defense is to change the site in some way to minimize the disease impact. Fortunately, most forest disease control techniques are cultural rather than chemical. Stands can be manipulated in a variety of ways to reduce the impact of diseases. The shift to ecosystem management methods mandated by public pressure leaves room for more tolerance of disease in certain stands. For example, wildlife habitat and nontimber producing lands could have higher levels of disease.

The practice of forestry is entering a new era. Climax forests are not always as healthy as the seral forests that preceded them. On a statewide basis, too much of Washington's forest land may be in the climax types. An underlying cause of this is the lack of natural fire. Much of eastern Washington has been without natural fire for as much as 100 years. Policies were made early this century to extinguish all fires. The resultant forests in this region have steadily declined in health as insects and disease found them attractive. Many eastside areas have up to 100 times as many trees as they did in the pre-European settlement period of the mid 1800s. More acres are so overstocked that root disease, dwarf mistletoes, defoliators, bark beetles and drought have caused substantial mortality.

A move is afoot to return to more of the seral forests, particularly in eastern Washington. Just how far back to the original savannah-like condition to go is open to debate. Taking this kind of action on a wide scale across all ownerships will bring many forests stands into better health.

Kenelm Russell is Forest Pathologist and Manager of Forest Health, Washington Department of Natural Resources. Olympia, WA 98504-7048. Parts of manuscript based on original work by Otis Maloy, Cooperative Extension Plant Pathologist emeritus, Washington State University, Pullman.

Appendix 3

Forest Environment Pesticide Study Manual

Appendix Three

The accompanying figures that describe disease situations of mostly Douglas-fir are meant to give a quick picture of some of the common pests. The two figures provide first level diagnosis clues to separate the pests into broad categories. Six categories are shown to separate adverse environmental damage from needle disease, needle feeding insects, root disease, bark beetles, and animal damage.

The second part of the appendix lists most of the common pests mainly of Douglas-fir. Many of these problems are found statewide and on other species. The first section deals with the adverse environmental problems found on most trees. The following categories deal with insects and diseases found on roots, stems, foliage, and cones and seeds. Short descriptions tell about "Important Facts, What to Look For, and Management."

ADVERSE ENVIRONMENT	IMPORTANT FACTS	WHAT TO LOOK FOR	MANAGEMENT
WINTER INJURY PARCH BLIGHT Boyce 1961	Most visible April-June. Found throughout coastal DF. Kills foliage and branches. Caused by cold, dry winter high pressure systems.	Red foliage or naked branches April-June. Foliage red but not distorted. If needles gone, buds often remain. Damage usually on side facing wind. Slice buds with sharp knife. Brown, mushy buds dead. Live buds bright green inside.	Live buds will refoliate branches in about two years. Prune dead branches from ornamentals in late summer. Forest trees usually recover. Create clearcut boundaries that follow edge trees acclimated to prevailing winds.
WINTER INJURY FROST LESIONS Foster and Wallis 1974	Stem cambium killed in patches on young to pole size trees. Future stem failure could result from decay filled compartment occupying tree diameter when injured. Subsequent freezing could cause internal radial shake to break out to the surface and become a new visible frost crack.	Bark and cambium killed by sudden drop in temperature before tissues harden. Lesion areas eventually slough, exposing sapwood. Callus grows over injury taking several years to heal.	Forest trees: change species or use resistant tree buffer in chronic damage areas and local seed sources. Urban trees: peel dead bark to new callus. Shade affected area and allow callus to heal.
WINTER INJURY TOP KILLING MEDIUM TO LARGE EXPOSED TREES Russell 1965	Found primarily in lowland DF of Fraser Valley, Puget Sound, Lower Columbia Basin, and Willamette Valley. Generally not found above 1,000 ft (300 m). Dry winds, usually after January 1, cause excess transpiration from tops when continuous water column in trees breaks. Once below wilting point, the top dies.	Large tree problem. Dead (red) or defoliated tops varying from 1 ft (0. 3 m) to 30 ft (10 m) or more in length. No sign of insects or fungus cankers. Sharp line from green to dead tissue. Most damage occurs on exposed trees along roads and fences or trees that protrude above general canopy. Trees growing where ground cover sparse most susceptible.	No practical forest management. In urban areas deep water trees during fall dry periods to provide good moisture prior to dormancy.
LEADER AND UPPER STEM DAMAGE **SCATTERED TREES IN YOUNG PLANTATIONS** Hoyer 1983	Widespread damage in coastal Washington and British Columbia DF plantations. Causes serious future loss when 30% or more of stand affected.	Occurs in plantations from 10 to 25 years old. Symptoms include dead leader, dead terminal bud, cut or broken leader, multiple tops, forking, and crooking. Some injury types caused by birds and insects or initiated by lammas growth.	Manage for other species on soil types where top damage known to occur. Change species when damage predicted to be over 25% of stand. Maintain best seed source for area. Final recommendations still being resolved.

ADVERSE ENVIRONMENT	IMPORTANT FACTS	WHAT TO LOOK FOR	MANAGEMENT
SPRING FROST INJURY	Most DF survives but growth rate reduced. Damage more serious once dormancy is broken. Most damaging to off-site seed sources, especially when southern seed sources are planted farther north or upward in elevation. May occur in both spring and fall but spring damage most common.	In summer, emerging shoots discolor and wilt, first turning dull green then brown. Dead shoots persist for one or more years showing chronic damage. Cold air drainage may form pools of cold air in broad valleys. Repeated frost looks like animal browse. Check shoots to rule out animals.	Shape stands and clearcuts to provide good air drainage. Prevent pooling of air. Use low brush as "heatsink aid in chronic pooling areas. Consider frost resistant nurse crop of shore pine in bad areas, then follow with DF using local seed source. Don't move seed source north. Once trees exceed 8 to 10 ft (2. 4 to 3 m) height they generally escape damage.
HAIL DAMAGE	Temporary but sometimes spectacular damage. Identifiable swath of damage traces storm path.	Spring-Summer. Rapidly healing wounds on upper sides of branches. Broken, torn foliage on all types of vegetation.	None. Trees will recover. Small wounds compartmentalize rapidly.
SUNSCALD Foster and Wallis 1974	Damage may occur after stands are thinned. Stem cankers cause eventual breakage and grade loss but decay not severe.	Summer. Stems on southwest sides of trees have patches of coppery red killed cambium. Color fades by season end. Common on droughty sites, rapidly growing trees, or areas recently thinned. Cankers may be short or extend entire length of exposed bole.	Do not thin over stocked stands so that branch-free boles are exposed to full sun. Streamline edges of stand with acclimated trees. Remove trees in two or three stages in urban areas to slowly acclimate residuals.
THINNING SHOCK	Vigor loss in newly pre-commercially thinned DF is usually temporary. Trees must switch from "shade" needles to "sun" needles.	Spring-Summer. Foliage appears unhealthy after thinning. Excess needle drop and poor vigor on crop trees. May last one year or more. See Swiss needle cast. Absence of stem cankers distinguishes this injury type from sunscald.	Consider impact when thinning certain stands. Mostly a precommercial thinning problem and usually only temporary, lasting 1 to 2 years. In dense stands where trees have poor crown ratios (less than 30%), recovery may be much longer.
AIR POLLUTION Davis and Gerhold 1976	Potential in lowlands and against certain Cascade slopes. Little is known about total air pollutant injury potential to DF. No areawide indication of air pollution in coastal DF. Damage may occur within a short distance of pollution sources, such as aluminum plants and creosote/penta wood treating plants.	Burned or tip dieback of foliage, or mottling. Yellowing may be found next to dead tissue. Progressively poor growth with thinning, ratty crowns. May be confused with weather damage. Damage most apparent on upwind side of source.	Reduce source through emission controls. Plant resistant trees near source selected from well-developed lists.

ADVERSE ENVIRONMENT	IMPORTANT FACTS	WHAT TO LOOK FOR	MANAGEMENT
CONSTRUCTION DAMAGE	Occurs around developments and campgrounds. Not generally a forest problem.	Fading, sickly trees. Trunk emerging without flare indicates backfilling. Check backfilled soil texture. Look for excessive wounds.	Backfilled clay soils eventually kill DF. Aerated gravel soils may be okay. Backfills can be removed and area relandscaped. Fertilize trees. Recovery often good if treated early enough.
FLOODING	DF cannot tolerate wet or periodically flooded sites.	Enlarged root mass with watery phloem. Roots with white hypertrophied lenticels about 1 mm long. They resemble small popped corn kernels.	Plant grand fir, redcedar, or shore pine in wet areas.
DROUGHT	May cause substantial branch or whole-tree mortality on soils containing more than 50% gravel. May be severe on reforested prairie soils.	Summer. Red foliage in late summer. Needles light red to brown, not deep red-brown of winter injury. Needles often curled; winter injured needles not distorted. Scattered plantation mortality without patten. Check for high gravel (or rock) content in soil. Damage occurs about one year out of a dozen and declines after plantation becomes established.	Plant drought resistant shore pine on rocky soils. Do not clearcut severe drought sites. Use shelterwood for heat protection. Problem often exists where DF has become established in gravelly outwashes along valley bottoms and on forested prairie soils. Not a problem on hillsides with better soil for growing trees.

INSECTS AFFECTING ROOTS	IMPORTANT FACTS	WHAT TO LOOK FOR	MANAGEMENT
ROOT COLLAR WEEVIL *Steremnius carinatus* Condrashoff 1968 Condrashoff 1969	Local problem in small areas. Reported feeding on first season DF seedlings and plugs in clearcuts burned prior to planting.	Adult weevils remove seedling bark from 1 cm below to several cm above the soil surface. Damage usually occurs on tender seedlings within a month of planting. Seedlings fade a month or more after they have been girdled. Girdled seedlings die, but partially girdled ones may survive. Large transplants more resistant.	Plant immediately after logging and slash burning. Use large transplants if weevil problems are anticipated. Plant high weevil risk areas in the spring (not in autumn) to allow a season of growth before exposure to autumn feeding.

DISEASES AFFECTING ROOTS	IMPORTANT FACTS	WHAT TO LOOK FOR	MANAGEMENT
ANNOSUS ROOT DISEASE *Heterobasidion annosum* *(Fomes annosus)*	Coastal DF is rarely damaged by annosus root rot.	---	No special management needed.
ARMILLARIA ROOT ROT *Armillaria ostoyae* (Old: *A. mellea.* Taxonomy has been restructured.) Hadfield et al. In press.	Most serious is growth reduction and loss of productive growing space. Fungus survives for decades in old stumps and roots and is most threatening to new plantations. In coastal DF, tree killing more common where trees are stressed. Examples are poor planting or rocky soil where trees were difficult to plant. Mortality may not show for 10 to 20 years. May cause reduced stocking after precommercial thinning of plantations. Losses from decay are minor in second-growth stands with short rotations. Decay rarely extends more than 4 ft (1. 3 m) above the ground.	Most common in plantations. Dead pockets of trees in several stages of decline. Look for fading crowns, shortened leaders, resin flow near ground, and distress cone crop prior to death. Green but infected trees difficult to detect. Mats of white fungal mycelium peel away like latex paint under bark of infected roots and around the root collar. Mycelium extends upward to 6 ft (2 m). Black rhizomorphs (rootlike) under bark on infected roots and bole. Honey colored mushrooms near trunk in fall.	Maintain vigorous growing stock. Do not plant DF off site. Insist on high quality planting over quantity. Avoid future root strangulation by careful root placement. Use natural regeneration where disease incidence high for low cost alternative. Do not space severely infected areas. Instead, thin lightly to allow for future mortality. Mark large disease centers prior to harvest. On severely infected sites, push stumps in and around infected areas to remove inoculum. Plant away from pushed stumps and broken, infected roots.
BLACK STAIN ROOT DISEASE *Verticicladiella wageneri* Hansen et al. In press	Occurs in scattered infection centers throughout coastal DF. Found mostly near disturbed areas such as roads, skid trails, and landings following precommercial thinning. Stain in wood results in a grade defect. Forest disturbance triggers higher incidence. Intensive management can result in more disease in DF stands.	Symptoms include fading crown, shortened leaders, reduced diameter growth, distressed cone crop, basal resinosis, rapid decline, and death. Chop into lower trunk near source of resin to expose stain. Purple-brown or black stain in sapwood of roots, and lower stem. Stain usually in outer ring, but may be buried by an inch or more of clear sapwood.	Remove DF within infection centers and surrounding 50 ft (17 m) buffer strip. Favor or regenerate with hemlock or spruce where feasible. Susceptible hosts may be planted one year after host trees are removed. Use high-lead or skyline systems near blackstain disease centers to minimize skid trails and soil compaction. Plant skid trails with resistant species like hemlock.

DISEASE AFFECTING ROOTS	IMPORTANT FACTS	WHAT TO LOOK FOR	MANAGEMENT
LAMINATED ROOT ROT *Phellinus weirii* Hadfield 1985 Thies 1984	Most destructive root disease in coastal DF. Causes 5 to 10% average loss in stand productivity throughout region. Localized losses may be much higher. Heart rot in living trees seldom extends far above the stump and has little effect on yield. Infected trees and windthrows are prime targets for bark beetles, which can spread to healthy timber. May cause reduced stocking after precommercial thinning of plantations. Disease pockets expand at about one foot per year. Disease pockets may double in area every 20 to 40 years.	Thinning and yellowing of foliage, short leader and a distress cone crop. Scattered windthrow and mortality. Gray to cinnamon colored mycelium on bark at the root collar and roots. Early decay usually appears as crescent shaped reddish stains on outer sapwood of stump cuts. Advanced decay becomes soft with small pits, and wood separates at annual growth rings. Thin, velvety layers of cinnamon colored fungal hyphae are usually present in crevices. Dead standing trees and windthrows create pockets in forest stands of various sizes. Symptomatic trees in all stages of decline found throughout disease centers.	Mark disease centers before harvest so that diseased stumps can be found after logging. Permanently record disease center locations. Patch-cut disease pockets and surrounding trees within a 50 ft (17 m) buffer during commercial thinning. Harvest severely diseased stands early. Regenerate with root rot tolerant species such as lodgepole pine, western white pine, western redcedar, western hemlock, or red alder. When alternative species selection not acceptable, push stumps within disease centers to remove bulk of inoculum from severely infested sites. Replant with DF, but use wider spacing to prolong root closure. Plant away from pushed stumps and broken, infected roots.
RHIZINA ROOT DISEASE *Rhizina undulata* USDA Forest Service 1983	Pioneer fungus of burns. Kills newly planted DF and other conifers. Regionally, not a widespread problem but can be severe tree killer confined to local drainages or areas. Spores blow into new cutting units from lower infected units as logging progresses up the valley.	June-July first year. Dead tree pattern in new plantations burned pior summer or fall. Buds of infected seedlings elongate then droop or emerge "bottle brush" like. Trees die same summer. Fruiting bodies soft and half spherical. The "scatlike," brown to black sporocarps, with creamy margins, grow around bases of seedlings and along roots of burned conifer stumps.	Local knowledge of infection distribution helps pinpoint disease potential. Do not stop burning to "control" this pathogen. Replant following year. Balance need to replant with brush regrowth.

INSECTS AFFECTING STEMS	IMPORTANT FACTS	WHAT TO LOOK FOR	MANAGEMENT
DOUGLAS FIR BEETLE *Dendroctonus pseudotsugae* Furniss and Carolin 1977 Furniss et al. 1981 Pitman 1973	Major outbreaks triggered by catastrophic events (wind, fire, etc.) allowing populations to build and spread into standing overmature DF. Small outbreaks can begin in root rot centers in older stands and spread into surrounding green timber.	Late spring-early summer. Reddish-brown boring dust in bark crevices. Later in summer, needles fade until entire tree is red. Resin streaks on bark from upper limit of attacks. Trees killed in groups, with several trees reddening same year. Root rot trees die progressively over several years.	Direct control not practical. Prevent by removal of susceptible trees, i. e. , breakage, overmature, and root rot infected trees. Maintain desirable spacing until harvest. Salvage infested trees promptly. Prevent scarring during thinnings.

DISEASES AFFECTING STEMS	IMPORTANT FACTS	WHAT TO LOOK FOR	MANAGEMENT
WOUNDING AND DECAY (Many decay fungi) Shigo and Marx 1977	Exessive or large wounds cause loss of valuable butt log when stand entry cycles are greater than 20 years. Trees with decay become hazardous to people in recreation sites or around homes.	Inspect thinnings carefully for trees with wounds greater than 1ft^2 (0.3m^2) in area. Animal feeding scars on large or small diameter trees.	Make low or zero wounding an objective of thinning. Use "bump" trees, skid road design, and falling pattern to prevent damage. Do not worry about animal feeding scars on nonmerchantable size trees. Wound heals fast and leaves small stain cylinder only. Do not leave large trees with wounds in woods for more than 20 years.
DOUGLAS-FIR DWARF MISTLETOE *Arceuthobium douglasii* Hadfield and Russell 1978 Hawksworth 1977	Found only in DF transition zone along the Cascade crest and south of Umpqua River drainage in Oregon to about 40° latitude. Causes growth loss, deformity, and mortality. Growth loss in both diameter and height significant. Wood quality reduced from numerous large knots. Stain and decay fungi cause additional defect.	Dwarf mistletoe plants emerge from bark of branches and twigs. Plants do not extend beyond length of needles. Large distortion in normal growth common. Trunk cankers result when parasite enters main stem. Tree crowns ragged and patchy from loss of vigor except in brooms.	Control silviculturally by special selection sanitation. Even-storied stands prevent most rapid disease spread from upper to lower stories. Clearcut heavily infected old-growth stands, including all regeneration. Do not thin heavily infected young-growth stands. Instead, plan early harvest. Concentrate control in intermediate ages using Hawksworth dwarf mistletoe classification to dictate cut trees.

INSECTS AFFECTING FOLIAGE	IMPORTANT FACTS	WHAT TO LOOK FOR	MANAGEMENT
DOUGLAS-FIR NEEDLE MIDGE *Contarinia pseudotsugae* Condrashoff 1962	Seldom causes damage in native stands. Important defoliator in Christmas tree plantations.	Midge larvae mine inside needles, causing swelling or bulge. Enlarged area often turns purple (June). Damaged needles drop early.	Control not needed in forest stands. Thiodan and Orthene insecticides used in Christmas tree plantations (Capizzi et al. 1985). Apply Orthene about 2 weeks prior to bud burst. Apply Thiodan when trapping indicates peak female emergence.
DOUGLAS-FIR TUSSOCK MOTH *Orgyia pseudotsugata* Brooks et al. 1978	Does not cause problems in coastal Douglas-fir. Serious defoliator of eastside DF. Westside foresters often confuse Douglas-fir tussock moth with the silver spotted tiger moth.	Eggs hatch in early spring and small hair larvae begin feeding on new foliage. Defoliation in or near tops of trees. Mature larvae have four conspicuous white tufts (tussocks).	Since insect is rare in coastal DF, control not necessary in natural stands.
SILVER SPOTTED TIGER MOTH *Halisidota argentata* Silver 1958	Not a problem in native stands. Often reported defoliating individual branches on ornamental conifers. Sometimes confused with DF tussock moth. Overwinters in webs in coniferous trees and sometimes feeds during warm days in winter.	Reddish-orange caterpillars feed gregariously on single branches, producing silken webs. Mature caterpillars disperse and feed individually.	None necessary in forest stands. Prune and burn branches when on ornamentals.
WESTERN SPRUCE BUDWORM *Choristoneura occidentalis*	Occurs occasionally in coastal DF but does not cause problem.	Light feeding on new foliage.	None
COOLEY SPRUCE GALL APHID *Adelges cooleyi* Capizzi et al. 1985 Cumming 1959	Rarely causes problems in native stands, but is capable of killing small groups of young trees in plantations during dry years. Major Christmas tree problem.	Needles become distorted, and mottled with pale yellow spots. Severe feeding causes needles to drop.	Control not necessary in forest conditions. In Christmas trees apply Thiodan just after bud burst.

DISEASES AFFECTING FOLIAGE	IMPORTANT FACTS	WHAT TO LOOK FOR	MANAGEMENT
SWISS NEEDLE CAST *Phaeocryptopus gaumanni* USDA Forest Service 1983	Common foliage disease of DF. Christmas tree plantations have the most problem throughout the coastal type. Isolated plantations build chronic infection which weakens crown and root systems, causing up to an estimated 30% growth loss.	Spring. Entire plantation appears yellow and leaders may show 50 to 70% of normal growth. Hundreds of tiny black fruiting bodies appear in stomatal openings on under side of one-year-old or older needles. Other needles begin to drop in early spring and continue into early summer. Infected trees often have only one-year-old needles plus new flush of current year needles.	Control is routinely done in DF Christmas tree plantations with helicopter-applied chlorothalonil fungicide at either 0. 5 or 1. 0 gallons of material per acre in 10 to 12 gallons of water (1. 9 to 3. 8 liters of material per ha in 93 to 112 liters of water). A single application is made in early June when new needles are 1 to 1. 5 inches (2 to 4 cm) in length. Critical analysis by a pathologist should be done before controlling this disease in forest plantations.
RHABDOCLINE NEEDLE CAST *Rhabdocline pseudotsugae* USDA Forest Service 1983	May erupt in local areas of coastal DF especially in Christmas tree plantations. This disease tends to build up over several years then gradually drops to endemic levels. It was much more common in the late 1960s than in the 1980s.	In spring, trees appear yellow and have only 1 or 2 years of needles. By mid-May undersides of one-year-old needles covered with salmon colored fruiting bodies about 1 mm long. Tops of needles have yellow (early) then red spots or bands.	Maintain trees in vigorous condition. No fungicidal sprays are recommended although chlorothalonil may be effective. Usually not a serious problem in forest plantations.

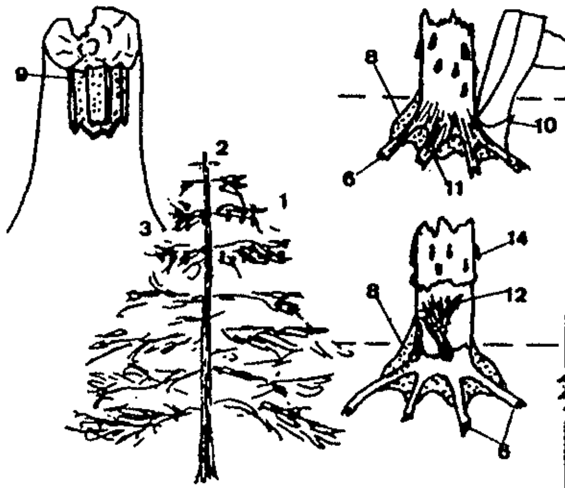
INSECTS AFFECTING CONES AND SEEDS	IMPORTANT FACTS	WHAT TO LOOK FOR	MANAGEMENT
DOUGLAS-FIR CONE MOTH *Barbara colfaziana* Hamel 1983 Ruth 1980	Larvae feed inside cones and destroy the developing seeds.	Pitch and frass on outside of cones.	Control only in selected seed production areas and orchards. Use systemic insecticides for control (Hamel 1983). Details too complex to be listed here.
DOUGLAS-FIR SEED WASP *Megastigmus spermatrophus* Ruth 1980	Larvae destroy individual seeds. Seed losses not usually severe. Endemic populations occur throughout host range.	Larvae found inside seeds by dissection. Distinct exit holes in seeds after adults emerge.	Seed losses usually not severe.
DOUGLAS-FIR CONE GALL MIDGE *Contarinia oregonensis* Hamel 1983 Ruth 1980	Midge larvae reduce seed yield by producing galls that cause seeds to stick inside cone scales during cone processing.	Galls inside cones contain tiny pink larvae.	Control only in selected seed production areas and orchards. Use systemic insecticides for control (Hamel 1983). Details too complex to be listed here.

INSECTS AFFECTING DEAD TREES AND LOGS	IMPORTANT FACTS	WHAT TO LOOK FOR	MANAGEMENT
AMBROSIA BEETLE *Trypodendron lineatum* Chapman 1974 Nijholt 1978 Richmond and Nijholt 1972	Found in dead and dying timber (logs). The beetles construct galleries in wood and introduce stain fungus. Responsible for reducing value of export products.	Bark fissures of dead and dying trees and logs have small piles of fine, light colored boring dust. Wood under peeled away bark has tiny black holes called "pinholes. "	Move logs from forest right after felling. Avoid leaving fall and winter cut logs in the woods through spring beetle flight period. Reduce spring and summer inventories in log storage yards. Use water mist to protect logs from attacks in dry storage.

DISEASES AFFECTING DEAD TREES AND LOGS	IMPORTANT FACTS	WHAT TO LOOK FOR	MANAGEMENT
SAPWOOD ROTTERS WEATHER CHECK Russell 1983b	Reduces usable wood cylinder diameter in standing or downed trees after catastrophe (wind, volcano, fire, etc.).	Weather checking of logs and fruiting bodies of wood rotters, Lenzites Schizophyllum, and others.	Log fallen or standing timber within the first year if possible. Projection losses from graphs (Russell 1983).

Adapted from: Disease and Insect Management for Douglas-fir, in Oliver, C. D. , Hanley, D. P. , and J. A. Johnson (eds.) 1986. *Douglas-fir: Stand Management for the Future.* Institute of Forest Resources Contribution No. 55, College of Forest Resources, University of Washington.

ROOT ROT

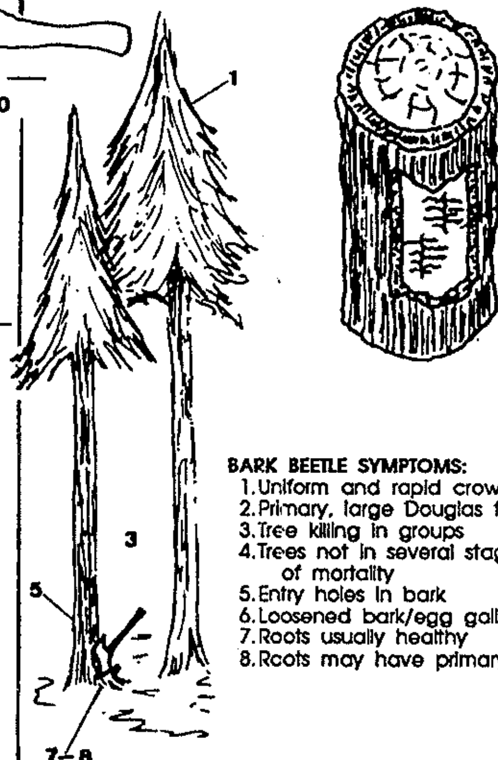


ROOT ROT SYMPTOMS:
1. Uniform crown fade
2. Slowly shortening leader: 2-3 years
3. Distress cone crop
4. Trees in several stages of mortality
5. Mortality in patches: rotted stumps evident
6. Broken, rotted roots on pulled up trees
7. Blowdown without root wad
8. Resin-soaked soil at root crown

***PHELLINUS WEIRII* ROOT ROT SYMPTOMS:**
9. Rotted wood separates at growth rings
10. Reddish-colored setal hyphae in pockets under bark (use lens)
11. Thin, buff-colored fungus covering root surface

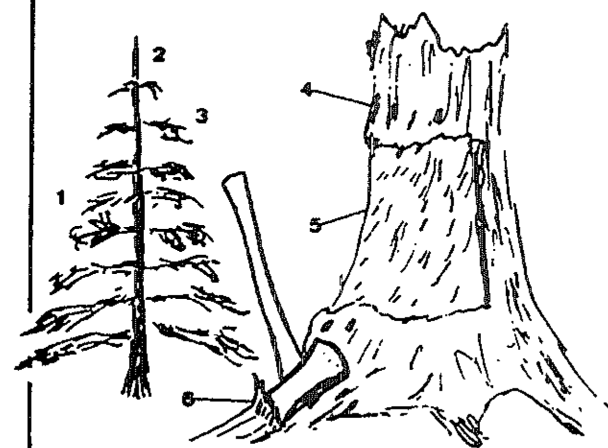
***ARMILLARIA* ROOT ROT SYMPTOMS:**
12. White, fan-like fungus felts under bark
13. Mushrooms at base of tree in fall
14. Considerable pitching above root crown

BARK BEETLES



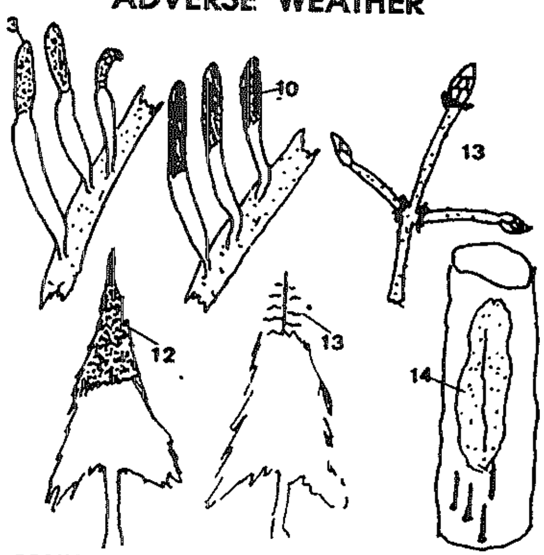
BARK BEETLE SYMPTOMS:
1. Uniform and rapid crown fade
2. Primary, large Douglas fir
3. Tree killing in groups
4. Trees not in several stages of mortality
5. Entry holes in bark
6. Loosened bark/egg galleries
7. Roots usually healthy
8. Roots may have primary root rot

ANIMAL DAMAGE



ANIMAL DAMAGE SYMPTOMS:
1. Uniform crown fade to injury
2. Leader does not shorten
3. No distress cones
4. Bleeding resin
5. Chewing or girdling
6. Roots usually healthy

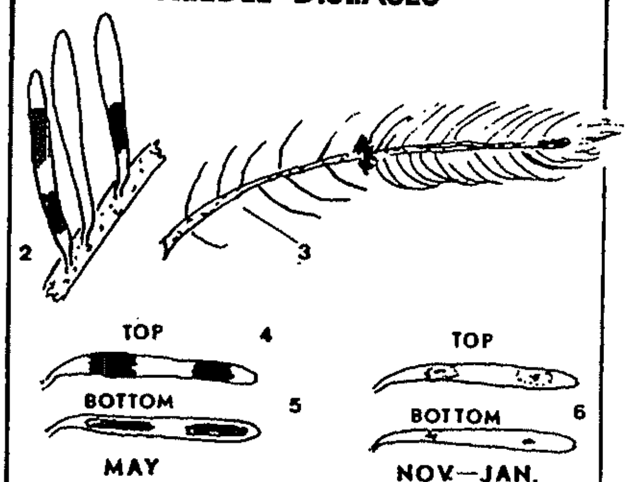
ADVERSE WEATHER



DROUGHT INJURY SYMPTOMS:
1. Tree has a yellow-brown cast
2. Injury usually confined to this year's needles
3. New needle tips yellow-brown and shrunken
4. Injury most evident late summer
5. Mortality occurring August-October
6. Root rot and beetle or herbicide symptoms absent
7. Roots dry but healthy looking

WINTER INJURY SUMPTOMS:
8. Tree has a red-brown cast
9. Current needles injured
10. Needle tips not shrunken, only red
11. Injury most evident early summer
12. Needles intact; tree top red
13. Top needles gone; buds intact; twigs succulent; no chewing
14. Bleeding cracks; bole, cambium dead
15. Roots healthy

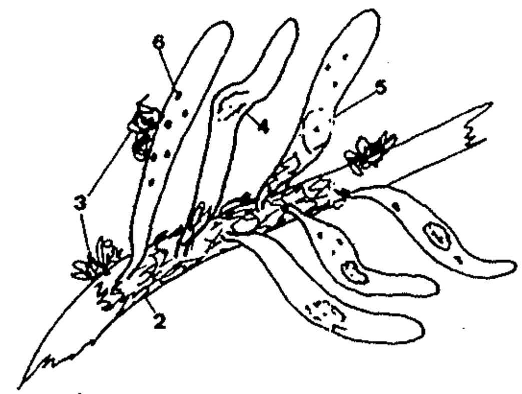
NEEDLE DISEASES



(EX RHABDOCLINE NEEDLE CAST DOUG FIR)

NEEDLE DISEASE SYMPTOMS:
1. Tree has red-brown cast
2. Random current year needles affected
3. Many of last year's needles gone
4. Top of needle has red patches - May
5. Fruiting structures underside needles - May
6. Small, reddish dots; yellow halo underside - Nov/Feb

NEEDLE INSECTS



(EX. APHIDS ON DOUG. FIR)

NEEDLE INSECT SYMPTOMS:
1. Tree has yellow cast
2. Twigs and needles covered with honeydew; later turns moldy
3. Woolly egg mass on twigs and needles
4. Needles may be distorted
5. Small yellow spot on needle
6. Black crawlers on needle 1/32" diameter

Conifer Disorders. Revised 9/91. State of Washington Department of Natural Resources-Forest Health; 111 Washington Street, SE, PO Box 47037 Olympia, WA 98504–7037. Reprinted with permission.

Chapter Six

Animal Damage Management and Pesticide Uses on Forest Lands

Dan L. Campbell

Appendix 4

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Animal Damage Management and Pesticide Uses on Forest Lands

Dan L. Campbell

Introduction

The activities of wild mammals in Pacific Northwest forests often conflict with management objectives for establishing, growing, and harvesting forest crops. The primary problem species include deer, elk, black bear, porcupine, rabbits and hares, mountain beaver, pocket gophers, mice and voles, and occasionally, tree squirrels. Girdling of conifers by beaver is increasing as these animal populations increase because of reduced trapping. The normal activities of feeding, burrowing, nest building (by rodents), gnawing and girdling, gathering food, trampling and antler rubbing are usually tolerated and may be beneficial in control of competing vegetation in most forest stands. However, when these activities by wildlife cause severe reductions in forest production, the value of the potential forest crop is significantly reduced or lost.

Nearly all forest protection efforts against animal damage are now directed at tree seedlings, precommercial stands, and even commercial trees. Artificial seeding in forest land virtually stopped in the 1970s because of failures to establish suitable plantations. Damage to seed and germinating seed by birds and mice is now primarily limited to forest nursery operations and where natural reforestation relies on seedfall. Artificial coloration of seed has been effective for protection against birds (Pank, 1976) but no seed treatment for protection against rodents is registered.

Livestock once ranged throughout most westside and eastside forest lands, but are presently found mainly in regions having lower precipitation. Livestock may cause damage by trampling young trees and feeding on the foliage of both conifers and commercial hardwoods. Livestock foraging may reduce available browse for deer and elk and thereby direct more browsing onto commercial tree species. Moderate livestock grazing, however, can be beneficial for control of competing vegetation. Grazing by livestock should be closely regulated to avoid unwanted browsing and trampling. Discussion of the benefits and limitations of livestock use in forestry practices have been reviewed (Graham, et al., 1992 and Kingery and Graham, 1987). Where voles cause damage by clipping and girdling tree seedlings, managers can use cattle to reduce the grass habitat voles require. The role of livestock to control habitat used by pocket gophers is being investigated; previous studies have indicated the use of certain herbicides could reduce use of sites by pocket gophers, but questions on the use of herbicides and pesticides in general in forest environments have slowed that research activity. Another consideration when combining livestock with forest operations in areas where black bears are girdling conifers, is that bears sometimes prey on livestock.

Changing Needs in Forest and Wildlife Practices

Wildlife feeding on tree seedlings, saplings, and older trees is widespread and sometimes complicated by the expansion of small farms and residential development into forest lands. Development is often followed by restrictions in sport hunting, resulting in increased deer and other wildlife activity near residential woodlots. A result has been increased feeding injuries to reforestation and to agricultural and ornamental crops. The need to protect these "residential" forest crops, where wildlife populations cannot be managed by harvests of excess animals, makes it more necessary to develop acceptable barriers or repellents to control these damage problems.

Forestry practices now require retention or development of habitat within forest stands to promote fish and wildlife. The protection of streamside vegetation, the practice of leaving trees within harvested stands, and related rules are relatively recent requirements (Anonymous, 1992). Research and management effort directed toward the selection and production of mixtures of native plant species within forest plantations can help avoid serious problems between wildlife and forest establishment (Campbell and Evans, 1978; Campbell and Johnson, 1981; and Rochelle, 1992). Managers must choose desired plant species carefully for developing forest stands to allow good production of timber and wildlife habitat. Much more research information is needed on habitat conditions to minimize forest-animal conflicts and help managers design suitable forest and wildlife habitats.

As forest and wildlife managers seek more diversity in forest stands, they must measure the influence of wildlife on stand development carefully. Anticipate animal activities to allow management of effects on forest production and forest diversity. Forest prescriptions may require modification during the establishment of stands to achieve desired tree densities, spacing, and species mixtures. Pesticides may be part of the prescription to help avoid or reduce the impacts of wildlife on good forest development.

Regulations Affecting Pesticide Applications

Any chemical formulation, either toxic or nontoxic, marketed to reduce animal damage is considered a pesticide and must be registered with the appropriate state Department of Agriculture or the U.S. Environmental Protection Agency (EPA). Registered or experimental chemicals may be restricted or their use excluded from areas used by threatened or endangered species as specified by the U.S. Fish and Wildlife Service. Labels are periodically updated to list species of concern but may not list specific areas where use is prohibited. Experimental permits may be issued by the state for the evaluation of pesticides when the total area to be treated is less than 10 acres. A test area exceeding 10 acres requires an Experimental Use Permit (EUP) from the EPA. This includes any cumulative acreage where a chemical is tested at several concentrations. An EUP usually requires product information and it may require more than 1 year to obtain a permit.

All field applications of experimental and registered pesticides that are operationally applied are subject to inspection for compliance with either the experimental permit or registered label. EPA inspections may be conducted at any time during application of pesticides to assure compliance with the requirements of the permit or label. The application of some pesticides is restricted to use only by licensed applicators or individuals under the supervision of licensed applicators. Pesticide applicator licenses are issued for several purposes and usually require an individual to pass an examination conducted by the state Department of Agriculture. Recertification of pesticide licenses usually requires obtaining credits by attending recognized instructional meetings or pesticide recertification training classes.

The registration of a pesticide label is an indication of the efficacy of the product. Many pesticides, however, which become registered for forest animal use were initially developed for another use and the registration expanded for use on forest land. The high cost of pesticide registration often prevents the registration of products most suitable for the relatively minor market found for forest animal pesticides when compared with other agricultural markets. Although most EPA registered products must meet some efficacy requirements, the use of a registered pesticide does not assure that it will control a specific forest animal (vertebrate) problem. Additional testing may be required to determine if a registered product meets the needs of the user. The EPA periodically reviews registrations and may require additional information for reregistration. Registrants may discontinue registrations if they become unprofitable.

Economics of Forest Animal (Vertebrate) Damage

Surveys of animal damage to reforestation efforts have centered primarily on early stand establishment. A research study published in 1979, which was conducted mainly on coastal forest lands, estimated that $60 million was lost annually in Washington and Oregon (Brodie, et al., 1979). Projected values of 1993 timber crops probably double that amount. The use of both animal damage and vegetation control usually produces more economic return on higher quality sites (Knapp and Brodie, 1992). Increased reforestation efforts will be necessary to meet the needs of increased harvests of second growth and even third growth stands of timber, as they become more valuable in an expanding market.

The damage caused by mountain beavers is conservatively estimated at about $100 per acre to tree seedlings and saplings on sites occupied by mountain beavers. The need to replant coupled with a need for control of competing vegetation escalates replanting costs. Mountain beaver occupy about 300,000 acres of forest land in the Pacific Northwest and probably account for losses of about $30 million annually in direct damage to trees and indirect expenses in protection of trees and reforestation efforts. Amounts of girdling damage by mountain beavers are increasing on precommercially thinned stands. This increases the economic loss.

The economic impact of pocket gophers may equal that of mountain beaver. Even though pocket gophers occupy many timberlands of lower site quality than those occupied by mountain beavers, they are more widespread in interior and southern coastal forests of the Pacific Northwest. Many attempts to reforest sites occupied by pocket gophers have been failures because of inadequate methods to protect young trees from damage. Sites occupied by pocket gophers often have tree seedlings already stressed by marginally adequate moisture and suffer severe "natural" mortality. The addition of pocket gopher damage often results in complete failure of these plantations. Pocket gophers also quickly invade interior Pacific Northwest forests killed by insects. To reforest those sites, forest managers must control the increased competition from vegetation plus the newly established pocket gopher populations.

Deer and elk damage is widespread where quantities of more preferred forage are inadequate in sites being reforested. Browsing damage to Douglas-fir, pines, and most other conifers usually causes reduced growth, which can result in overtopping by shrub species and eventual mortality. Although some pulling of tree seedlings and antler rubbing occur, areas where that happens are usually localized. Seasonal damage may occur where animals are migratory. The most severe damage, sometimes causing mortality, occurs in areas that suffer both spring and winter damage. Browsed trees are stunted and may be subsequently damaged by hares, mountain beavers, and pocket gophers. Economic losses to deer and elk resulting in lost growth over a broad area are probably equal to losses from either mountain beavers or pocket gophers.

Black bear girdling of trees, mainly 15 to 30 years old, has become an increasingly important problem to designated crop trees following precommercial thinning. The bears seek the sapwood layer in late spring as a source of food. The economic loss can be substantial. Removal of bears by trapping or hunting to reduce damage appears economically justified but requires further evaluation. The damaged crop trees are often of marketable size but may be uneconomical to harvest because of the dispersed damage throughout a stand. Evaluations of supplemental feeding during the April to June period of girdling are being started, along with further evaluations for determining the reasons damage occurs in some bear occupied areas and not in others.

Forest Tree Species Damaged by Animals

Forest managers generally recognize that some tree species are usually preferred by wildlife, particularly deer. Young western redcedar is the commercial timber tree species usually most preferred by deer and elk. Older western redcedar trees are girdled and stripped by black bears. Similar stripping of redwood is done by black bears, but redwood otherwise appears to rank lower than western redcedar in damage from wildlife. More information is needed on the occurrence of damage to western redcedar as the economic value of second-growth trees increases. A test of western redcedar on the Gifford Pinchot National Forest indicates increased browsing by deer and elk in early winter, but the timing may be different in other areas. Recent pen tests by the Denver Wildlife Research Center at Olympia, WA, have shown extensive damage to western redcedar by black-tailed deer and mountain beaver throughout the year.

The western yew, currently of high economic value for its medicinal properties, is probably the most extensively damaged by wildlife. Natural regeneration of western yew is generally sparse or totally absent, apparently because of high feeding preference by wildlife.

The true firs (*Abies*) are generally resistant to animal damage. The true firs are seldom browsed by deer, elk, or livestock and other wildlife except pocket gophers. Research is needed to determine the reasons for this reduced preference.

Douglas-fir and most pines are usually intermediate in preference by wildlife, usually less preferred than western redcedar, but more preferred than western hemlock. Douglas-fir is damaged by most wildlife species, but this damage can be reduced by establishing an abundance of alternate preferred forage (Campbell and Evans, 1978). The use of abundant alternative forage to reduce damage to Douglas-fir for other wildlife species needs further research. Western hemlock is less preferred by most wildlife than Douglas-fir. Tests with black-tailed deer and snowshoe hares have shown Western hemlock is accepted about one-half as often as Douglas-fir. Data are presently being gathered on other preferences by wildlife species for conifers.

Few broadleaf tree species have been commercially managed in the Pacific Northwest, and the potential for animal damage depends on the tree species. Cottonwood is more preferred browse than red alder. Red alder is sometimes browsed by deer and elk, and stems are clipped and girdled by mountain beavers, stream beavers, and voles. As broadleaf trees become more valuable, the need for protection from wildlife, and for use by wildlife, will increase. Some research has been started to determine ways to protect cottonwood and other deciduous species.

The reasons for animal preferences for certain tree species are usually related to differences in odors and palatability from differing chemical properties. These chemical properties are generally undefined. The identification and utilization of the "natural" chemical defenses of these tree species might act as safer "pesticides" for the protection of more preferred forest tree species from animal damage. Some plants that have chemical defenses against foragers contain toxic chemicals. Research is needed to define the repellent properties of resistant tree species and the attractant properties of preferred species.

Identification of Animal Damage to Forest Crops

Early detection and identification of wildlife damage to reforestation is necessary to avoid further serious damage and to apply practices to avoid damage on similar sites. The proper identification of wildlife species causing damage is critical for the proper application of control methods. Identification guides, listed by Evans (1987), have described many of the features to look for in identifying the causes of damage. Professional advice is often necessary to identify the causes and possible management solutions or methods to avoid animal damage to forest plantings or stands. Forest wildlife specialists can assist with proper identification of these problems.

Proper identification can sometimes be confused with similar damage caused by several species of animals. Tree stems have been girdled in the same locality and even on the same trees and time period by mountain beavers, bears, and porcupines. Tree seedlings may be clipped by hares and mountain beavers living in the same area. Deer and elk cause similar browsing damage to tree seedlings and similar antler rubbing on stems. Pocket gophers will clip small trees and will girdle older trees in the same manner as mountain beaver, but the above ground girdling by pocket gophers is usually done while burrowing in snow. Damage by voles by stem clipping and girdling is often similar but is usually associated with surface and subsurface runways. Fortunately, mountain beaver and pocket gophers seldom occupy the same sites, but voles may be associated with either species. Stem and root damage caused by mountain beavers is either becoming more common or is being noticed more often as stands about 8 to 20 years old are more intensively managed.

It is important to know the specific times that damage may occur so that the correct preventive or protection methods may be used. In the Pacific Northwest most deer and elk browsing damage occurs on new growth in spring, from April through June, or in the winter in January and February when preferred forage is inadequate. Spring browsing usually occurs after bud-burst on conifers and before there is an abundance of palatable alternative forage. Winter browsing usually occurs where there is a shortage of preferred plants such as trailing blackberry. Mountain beavers clip seedlings primarily in winter, but damage often continues throughout the year. Girdling of stems and roots by mountain beavers occurs at least in winter months. Most injury by pocket gophers occurs in winter and spring by clipping tree seedlings and girdling older trees. Snowshoe hare damage to seedlings is most severe in winter. Bear damage from girdling is mainly from April to June. Most porcupine girdling occurs in winter.

Current Role of Pesticides in Forest Animal Damage Management

Pesticides have helped to establish many forest plantations by protecting tree seed and seedlings from wildlife; however, the number of pesticides registered to reduce forest damage by animals has declined in recent years. Many of the specialized minor use registrations have not been maintained because of the cost to gather data required by EPA to maintain registration. Some registrations have not been maintained because of questions of possible adverse effects on the environment and the costs required to answer those questions.

Repellent Formulations

Very few repellent formulations are currently registered in Washington, Oregon, or Idaho. A formulation of the repellent thiram (tetramethylthiuram disulfide) was still registered in Washington in 1994 and may still be reregistered. It is a good repellent against snowshoe hares. Thiram is also moderately effective as a repellent against deer browsing on Douglas-fir. Thiram, however, is now seldom used in forest nurseries. Possible neurotoxic effects of thiram, and closely related thiuram (antabuse) which has been used to treat chronic alcoholism, have been reviewed (Lee and Peters, 1976). Many managers believe that the liability associated with exposing workers to thiram is excessive. Thiram is otherwise low in toxicity and has been safely handled for many years in forest nursery operations and is used as a fungicide to treat a variety of vegetable and other seed.

Unpublished research by the Denver Wildlife Research Center Field Station at Olympia has shown that thiram is of value for protecting Douglas-fir from mountain beaver damage. Research on thiram for protecting tree seedlings against mountain beaver was discontinued, however, because of limited probable use of thiram. Personnel applying thiram in the field to protect seedlings against mountain beavers would have similar exposure as nursery workers.

Few repellent chemicals are now applied to tree seedling foliage at forest nurseries because of potential exposure of nursery employees to pesticides. This situation is unlikely to change in the near future and should be considered in the development of new or modified repellent formulations and application methods. The potential exposure to nursery personnel also applies to the testing of candidate systemic repellents, including any residues that may remain in nursery soils or may be leached into water supplies.

Registrations currently exist for protection of forest trees with several formulations of putrescent egg solids. This material was reregistered in 1994. Concentrations of 15%, 36%, and 37% active have also been registered against black-tailed deer, white-tailed deer, and Roosevelt elk. Lower concentrations, about 5% active, may be reregistered but have not been very effective against black-tailed deer in some research trials. Powdered putrescent egg material formulated at 36% active has been an effective repellent on Douglas-fir for 1- or 2- month periods against deer.

The 36% putrescent egg powder was found active in research studies on mountain beaver (unpublished report, Denver Wildlife Research Center) and was registered in Washington and Oregon for several years. This registration has not been renewed because of the cost of maintaining registration for the relatively small amount of the material used against mountain beaver damage.

Other candidate repellents for application to foliage or to roots as systemic repellent treatments are currently being evaluated on forest tree seedlings. The current status of these registrations should be checked by contacting the State Department of Agriculture.

BAITS

Few toxic baits are registered for forest land use in Oregon, Washington, or Idaho. Baits registered to control pocket gophers include formulations of strychnine, zinc phosphide, and diphacinone. Although the active component of diphacinone is as toxic as the other toxicants listed, it is formulated at a lower dosage and usually requires several feeding periods to be lethal to pocket gophers. The other baits are usually lethal after one feeding. Strychnine bait is registered at 0.5% active, diphacinone at 0.005% active, and zinc phosphide at 1.88% and 2.0% active. Zinc phosphide is also registered for some voles.

Strychnine bait was registered for control of mountain beavers only in Oregon. Recent tests in Washington and Oregon have shown poor field efficacy (Campbell, Farley, and Engeman, 1992), and registration is being discontinued.

Strychnine bait for the reduction of pocket gopher populations has been effective in some areas (Evans, et al., 1990) and less effective in others (Campbell, et al., 1992). Reinvasion is usually rapid, and population reduction may last for only a few months. Diphacinone baits designed for long-term reduction of reinvasion by pocket gophers were less effective than strychnine baits (Campbell, et al., 1992).

Increasingly, restrictions are being placed on testing experimental baits and on registered bait materials for rodent control because of concerns for effects on nontarget and endangered or threatened species. Proposed test sites for evaluations of baits for mountain beavers and pocket gophers have been moved because of potential effects on food animals of spotted owls and bald eagles found in or near the sites. Future bait registrations will require additional information on possible effects on the environment, including nontarget animals.

Other Alternatives to Pesticides

Rigid plastic mesh tree seedling protectors developed at the Denver Wildlife Research Center in the late 1960s for protecting individual seedlings for several years are the most effective form of above ground protection against a variety of animals (Campbell and Evans, 1975 and Campbell and Evans, 1988). This material has also been effective below ground against pocket gophers (Anthony, et al., 1978), but methods used against pocket gophers were expensive and simpler installations are being evaluated. This material should be used when several years of protection are needed and should be applied so that no maintenance of the protectors is required. To minimize deformed growth and installation costs, use only the materials which have been properly tested. These or similar barriers should also be considered where chemicals cannot be applied, such as in protected watersheds.

Trapping with either quick-kill or live traps can be effective for temporary reduction of populations of mountain beavers and pocket gophers. The established burrow systems, however, will usually be reoccupied within a few months or a year unless efforts are made to discourage further use of the underground nest or the burrows. Experimental removal of mountain beaver nests and use of predator odors in pocket gopher systems have shown promise in reducing reinvasion of burrow systems.

Sport hunting should be used wherever possible to avoid concentrations of big game, huntable small game, or nongame species that are not protected. This can reduce damage pressure while providing recreation and economic values.

Several types of fencing can be used, but costs are generally prohibitive on large areas of forest land. Total exclusion of animals is seldom desirable, and may even cause additional problems because other vegetation is not browsed and competes with crop species. Conflicts may also occur if recreational access is restricted.

Vegetation management can be effective as part of silvicultural operations through early establishment of plants suitable to reduce damage to trees. This practice needs further research on a variety of wildlife species and on a variety of sites. The use of some silvicultural methods recently have been reviewed for mountain beaver (Cafferetta, 1992) and pocket gophers (Marsh and Steele, 1992). Particular efforts should be directed toward evaluating habitats where existing populations have not caused significant damage. These conditions might then be developed to help avoid serious forest-animal conflicts.

Summary

The role of pesticides in forest animal damage management will continue to be important, but with increased emphasis on nonlethal chemical repellents and other nonlethal methods. The number of toxic bait materials or repellent materials registered as pesticides for control of forest animal populations has been decreasing. New emphasis is needed on the development of effective repellents, including the identification of nontoxic materials in plants which are resistant to foraging by animals. New pesticides for lethal control must be very selective and have minimal effect on the ecosystems where they are to be applied. The costs associated with registration of new pesticides and the reregistration of existing pesticides to protect forest crops will continue to reduce the number of new or continued pesticide registrations. The other methods and alternatives discussed or referenced should be considered and possibly applied in conjunction with the use of pesticides for the management of damage by forest animals.

Dan L. Campbell is Wildlife Damage Consultant, Wildlife Services Company, Forest and Urban Wildlife Management, Olympia, WA. Formerly Project Leader for USDA APHIS, Denver Wildlife Research Center, Forest Animal Research, Olympia, WA 98512.

Appendix 4

Forest Environment Pesticide Study Manual

The following articles on Pocket Gophers, Mountain Beaver, and Deer and Elk are reprinted from Huch C. Black, Technical Editor, *Silvicultural Approaches to Animal Damage in the Pacific Northwest,* courtesy of the USDA Forest Service, Pacific Northwest Research Station.

Silvicultural Approaches to Animal Damage Management in Pacific Northwest Forests

Hugh C. Black
Technical Editor

U.S. Department of Agriculture, Forest Service
Pacific Northwest Research Station
Portland, Oregon
General Technical Report PNW-GTR-287
January 1992

SECTION FOUR
SILVICULTURAL METHODS IN RELATION TO
SELECTED WILDLIFE SPECIES

Chapter 10
Pocket Gophers

REX E. MARSH AND ROBERT W. STEELE

Abstract

The description and presence of western pocket gophers of the genus *Thomomys* is common knowledge to most practicing foresters. Population densities vary widely and are influenced by weather, altitude, soil characteristics, and, most importantly, by food quality and quantity. Logging practices that improve habitat can result in constant, annual increases of the gopher population in a new plantation until the carrying capacity of the habitat is reached. In preferred forest-habitat, a high-density population of gophers (15 to 25 gophers per acre) can damage a significant percentage of conifer seedlings.

Gopher populations expand into unoccupied but suitable habitats predominantly by the dispersal of young gophers. An area that has been depopulated by baiting may be reinvaded by young animals from other areas or by high survival of young born to the few gophers that survived the control operation.

Gophers can tolerate a wide range of environmental situations and are highly adaptable to favorable but changing ecological conditions. Gophers in logged-over areas feed on a wide variety of plants but generally prefer fleshy or succulent roots and stems of herbaceous plants. They injure tree seedlings by root pruning, stem girdling, and stem clipping.

REX E. MARSH is specialist in vertebrate ecology, Wildlife and Fisheries Biology, University of California, Davis, CA 95616. ROBERT W. STEELE is research forester, Forestry Sciences Laboratory, Intermountain Research Station, U.S. Department of Agriculture, Forest Service, Boise, ID 83702.

The plant succession predicted for a site after logging, its capacity to support a high population of gophers, and the current abundance and distribution of gophers on the site and adjacent lands, are the major factors predisposing a new plantation to significant gopher problems.

Approaches for preventive management of gophers begin with the selection of silviculture systems. Minimizing disturbance of a site during logging and site preparation decreases the probability of gopher population growth and invasion. Natural or near-natural buffers of undisturbed strips of 400 to 600 feet in width between gopher-occupied areas and sites selected for harvest provide protection against rapid invasion by gophers. Planting as soon as possible after harvest is the single most important method of all the preventive silviculture practices available for pocket gopher management. Higher densities of stocking can compensate for seedling losses anticipated from gophers, and the planting of larger seedlings of top quality enhances rapid establishment of plantations. Larger stock also can survive greater injury from gophers.

Aggressive vegetation control with herbicides lowers gopher populations by reducing their food supply. Good results require a lag period of about 1 year, so herbicide treatments should considerably precede planting unless supplemented with gopher poisoning. Caution should be exercised with herbicides applied to release conifer seedlings in areas with moderate-to-high densities of gophers, because feeding pressure on seedlings may increase if alternate food sources diminish.

Where pocket gophers are traditionally a problem, silviculture approaches (including habitat management) often must be supplemented by direct-control measures to protect seedlings with physical barriers (plastic mesh tubes, for example) or with poison baits. Direct control of gophers with poison baits applied by hand or with burrow builders is the most common method of reducing tree damage. Population reduction also can be achieved by trapping gophers or fumigating burrows. The integration of silviculture practices with direct gopher-controls probably is the most effective approach to reducing gopher damage.

Keywords: Pocket gopher, *Thomomys* spp., vertebrate pest, gopher control, gopher damage, preventive control, gopher invasion, control strategies, seedling mortality, pest control, animal damage control.

Biology / Ecology

Taxonomy and Distribution

The most widely distributed species associated with forest damage is the northern pocket gopher, with the Mazama gopher second in importance. The Botta, mountain, and Townsend gophers also cause serious damage, but their distributions encompass fewer forests.

Pocket gophers, so named because of their external, fur-lined cheek-pouches, are fossorial (living belowground) and herbivorous rodents of the family Geomyidae; three genera are found in North America. Eight species make up the genus *Thomomys,* which is found over most of the Western United States in a range extending from central Alberta in Canada and well into Mexico, and from eastern North Dakota and eastern South Dakota to the Pacific Ocean. *Thomomys,* the predominant genus in the 13 western states and two western provinces of Canada (fig. 1), represents one of the major pests of western forests and is the only genus addressed in this chapter. Pocket gopher genera and species rarely overlap to any major extent in their distribution.

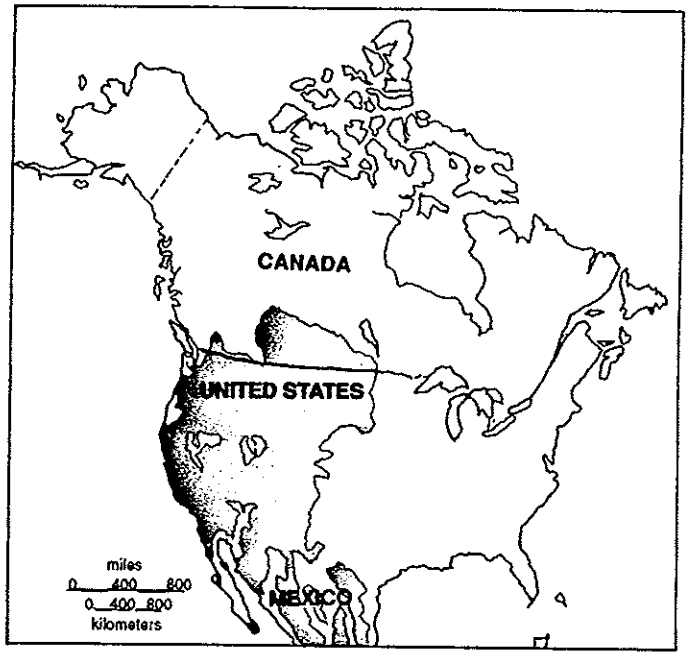

Figure 1—The distribution of the genus *Thomomys* in North America.

Description

Pocket gophers are morphologically and physiologically well suited for spending nearly their entire lifetime belowground. The gopher has a rather broad head with a short, thick neck. The shoulders are stout and limbs muscular, and the tail is relatively short and almost naked. The eyes and ears are small and inconspicuous. Gophers have poor vision but their senses of smell and taste are well developed. Their mouths can close with the four front teeth (incisors) protruding outside the lips; this permits digging with the teeth without getting dirt in the mouth (fig. 2). Gophers carry food items in external, fur-lined cheek-pouches located on each side of the head. Gophers vary in body size; the length of the head and body ranges from 5 to 9 inches. Adult males are substantially larger than females.

Figure 2—The pocket gopher is well suited for spending nearly its entire lifetime belowground and feeding on a variety of plants. They are observed aboveground in this photograph (Photo by Jerry P. Clark).

Activity Periods and Burrow Characteristics

Gophers may be active belowground at any time, day or night, and may cause damage year-round, because they do not hiberate. Seasonal changes in burrowing behavior that presumably relate to optimum soil-moisture and weather cause many fresh mounds of soil that appear in early summer and fall. Extensive summer mounding, however, may be delayed at higher elevations. During other periods of the year, mounding is less frequent. Gophers routinely move displaced soil into abandoned tunnels. Under a snowpack, they also place excavated soil in vacated snow tunnels. As the snow melts, these soil-filled tunnels collapse, leaving a network of conspicuous soil casts on top of the ground.

Pocket gopher burrow-systems provide shelter, protection from predators, and safe, reliable access to food resources. Each gopher maintains a complex network of tunnels from 2 to 3 inches in diameter. These often consist of several hundred linear feet of tunnels, most of which run parallel to the ground surface. Feeding or subsurface tunnels are usually 4 to 10 inches belowground and are constantly modified. The more permanent and commonly used tunnels are deeper. Gophers use short side (or lateral) tunnels to move soil aboveground.

Excavated soil pushed out through a lateral tunnel forms a crescent or fan-shaped mound on the ground. This characteristic distinguishes gopher mounds from mole mounds, which are shaped more like miniature volcanoes. Gophers plug entrances to burrow systems with loose soil to regulate the burrow microenvironment. If an occupied burrow system is deliberately opened with a shovel, the gopher will rapidly close the opening with soil, sometimes within minutes, but occasionally it may take as long as 48 hours for the opening to be discovered and closed. This trait can be measured to provide census data and assess the presence or absence of a gopher in the burrow system.

In addition to lateral tunnel entrances where displaced soil is deposited, other openings to the soil surface in forest and rangeland habitats are used as feed holes where the gopher comes aboveground to gather plant food and nest material. Gophers rarely travel more than 12 to 18 inches from the hole, and they immediately retreat when disturbed. Feed holes frequently lack any associated soil mounding and are often numerous and most prevalent in late summer and early fall. When not in use they are kept plugged with soil. These holes with "plugs" are relatively inconspicuous to the untrained eye, but their presence indicates gopher activity.

Burrow chambers constructed for nests and food storage vary widely in size, but they average about 8 to 14 inches across and may be as deep as 5 or 6 feet. Several nest chambers in one gopher system are not unusual. Multiple food chambers for caching food are also common; some of these may be very shallow and near the ground surface.

Reproduction

The typical breeding season for pocket gophers is late winter and spring. The major breeding period of about 4 weeks, however, seems to vary from year to year, presumably because of such factors as weather and food availability. In more northerly latitudes, at higher elevations, and in regions with a cold winter, breeding may be delayed by a month or two. The gestation period is 18 to 19 days. One litter per year is the norm for *Thomomys* spp. in forest habitats. Litter size is normally four to five offspring, but it also may vary depending on the year and area. The young gophers do not breed until the following breeding season, when they are about a year old.

Home Range and Territory

The home range of a gopher is defined as its current and recently occupied burrow system. Home range is synonymous with territory except possibly during breeding periods. The home ranges of male Botta gophers on rangeland average about 2,700 square feet (0.06 acre) with an approximate maximum of 8,000 square feet (0.18 acre) (Howard and Childs 1959). The range of females (1,300 square feet) is about half the range of males. These ranges are comparable with data collected for other *Thomomys* species. Food requirements, the abundance of suitable food year-round, and population density, apparently are paramount factors in determining the size and shape of home range. The shape is highly variable and follows no particular pattern. Home ranges change over time, but any shift normally is not dramatic.

Gophers are highly antisocial and live alone in their burrow systems except during the breeding season and when the mother is rearing young. Both sexes vigorously defend their territories against intruders of either sex.

Longevity and Mortality

Maximum longevity for gophers is about 5 years; however, the average lifespan ranges from 1 to 1.5 years. Less than 10 percent of the gopher population is estimated to reach 2 years of age, and females live somewhat longer than males.

Parasites and predation apparently play minor roles in regulating population densities, but information on disease-caused mortality is unavailable. Inclement weather, adverse environmental conditions, and a shortage of quality food, apparently, are the major factors that contribute to mortality. Mortality is highest among juveniles (less than 1 year old), and winter mortality of all age groups takes the greatest toll.

Population Dynamics

Gopher populations are relatively stable compared with many other rodent species, but they can increase annually until the carrying capacity of the habitat is reached. In rare situations, rapid declines occur with no apparent cause.

Population densities vary widely and are influenced by climate, altitude, soil (depth, type, drainage), and, most importantly, by food quality and quantity. Territoriality and social characteristics undoubtedly play a significant role in determining the upper limits of gopher populations. Densities as high as 41 gophers per acre have been reported (Howard and Childs 1959), but a population of 15 to 25 gophers per acre is considered high in forest lands. Mean densities per acre are often much lower than average overall densities, because population distributions are patchy. Local distribution is limited by unsuitable soils, excessive moisture conditions, or nonpreferred plant-community types.

Population patchiness caused by ecological factors (such as excessive moisture, unsuitable soil) seldom changes much, especially if the habitat is not significantly modified for several years. Population patchiness, however, may result from spotty invasions of recently disturbed habitat previously unoccupied by gophers. Spotty infestations of gopher populations in these cases expand until all of the suitable habitat is populated. Patchiness resulting from only a partially successful poisoning program is a similar scenario. Assessments of overall densities and the potential for seedling damage must, therefore, consider wide gradations of gopher densities. Effective management requires a recognition of the propensity for a gopher population to increase.

Movements, Dispersal, and Reinvasion

Young gophers disperse at approximately 8 weeks of age. Some remain close to their natal burrows; others may disperse overland or through existing tunnels. Dispersal of these juveniles is most common during late spring, summer, or early fall, depending on the breeding period. The distances traveled vary from a few yards to several hundred feet. Aboveground travel probably occurs mostly at night.

In areas free of winter snow, most movement into new territory by established adults takes place through tunnels dug belowground. In areas of high snowfall, however, substantial tunneling may occur aboveground within the snowpack. Burrowing through snow facilitates dispersal, because it enables gophers to cross terrain unsuitable for underground burrowing.

Feeding Habits and Preferred Foods

Gophers prefer vegetation associated with early successional stages of forest development, and they are capable of utilizing a wide variety of plants (Cox 1989). The pocket gopher's diet consists mainly of the fleshy and succulent roots and stems of herbaceous annual and perennial plants that are commonly abundant in early successional forests. Gophers, however, will feed on most plant parts, including tubers, leaves, bark, sapwood, and (occasionally) seeds and fruits. Smaller plants may be severed from their roots, pulled through the soil into the burrow, and entirely consumed by gophers. In early forest development, grasses are a significant but smaller component of the total diet (Burton and Black 1978), and gophers often are abundant in climax meadow communities.

When preferred food becomes scarce belowground, gophers may venture a few inches from their burrow opening to feed or collect food items aboveground. Root feeding, stem debarking, and clipping of certain shrubs and seedlings of conifer species may occur at any time of year, but injury is most severe in the winter. Burrow food-caches of roots and stems help gophers survive during food shortages.

Preferred Habitats and Environments

Pocket gophers occupy a wide variety of habitats. They can tolerate a wide range of environments and are highly adaptable to favorable, changing conditions that result from activities such as logging and agriculture. This, together with their wide geographic distribution, relatively high densities, and preference for many plant species important to man, makes gophers a serious pest to agriculture and forestry.

Gophers favor habitat with an abundance of annual and perennial forb species; however, they do well in mixtures of forbs and grasses. Dense populations often are found in mountain meadows, foothill rangelands, and low-elevation valleys.

In forest lands, gophers prefer more open habitat with little overstory canopy, and in the Pacific Northwest they are widely distributed in Douglas-fir, pine, true fir, and mixed conifer forests where they occur in natural openings, clearings for roadways or power lines, and in cut-over or harvested areas (including recently burned forests). Gophers generally avoid dense mature forest and dense conifer/shrub communities, but if these areas are set back to early seral stages by logging or fire, then they become suitable for dense populations of gophers.

Pocket gophers co-evolved with plants, so it is natural for gophers to favor the same soils and conditions that support their preferred food-species. Some soil factors limit local distribution, but gophers tolerate a wide range of soils. They prefer clay loams and sandy loams, granites, pumice, schist, and other soils that are light in texture and very porous. These soil characteristics facilitate the good drainage and gas ex-changes necessary for survival in burrows. Gophers may contribute to the increased percolation and penetration of water, but they also may significantly hasten surface and subsurface erosion of soil. In some regions, however, imperfectly drained soils may contribute to increased numbers of gophers, because the condition favors certain preferred forbs (Volland 1974). Gophers avoid very rocky or gravelly soils and soils with small particle sizes, such as heavy or gumbo clays; consequently, these soil types support few gophers. Gophers prefer deep soils that allow them to avoid temperature extremes near the ground surface. Shallow soils limit food resources and space for burrowing; consequently, gophers are more vulnerable to high-moisture conditions and predation.

Excessively wet soils, seasonal ponding and high water-tables from melting snow, and shallow soils unprotected from freezing temperatures by an insulating snowpack, are devastating to gophers. A snowpack that lingers into the summer decreases gopher survival, because the quality and quantity of food diminishes as the dietary needs for successful reproduction and nursing of gopher litters increase.

Certain topographic and physical features directly influence habitat suitability. Slopes in excess of about 35 percent generally are less populated with gophers. Slope direction influences such factors as wind, temperature, soil freezing, snow accumulation, and the speed of complete snowmelt. Rock outcroppings and streams inhibit gopher movements.

Tree Injury and Damage Identification

Pruning of seedling roots, stem girdling, and stem clipping are the most common kinds of gopher injury to seedlings. Stems of small seedlings of 0.5 inch or less may be clipped at or near ground level and the roots and stems may be eaten. Small seedlings may be pulled from below into tunnels, leaving little evidence of the tree's existence. Root pruning in plantations may go unnoticed until the tops turn brown from summer drought or until normal-appearing seedlings tip over at odd angles (fig. 3). These trees easily can be pulled from the ground to reveal the absence of roots (fig. 4). Damage to seedlings and saplings occurs year-round but is most frequent and severe in winter.

Larger seedlings or saplings may not be killed outright if gophers remove only a portion of the roots or root bark and if the stem is only partially girdled. Shortened needles, premature needle drop, shortened internodes, poor color, or poor growth are common characteristics of excess root-pruning or injury. Saplings and older trees sometimes die if gophers repeatedly feed on them. When conifers reach about 10 years of age, however, they generally are much less vulnerable to injury.

Extensive aboveground clipping and girdling of seedlings, saplings, and larger trees occurs under the snow, and damage is more frequent and severe if snow remains all winter and well into spring or early summer (fig. 5). Under deep snow, gopher injury (barking) sometimes extends 6 feet or more above the ground on small limbs or stems of saplings and poles, but it is of little consequence. This type of injury is sometimes confused with porcupine damage. Bark girdling of seedlings by gophers, however, may be complete or nearly complete; this leaves considerable wood exposed in the spring as evidence of winter feeding-activity. Gophers may gnaw deeply into the wood of seedlings and leave a sculptured effect (fig. 6). This helps distinguish gopher damage from damage by rabbits, voles, and porcupines, which rarely gnaw into the wood.

Figure 3—*Top left:* Pine seedling that is loose (unanchored) in the soil, because all major roots have been severed by gophers (Photo by Rex E. Marsh).

Figure 4—*Top right:* All the fine roots and root bark of this seedling have been eaten by a pocket gopher. This type of damage is typical (Photo courtesy Weyerhaeuser Company).

Figure 5—*Right:* Diagonal clean cut of pine stem several inches aboveground occurring while seedling was covered with snow.

Figure 6—*Bottom right:* Aboveground injury to pine seedling caused by pocket gophers burrowing through the snow. Note that gophers gnaw into the wood, giving the stem a sculptured appearance (Photo courtesy Weyerhaeuser Company).

Factors Predisposing a Stand to Gopher Damage

Factors that predispose a site to gopher problems should be evaluated before logging and include:

1. Local gopher-history concerning the severity and ecological distribution of damage relative to forest regeneration
2. Current herbaceous understory in its undisturbed condition
3. Predicted plant succession after logging and site preparation, and its suitability for sustained populations of pocket gopher
4. Current gopher population (density and distribution) on site and on adjacent lands
5. Percentage of border adjacent to (or within a short distance from) land vegetated with preferred forage species and free of a dense complex of trees/shrubs
6. Suitability of soil and percentage of site suitable for burrowing by gophers
7. Amount of snow accumulation and date when 75 percent of area is normally free of snow
8. Topographical and physical features (such as degree of slope, direction of slope, and drainage of soils

Many of the above factors are included in models that predict gopher damage in conifer plantations. One such model developed for use in conifer plantations in south-central Oregon (Horton 1987) is a good starting point for computer-oriented managers interested in predictive models. Modifications will be required to accommodate specific local conditions and situations.

The identification of plant communities that are more prone to high densities of gophers is a major step toward predicting current and future gopher problems in regenerating stands of conifers. Volland (1974) and Steele and Geier-Hayes (1987, 1989) have made substantial strides, regionally, in identifying plant communities or seral stages highly preferred by gophers. Predisposing factors that favor gophers after natural catastrophes (such as fire, blowdowns, and epidemics of mountain pine beetle) are comparable to factors that accompany logging, and the same considerations, therefore, are needed.

History of Damage and Control

The history of pocket gopher damage to seedlings in the immediate area of a site and the characteristics of sites or stands where the most damage occurred provide the essential clues and background for predicting future injury. Information on the success or failure of past control efforts also provides significant direction for future control.

Assessing and Monitoring Gophers

Reconnaissance surveys of gopher abundance, distribution, and source areas (such as meadows, road banks, etc.) may indicate potential problems. A review of the records for adjacent or similar areas may provide some clues of pending gopher problems, and decisions should be made accordingly. Where the regeneration history indicates that the potential for gopher damage is high, a reconnaissance survey may be warranted before harvest of a particular block is even considered. High potential for gopher damage may influence the type of harvest, the size and shape of the block, and the need for buffer areas or other methods of control, such as preharvest gopher baiting.

If the initial survey suggests a potential gopher problem, then one or more in-depth gopher appraisals should be conducted before site preparation and prior to planting. A series of 0.01-acre plots should be established to measure gopher abundance in terms of the percentage of "active plots" (USDA 1988). At least 1 percent, and preferably 5 percent of the area should be surveyed for the presence or absence of fresh (less than 48-hour-old) gopher mounds. Plots (11.8-foot-radius) should be located systematically throughout the parcel and spaced approximately 209 feet from center to center for a 1-percent sample or about 93 feet apart for a 5-percent sample (fig. 7). Old gopher mounds first should be knocked down, and the plots should be reread 24 to 48 hours later.

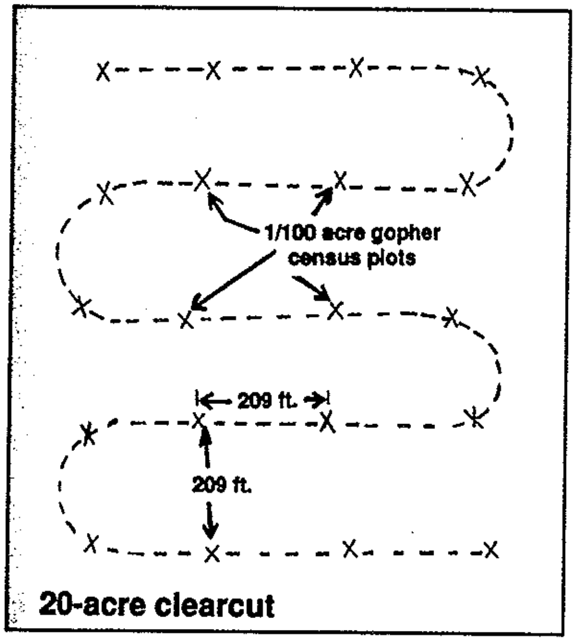

Figure 7—To assess gopher popula-tions, 0.01-acre plots at about 1 plot per acre are placed in a zig-zag fashion across the parcel with the plots spaced approximately 209 feet apart.

In parcels to be planted or before the winter-damage period in new plantations (0-2 years old), the Forest Service suggests that a positive reading for the presence of gophers in 25 percent or more of the 0.01-acre plots is a good rule-of-thumb indication that gophers should be controlled. In older plantations, 40 percent or more gopher-infested plots indicates the need for control action. In areas with a history of severe gopher problems, these action-thresholds (percentages) should be reduced by 50 percent or more. Early fall is the ideal time to take a census of gophers, because the mounding prevalent during that period re-flects the abundance of gophers just before winter (when seedling damage is most likely).

Gopher monitoring must be conducted on at least an annual basis over a period of 3 to 5 years after planting if a potential for gopher problems remains. Seedling stocking-surveys routinely are taken at 1 and 3 years by the Forest Service. These surveys often are used to determine gopher numbers and assess damage, but the frequency of these surveys often is inadequate for effective gopher control. With no intermediate check, extensive seedling damage frequently occurs by year 3. Routine monitoring, therefore, is a must.

The open-hole technique of determining gopher activity is a census method useful for evaluating the effectiveness of a baiting program. An established index of pretreatment activity can be compared with the posttreatment assessment to arrive at the percentage of control achieved (see the open burrow survey, USDA 1988).

Silvicultural Approaches for Preventive Management

Rationale

Foresters long have recognized the potential of certain silvicultural practices to minimize gopher problems, but they lack information about how, when, and where preventive measures can be effective. Current, published information is scattered and not readily available. Studies that attempt to synthesize the best current information cite many specific examples that describe specific methods for particular situations, but this does not necessarily imply that results from those methods can be extrapolated to different sites. General recommendations rarely suffice; therefore, the forester must appraise each site and manage it accordingly. Pesticide use is becoming more limited; consequently, preventive silviculture practices in animal damage management will, necessarily, play greater roles in the future. Direct control of pocket gophers with poison bait, however, will remain a major forestry practice for the foreseeable future.

Preventive measures of gopher management, ideally, should be considered when the type of silvicultural system is selected and when a stand is being considered for harvest. Management options are lost with each step from cutting through planting to final rotation. Once the seedlings are in the ground, the time is past for taking indirect preventive measures. Management options, therefore, become more limited, and direct control methods (such as baiting) become one of the few remaining effective options.

"New perspectives" (also called "new forestry") in forest management currently is receiving much favorable attention and will predictably have a major effect on wildlife habitat and potential problems of animal damage. The emphasis of new forestry is on partial cutting and less-severe disturbances; therefore, it should decrease gopher problems.

Types of Silviculture System

The major factors determining the effect of a harvest system on the potential for pocket gophers are: the amount of overstory removed, the amount of soil disturbance, and the response of the resulting plant community, especially the herbaceous vegetation. Partial cuts (single-tree selections, salvage, sanitation, or thinning) generally create less-favorable conditions than regeneration cuts (shelterwood, seed-tree, or clearcut), and light cuts have less effect on understory vegetation. Selectively cut stands of grand fir in Idaho, for example, have fewer gophers than clearcuts (Steele and Geier-Hayes 1987). In California, Buchner and Rorabaugh (1979) found no difference in gopher numbers between shelterwood and clearcuts; however, others have found that clearcuts support dramatically larger populations of gophers. Clearcutting tends to maximize all factors and contributes to conditions conducive to increases and invasions of pocket gophers. Repeated partial cuts in a stand, however, can result in higher and sustained densities of gophers than might result from clearcutting. Uneven-age management with group selection is more prone to gopher problems than individual-tree selection. The least amount of site disturbance generally decreases the probability of a buildup of the existing gopher population and invasion (Anderson 1976).

In some extreme cases, if direct gopher-control is not an available option or is ineffective, it may be advisable not to log certain parcels at all, because successful reforestation is too uncertain.

Buffer strips—As Volland (1977) suggested, natural or near-natural buffer strips left between gopher-occupied areas (sources of infestations) and sites selected to be logged may reduce invasion or at least slow rapid invasion. Buffer strips probably should be at least 400 feet and preferably 600 feet in width. Any buffer width over 200 feet is helpful, but wider strips offer better protection from invasion.

Partially cut strips are less effective than uncut buffers, but they may be left to separate a clearcut from a gopher-infested meadow or riparian area. Barnes (1974) found that this method effectively inhibits gopher invasion for about 2.5 years. Barnes (1974) also found no evidence, after 4 years in another situation, of gophers moving across a 600- to 700-foot strip of uncut lodgepole pine that separated gopher-occupied habitat from a clearcut. In both instances, gopher baiting or vegetation control would have slowed the gopher invasion or served as a practical alternative to wide buffers. Buffers can be logged after the trees of the protected block(s) are established and less susceptible to gopher damage; otherwise they may be left indefinitely as wildlife habitat.

Size and shape of logged area—The size and shape of a plot contributes to the speed with which a gopher-free area is invaded from surrounding, infested habitat. This is especially true for gopher-susceptible clearcuts. Assuming an area is free of gophers, the time required for gophers to invade the entire area from the outside increases with the size of the block. Even if the area is already populated with gophers, larger blocks may facilitate control efforts, because they are less influenced by gopher invasion from outside areas. This is related to the edge effects: as the distance from an infested edge to the center of the block increases, gophers must travel further to occupy the same space. Long narrow plots, therefore, should be avoided in favor of square-shaped blocks when gophers are a potential problem, unless this restriction seriously conflicts with other resource considerations.

Site Preparation

The type of site-preparation ordinarily has a relatively minor impact on direct mortality (Downhower and Hall 1966) among existing pocket gophers, except for a few special situations like deep disking. More importantly, however, site preparation strongly influences post-logging plant-communities that, subsequently, have a significant influence on gopher populations. The effects of different site-preparations vary widely, depending on existing plant communities and physical and abiotic site factors.

Mechanical—Hand scarification before planting, although expensive, is the site-preparation method that probably is the least favorable to pocket gophers, because it disturbs the least amount of soil. Mechanical preparation with a bulldozer typically creates continuous 10-foot-wide strips 10 to 12 feet apart. This method disturbs about one-third or more of the soil surface and results in an early seral stage of herbaceous plant species. Narrow scrapers attached to bulldozers or scarifying machines drawn by a tracklayer efficiently accomplish the task and minimize soil disturbance.

Plowing and deep disking results in highly disturbed soils, but it may actually kill a substantial number of existing gophers and destroy their burrow systems. Intensive and deep rototilling of the soil over an entire area on a tree farm is an example of this method. Soil disturbance in continuous strips interspersed with undisturbed strips, however, often predisposes seedlings to gopher damage by rapid reinvasion, because the strips of loose soil are virtual freeways for easy burrowing. Gophers can take down a row of seedlings with amazing speed by following the path of least resistance.

Steele and Geier-Hayes (1987,1989) concluded that in certain Douglas-fir and grand fir habitats of Idaho, machine scarification or unintentional soil disturbance by heavy grazing with livestock results in early seral herbaceous-growth that favors gophers. Many of these early seral herbs exist on-site in the form of seeds buried in the soil and duff that profusely germinate after significant disturbance. Barnes (1974) suspected that harvesting methods and slash-piling in clearcuts (which resulted in mounds or ridges of loose soil) facilitate easy digging by young, dispersing gophers and provide starting points for new burrow systems.

Burning—In the grand fir/blue huckleberry habitat of central Idaho, gopher activity is apparent in clearcuts scarified without burning, but virtually no activity is apparent on similar sites scarified and broadcast burned or just broadcast burned (Steele and Geier-Hayes 1987). This relationship is also evident in Douglas-fir/pinegrass, Douglas-fir/white spirea, and grand fir/mountain maple habitat-types. The results of prescribed burning or scarification followed by prescribed burning in these habitat-types also are less favorable to gophers than scarification alone. Burning without scarification sometimes results in a dense shrub layer that quickly reduces early seral herbs. Burning can also produce mid-to-late seral herbaceous layers commonly less preferred by gophers. Mechanical scarification alone, in contrast, generates early seral herbaceous layers that favor gophers.

Some areas burned by wildfire, however, regenerate with an herbaceous plant community very favorable to gophers. The reforestation of the Cave Mountain burn in south-central Oregon, for example, was severely impacted by gophers (Barnes 1974). The 1960 Chiloquin burn in Winema National Forest was one of the largest single areas with a gopher problem in the Pacific Northwest. Restocking on some 1,600 acres was virtually destroyed by pocket gophers within 6 years of planting (Canutt 1970). Wildfire and prescribed burns, unless extremely hot and very slow moving, have almost no direct, detrimental effects on gophers, because these burrowing rodents often have nests more than 4 feet belowground.

Chemical—One successful and current strategy controls vegetation during the year before planting or seeding and allows the vegetation to recover and develop with the seedlings. The objective of this strategy is to give seedlings an advantage by first reducing the vegetation and gophers and then letting the vegetation develop as an alternative food-resource for any remaining gophers. Potential conifer damage, thus, is minimized (K. Wearstler, Jr., personal communication). This strategy strives for initial success of reforestation and avoidance of multiple treatments for vegetation-control, but it requires continuous monitoring and rapid action if gophers begin to increase.

Competitive vegetation—In some locations east of the Cascade Range, fine-rooted grasses seeded on clearcuts prevent invasion of bull thistle, which is a major food source for pocket gophers (Hall 1974). This approach also controls other gopher foods, but seed mixes must not include the thick-stemmed grasses (such as bromes) that support gopher populations. Gophers reportedly prefer orchard grass, timothy, and smooth brome over chewings, hard fescues, and some wheatgrasses.

Overstory removal by logging or wildfire sometimes results in a rapid increase of shrubs that significantly impede herbaceous growth favored by gophers. Moderate-to-dense shrub cover usually supports few pocket gophers. This is particularly true where snowbrush and greenleaf manzanita thrive, as in central Oregon. Bitterbrush cover also supports few gophers. The value of shrub cover in limiting gopher populations under some circumstances may be counterproductive, because it has detrimental effects on conifer establishment and growth (Barnes 1974). Shrub establishment, nevertheless, may be a practical silvicultural approach to maintaining low gopher populations or to confining gopher populations to certain areas (for example, by buffering a larger area). In central Idaho, for example, snowbrush not only reduces gophers but also provides microsites for natural establishment of Douglas-fir. It is also a recommended cover on severe sites where Douglas-fir seedlings need protection (Steele and Geier-Hayes 1987). Bitterbush cover also helps regenerate Douglas-fir in the Rocky Mountains, but it is somewhat less effective than snowbrush.

Seeding and Planting

Foresters agree that speed in reseeding or replanting a logged area is critical (especially in the absence of vegetation control) to reduce gopher damage by getting ahead of gopher population-buildup. Planting should be as soon as possible after harvest and preferably within 8 months. Seedlings should have time to become established before a new stand of gopher-preferred forbs proliferates. Early seral herbaceous-vegetation generally requires 2 to 3 years to reach its maximum after logging, and gophers may increase during that time. Early planting is the single most important of all the preventive silvicultural practices available for pocket gopher management.

Stocking density—The type, amount, and time of planting of seedling stock may influence injury by gophers. Where serious gopher problems are predicted, planting more seedlings per acre increases the probability that a desired number of trees will escape damage. This is not as simple and straightforward as it may seem, however, because depending on the level and distribution of gopher populations, doubling the number of trees planted may not double tree survival. An increase in planted trees, usually, is disproportionate to tree survival, and the cost-benefit ratio may be unacceptable or marginal at best. Gopher damage often is patchy, and the distribution of the surviving trees, therefore, may not be desirable, even if numbers are adequate.

Size of stock—Trees larger than 2-0 with a good root-to-shoot ratio would have a better chance of survival against gophers, assuming they can survive on a site. Larger planting stock should be capable of rapidly reaching a growth stage where it is less susceptible to gopher damage (Capp 1976). With larger diameters, more bark can be removed from the stem before it is completely girdled. Seedlings with larger-diameter stems, moreover, seldom are bent or pinned by gopher movements in the snow or by the formation of casts; this avoids misshapen trees.

Quality of stock—High-quality seedlings with inherent vigor are extremely important, because they become established and grow more rapidly. Improved methods of handling tree seedlings from the nursery to the field have significantly decreased losses from a variety of causes (including gophers). Healthy trees can tolerate more damage (stress) than trees with poor vigor can tolerate.

Tree-feeding preference of gophers—Crouch (1971) found no difference among ponderosa, Jeffrey, and lodgepole pines in their susceptibility to gophers. Black and Hooven (1977) also found no significant difference in gopher-damage occurrence among five tree species planted in southwest Oregon. This evidence supports the general conclusion that all major, commercial conifer-species planted in the West are subject to serious damage in areas with high populations of gophers.

Radwan and others (1982) found that the source of tree seeds affected gopher-feeding preferences and associated damage by as much as 31 percent. They speculated that trees from some areas might contain greater proportions of chemicals that naturally deter gopher damage. Genetic manipulation to increase resistance to gopher damage is of interest, but it has not been developed; therefore, it is not a management alternative for practicing foresters.

Stand Tending

Chemical vegetation management—Herbicide application as a silvicultural practice to modify habitat and reduce or eliminate food resources is an important gopher-management option. Some foresters practice aggressive vegetation control early in the establishment phase of regeneration, and they consider this method critical to the reduction of gopher problems. Reduction in gopher food, however, often is the secondary result of herbicide applications intended to release valued species of trees from competition with other plants.

Early experiments to control pocket gophers by altering their food source with herbicides were conducted on a mixed forb-grass rangeland in Colorado. The concept was first mentioned by Cummings (1948). Spraying with 2,4-D resulted in an 83-percent reduction of perennial forbs and an 87-percent decrease in pocket gophers (Keith and others 1959). The diet of pocket gophers switched from 82 percent forbs and 18 percent grass species to about equal amounts of each. Gophers feed extensively on grasses when more preferred forbs are scarce, but their populations usually decline under such circumstances.

In a mixed conifer region of southwestern Oregon, Black and Hooven (1977) studied the effects of herbicide-induced habitat on the abundance and feeding activities of pocket gophers. Grasses were controlled with atrazine and simazine, and forbs and shrubs were controlled with 2,4-D. All three chemicals were applied in combination for complete control of vegetation, and the number of gophers decreased to about one-tenth the population found on untreated plots.

Applications of atrazine increased the survival of ponderosa pine by decreasing the number of gophers (Crouch and Hafenstein 1977). In south-central Oregon, one or two fall applications of atrazine on plots of ponderosa pine seedlings resulted in fewer gophers and significantly higher rates of survival and growth as measured 10 years later (Crouch 1979).

The application of herbicide after planting reduces the gophers' natural food and may temporarily increase gopher-feeding pressure on conifer seedlings by limiting alternate food sources. Two such instances have been documented. In one case, herbicides killed bracken fern and increased the mortality from gopher damage of five tree species. In another case, the grass/forb community was controlled with herbicides, and the mortality of lodgepole pine seedlings increased threefold (Boyd 1987). In both cases, the seedlings were planted before the gopher population diminished. This suggests that caution should be exercised when herbicides are applied to release tree seedlings in areas with moderate-to-high densities of gophers. Vegetation with manipulation by herbicides generally is short-lived, especially in areas of high rainfall. The most efficient and effective methods of vegetation management with current herbicides are discussed in detail in chapter 4.

Biological Control of Gophers

Concept and Potential

Biological control is the use of diseases, parasites, or predators for the control of a pest species. In practice, this generally involves the deliberate introduction of fatal or debilitating pathogens or exotic predators. Although biological control is effective for the control of certain introduced insect and weed pests, it generally is less effective with native species of pests. With vertebrate pests, most biological controls that introduce exotic diseases or predators are ineffective, and many have a deleterious effect on other wildlife species. A good example of a significant negative impact is the introduction of the mongoose into the Hawaiian Islands to control rats. Many similar examples can be cited. One of the few examples of effective biological control of a vertebrate pest is the introduction of myxoma virus (an often fatal pathogen) to control the (introduced) European rabbit in Australia. Pocket gopher diseases and their regulatory effect on populations are mostly unknown. The introduction of a fatal disease, even if biologically sound, therefore, is not a current option.

Encouraging Natural Predators of Gophers

Few studies have been conducted on avian, mammalian, or reptilian predators and their effect on pocket gopher populations. Most studies conclude that predation does not significantly reduce gopher populations. Hansen and Ward (1966) argued, for example, that weasel predation slows pocket gopher increases but does not prevent substantial populations from developing. Gophers are fossorial, and they are inaccessible, therefore, to all but a few predators except when they are aboveground. A few predators (such as badgers) effectively dig gophers out of their burrows.

Avian predators, such as long-eared and great horned owls, red-tailed hawks, ferruginous hawks, and northern goshawks, may be more efficient than mammalian predators in capturing gophers. Kimbal and others (1970) observed a reduction of gopher populations in the vicinity of an artificial roosting site for raptors. Similar studies of hunting perches and raptor predation on pocket gopher populations, however, were inconclusive (Christensen 1972). Hall and others (1981) also demonstrated that artificial perches increased raptor hunting in nearby areas, although no reductions in gopher populations could be measured.

The control of pest species with predators is a concept fraught with misconceptions about predator-prey relations. These species evolved together; the number of prey available generally controls the number of predators in the area rather than the predators controlling the prey. A study relating numbers of coyotes to numbers of pocket gophers found no correlation between the two (Robinson and Harris 1960).

Predators may regulate the population of a prey species in local situations but rarely to levels below economic damage thresholds. Unlike many insect predators and herbivorous insects that are host-specific, many vertebrate predators are generalists that feed on a wide range of prey that includes pest and nonpest mammals or birds. Strong evidence indicates, moreover, that limited predation is beneficial to the prey species, because it removes the less fit individuals from a population and actually may stimulate reproduction (compensatory replacement).

The best that might be expected from natural predation is that in combination with other methods (such as vegetation control or population reduction with poison) the decrease in gopher abundance will be greater than by any single method alone. Artificial perches or some unmerchantable "whip" trees left in clearcuts as natural perches, therefore, may be useful silvicultural practices (Hall 1974). Certain snags also might be saved to provide suitable nesting sites for predators. Predation is more likely to limit dispersal aboveground and slow population-growth than to reduce overall populations.

The New Forestry movement emphasizes the retention of fallen logs, piled and unburned slash, and greater protection for riparian vegetation. These components of new forestry enhance wildlife habitat and encourage small mammalian predators such as the long-tailed weasel, ermine, martin, skunk, wolverine and red fox. Other resource considerations, such as the impact of predators on endangered wildlife species and livestock, therefore, also must be considered.

Direct Control Measures

Traditional Methods

Silvicultural approaches that heavily rely on habitat management for gopher control often must be supplemented with direct-control measures. Direct control of animal damage or measures of vertebrate pest-management can be divided functionally into two categories; one aimed at reducing the population of the offending species, and the other directed at protecting the trees from damage with physical barriers, such as plastic-mesh tubing or chemical repellents. Biological and ecological factors and cost-benefit considerations determine whether to focus on the resource, the pest, or both.

The two approaches can complement one another or provide important alternatives. Where rodenticides may not be an option, for example, physical protection of trees may be the only available solution. Tubing is a preventive measure, because it must be installed at the time of planting and before damage occurs. The need for tubing, therefore, must be anticipated.

The reduction of gopher populations with traps, poison baits, or burrow fumigants is direct and immediate, and it is often termed "traditional control." Poison baits are most common, because they are the most cost-effective method, and they provide predictable control.

Direct methods of animal damage control should, when possible, be part of an integrated management plan that includes appropriate silvicultural practices. The USDA Forest Service Animal Damage Control Handbook for Region 6 (1988) provides more specific information on direct methods of control.

Seedling Protectors

Vexar or similar photodegradable polypropylene mesh has long been used to protect conifer seedlings from damage by snowshoe hares, rabbits, mountain beaver, deer, and elk. In the 1960s, Anthony and others (1978) evaluated Vexar tubes and their protection of conifer seedlings from gopher damage. Before planting, seedling roots and aboveground parts are slipped into Vexar tubing 2 inches in diameter and some soil is added to hold the roots in place until planting. Vexar tubes have also been tested with plug seedlings. The tubes provide substantial protection from gopher damage aboveground and belowground. Small-scale trials in which only the aboveground portions were protected were less successful. Gophers can gnaw through the tubing, but they generally tend not to do so. In one significant exception, however, thousands of seedlings were damaged aboveground by gophers that gnawed through the tubing beneath the snow.

Protective barriers substantially increase the cost of planting, and despite some impressive results, long-term effects on trees have not been adequately evaluated. The concept is sound, but the reduction of gopher damage with tube-type protectors presently is limited.

Repellents

Repellents suitable for protecting seedlings from gophers do not, at present, exist. Various commercial, chemical rodent repellents, such as R-55 (tert-butyl dimethyltrithioperoxy-carbamate) and bioMeT-12 (tri-n-butyltin chloride) have been tested, but their limitations include cost, lack of persistence, phytotoxicity, and poor efficacy in the protection of conifer seedlings. Thiram and BGR (putrescent whole egg solids) are effective at controlling several other forest mammalian pests, but they show no promise for controlling pocket gophers.

Trapping

Trapping, although labor intensive, effectively controls gophers where numbers are low and acreage is small. The Macabee trap is the most popular of several types of kill traps (Barnes 1973), principally because it is very effective and requires less digging to set (fig. 8). The Cinch trap, which has been around for a long time, is attracting renewed interest, but it is not marketed extensively. Trapping is reasonably cost-effective on large acreages only if it begins before gopher populations exceed about five animals per acre. Manpower must be adequate to ensure decisive results that avoid the cropping effect characteristic of long-term, minimal trapping. Trained and experienced gopher trappers significantly improve results from this method. Bounty systems have always proven ineffective and are not recommended.

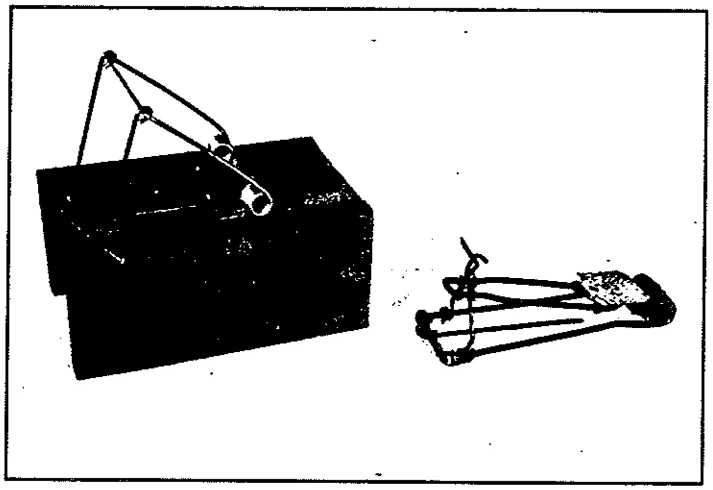

Figure 8—Trapping can be an effective method of control where gophers are not too numerous. Box-type trap is on the left and a Macabee is on the right (Photo by Rex E. Marsh).

Poison Baits

Baiting with rodenticides can be highly effective in reducing pocket gopher populations over large areas. Grains, such as oat groats, wheat, milo, and hulled barley, are the bait to which rodenticide is applied. Strychnine is the acute toxicant used most extensively, and several different bait formulations are commercially available. Zinc phosphide currently is registered for gopher control as loose grain and grain-based pelletized baits, but its effectiveness usually is considerably lower than results obtained with strychnine. Strychnine and zinc phosphide both are restricted-use pesticides, and applicators must be certified in the safe and proper use of these chemicals.

The chronic anticoagulant rodenticides, diphacinone and chlorophacinone, are marketed for gopher control as loose grains, grain-based pellets, and in paraffinized grain blocks (Marsh 1987). Anticoagulant baits act slower and require repeated feedings to cause death; therefore, control is more expensive. Anticoagulants recently have been scrutinized more closely as potential methods of gopher control in forest situations. Cholecalciferol (vitamin D_3) currently is under investigation and shows considerable promise. The potential for primary and secondary toxicity to nontarget species is minimal for all rodenticides in current use, because baits are placed belowground and the great majority of gophers die in their burrows.

Methods of Bait Application

Hand baiting—Hand application of gopher bait involves locating underground tunnels with a metal probe after noting the presence and location of fresh mounds. When the tunnel (preferably a main one) is located, the probe is rotated to enlarge the opening and then removed. The recommended amount of bait is then spooned or poured into the tunnel, and the hole is closed with a clod or with a piece of bark. At least two locations should be baited in each gopher system. Where gophers are very dense, baits may be placed about every 100 to 200 square feet.

Hand-operated probes have been designed with a bait reservoir to make hand-baiting operations more efficient. Burrow tunnels can be probed and located with this tool and a measured amount of bait is then released into the tunnel with a dispensing mechanism. This mechanization simplifies and speeds the baiting operation. Several designs and makes of these probes are on the market, and some are better than others. Models that deliver a precise amount of bait, do not dribble bait in the "off" position, and are least prone to plugging up with soil are most desirable.

Burrow builder—The burrow builder is a tractor-drawn device that constructs an artificial burrow 8 to 10 inches beneath the soil surface and deposits poisoned grain bait within the burrow in preset amounts and at preset intervals. The tractor operator runs the machine back and forth across the control area at regularly spaced intervals (about every 15 to 20 ft) to make a series of parallel burrows (fig. 9). Artificial burrows formed in this manner intercept most natural gopher-burrow systems in the area. Gophers, by nature, readily explore these artificial tunnels and consume the bait.

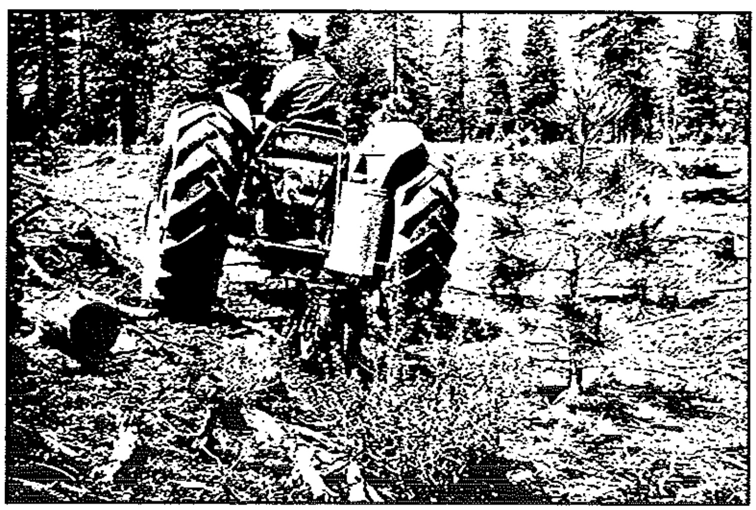

Figure 9—Gopher baiting with a mechanical burrow builder.

The burrow builder is recommended for use whenever and wherever possible, because it greatly speeds gopher control. Most importantly, however, it does not rely on visual identification of individual gopher systems as in the case of hand baiting. The burrow builder, therefore, often controls gophers more effectively than hand baiting. Machine baiting is especially useful in the spring, when the density and locations of gophers may not be evident, because few fresh gopher mounds may be produced at that time. New forestry methods, however, leave more obstructions in the habitat and limit the acreage that can be serviced by this method. Modified use patterns, however, can overcome some of these problems.

Burrow builders were designed for agricultural use, and commercially available models are not rugged enough for the more severe terrain and conditions in forests. Reinforced models, however, have been constructed specifically for use on forest land (Canutt 1970) (fig. 10). The site cannot be too steep or contain much slash or rocky or gravelly soil. Flat or gentle, sloping, and open-type sites with deep soil and few obstructions are most suitable for this method. The soil must contain enough moisture to produce good, firm burrows with few collapses.

Figure 10—Loading bait into a heavy-duty burrow builder modified for forest use (Photo by Warren Sauer).

Baiting with a burrow builder, however, may provide underground avenues for gopher dispersal if a high degree of gopher control is not achieved. This potential problem can be minimized by running the rows parallel with the edge of the plot with the greatest likelihood of supplying invading gophers. Artificial burrows should not extend across the block so that easy movements throughout a clearcut are minimized. Lifting the baiter from the ground momentarily every few hundred feet breaks up continuous tunnels and helps avoid this problem. Tree planting machines that produce avenues of disturbed soil cause a similar problem by making it easier for gophers to tunnel from tree to tree.

Efficient and effective gopher control, regardless of the method of bait application, requires well-trained personnel. Poor control often can be attributed to poor timing and improper techniques of application or a lack of attentiveness by control personnel.

Baiting Strategies

When the predicted potential for increases in the gopher population after logging is high, one of the most effective preventive-measures is to control gophers on the block to be logged and on adjacent sites with traditional methods (poison bait or trapping, for example) before logging begins. Very little effort may be needed to reduce the population to very low levels at this early stage. Gophers usually are controlled with poison bait placed after harvest and before planting. Waiting until gophers start to damage seedlings is the least advisable strategy of control.

Hand baiting achieves the best results with follow-up baiting after the initial treatment. A residual 20 percent of the original population may be reduced by another 80 percent with a second baiting. This reduces the gopher population to a level that greatly prolongs the time to recovery. Controls that reduce the gopher population by 75 percent or less, in practice, generally result in the recovery of the population within 1 year.

The percentage of population killed is a misleading measure of control, because it does not take into account the propensity of the remaining population to return to damaging levels. This relates to a sigmoid-shaped population growth curve: the population must build momentum before it rises sharply (fig. 11). Ninety-percent control of a dense population leaves from 2 to 10 times as many survivors as 90-percent control of a medium or low population. The ability of the survivors to repopulate makes it highly desirable to control gophers when population densities are very low. Early control of a growing population prevents a later, more serious problem.

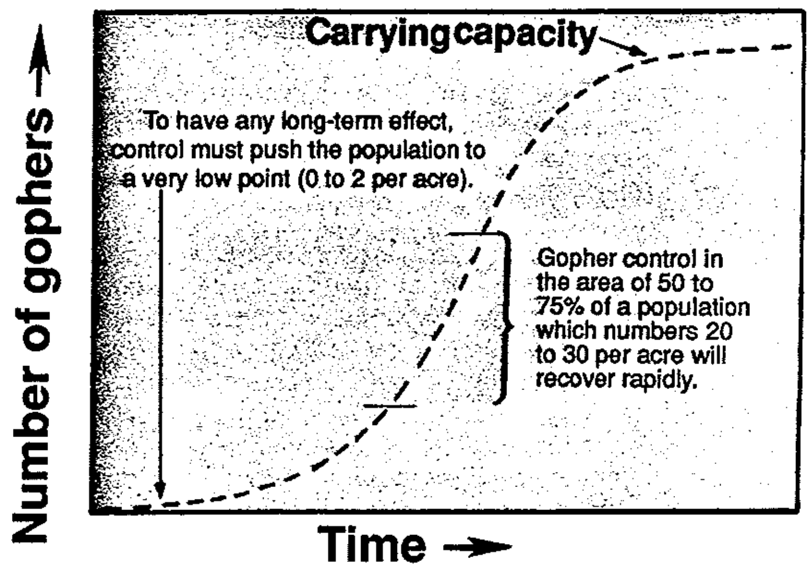

Figure 11—Gopher populations plotted over time result in a classic, sigmoid-shaped population-growth curve. Effective control must push the population to a level well below the steepest portion of the curve; otherwise, the population will recover rapidly.

A major problem with hand-baiting to control gophers in forest situations is the lack of a fresh gopher sign that indicates the location of burrow systems. This is especially true at higher elevations in spring or early summer, when mound building is infrequent or absent. If hand-baiting is carried out in early spring before mounding is extensive, old mounding and winter casts also should be used as baiting cues. Spring baiting is highly desirable from a biological point of view, because it controls gophers before breeding, during gestation and before the young can fend for themselves. Effective spring baiting with a burrow builder significantly reduces population recruitment; therefore, from a timing point of view, it is superior to baiting in the late summer or fall after the annual population increase.

Hand-baiting in summer and early fall, when visual evidence of gophers is at its highest and before the snow season begins, is a common practice. Increased gopher activity at this time partly results from dispersing young that start new burrow systems. Highly effective late summer or fall control pushes the population to low levels and reduces seedling losses, which are severest in winter.

Gophers also should be baited in a buffer zone of at least 200 feet but preferably about 400 feet in width and surrounding the primary block to prevent reinvasion. This substantially increases the control area; however, it results in more lasting control of gophers and greater savings from reduced seedling loss and less need for repeated treatments. Failure to treat gopher-infested buffer areas has doomed many control efforts.

Residual gophers that were missed or survived previous treatments are also a serious problem. Gophers repopulate poisoned areas more rapidly than they disperse into new areas, because unoccupied burrow systems provide instantly available harborage that assures high survival. Early treatments when populations are still low, therefore, are extremely important.

In suitable habitat, unless the gopher population is reduced to very low levels, baiting annually or biennially may be required until the herbaceous layer reaches a seral stage that supports few gophers or until the trees reach a size where gophers cause little damage.

Control of small, incipient populations of gophers in and around sites before logging is an excellent baiting strategy that, unfortunately, is rarely practiced. The trend towards new forestry probably will increase the emphasis on preharvest baiting of gophers. Sources of potential gopher infestation on adjacent meadows, along roads, etc., definitely should be controlled before planting.

Fumigants

Fumigants, such as gas or smoke cartridges, have been used for controlling various burrowing rodents. They are relatively ineffective, however, for controlling pocket gophers. Past failures to control gophers with fumigants were attributed to the extensiveness of burrow systems, the ability of gophers to detect toxic gas and rapidly block off tunnels, and the preference of gophers for porous soils that leak gases. Aluminum phosphide, a restricted-use pesticide registered for the control of burrowing rodent pests, apparently is an exception that is quite effective for controlling pocket gophers. It works best when the soil moisture is relatively high. It is used in landscaped areas and some agricultural situations, but because of its relative newness for gopher control, it has not been used in forest plantations.

Fumigants usually are more expensive than baits. They most often are used to control small numbers of pocket gophers in high-value crops or on sites where the costs can be justified. This method holds great promise as a followup application in cases where treatment results from baiting are unsatisfactory.

Assessing Control Results

The effectiveness of traps or poison baits as methods of control can be assessed by measuring tree survival and effects on the gopher population. Protective control with plastic-mesh tubing generally can be assessed only by measuring seedling survival. Assessments must be periodic, because the duration of the effects of control is an essential component of regeneration success. The USDA Forest Service Damage Control Handbook (1988) is a good guide to these methods.

Research Needs

Considering the monetary losses to forestry caused by gophers and the amount spent on their control, the magnitude and severity of the problem certainly justifies additional management attention and research expenditures.

The following are some of the most important research needs from a forester's point of view, with the emphasis on silvicultural approaches and habitat management:

1. More comprehensive data are needed concerning habitat types and their suitability for supporting gophers for each principal plant community within forest habitat. Computer models for predicting gopher problems should be developed, ultimately, including gopher-population models and expert-systems models to direct managers to the best combinations of indirect and direct control measures on the basis of costs and benefits.
2. Information is needed about the influence of specific silvicultural practices on gophers and their population response to habitat manipulation in each principal forest type.
3. Better correlation of surface activity (evidence) with actual gopher damage levels is critically needed.

Other research areas of somewhat lower priority include better analyses of costs and benefits and predator-prey relations, the relation of nursery fertilization schedules to the susceptibility of seedlings to gopher damage, and the breeding of trees resistant to gopher damage.

Summary

Pocket gopher management with a major emphasis on silvicultural practices and a secondary focus on an integrated approach to damage control can be summarized briefly with the following points:

1. Some basic knowledge of pocket gophers and their biology and ecology is essential to making the best management decisions. Knowledge of the history of gopher problems relative to harvesting methods, site preparation practices, and reforestation in the general area also are essential components of integrated management planning.
2. Assess and predict before harvest the potential for gopher problems after harvest.
3. Decide on a silvicultural harvest system that favors pocket gophers as little as possible in areas where the potential for gopher damage is high.
4. Apply silvicultural practices (size and shape of plot, buffer areas, site preparations, etc.) that minimize potential gopher problems during regeneration.
5. If gopher damage is a potential problem, it is most critical to plant as soon as feasible after harvest.
6. Monitor gopher populations on a regular basis and be especially alert to increases in the density or range of populations.
7. When appropriate, restrict food by managing vegetation to reduce gopher numbers or reduce population growth.
8. Continue to monitor for gophers at least once and preferably twice annually.
9. Bait when a gopher problem is imminent and do not wait until damage already is excessive. Rapid and thorough action is essential, especially in young plantations (0 to 3 years old).
10. Keep good records on gopher damage and management activities. Lessons from past successes and failures can lead to improved silvicultural practices.

Literature Cited

Anonymous. Early summer diet and food preferences of northern pocket gophers in northcentral Oregon. Northwest Science. 63: 77-82.

Anderson, Robert John. 1976. Relation of the northern pocket gopher to forest habitats in south central Oregon. Corvallis, OR: Oregon State University. 46 p. M.S. thesis.

Anthony, Richard M.; Barnes, Victor G., Jr.; Evans, James. 1978. "Vexar" plastic netting to reduce pocket gopher depredation of conifer seedlings. In: Howard, Walter E., ed. Proceedings, 8th vertebrate pest conference; 1978 March 7-9; Sacramento, CA. Davis, CA: University of California: 138-144.

Barnes, Victor G., Jr. 1973. Pocket gophers and reforestation in the Pacific Northwest: a problem analysis. Special Scientific Report, Wildlife 155. Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service. 18 p.

Barnes, Victor G., Jr. 1974. Response of pocket gopher populations to silvicultural practices in central Oregon. In: Black, H.C., ed. Proceedings on wildlife and forest management in the Pacific Northwest; 1973 September 11-12; Corvallis, OR. Corvallis, OR: Oregon State University: 113-119.

Birch, Lowell E. 1987. Monitoring pocket gopher control contracts. In: Proceedings, Animal damage management in Pacific Northwest forests; 1987 March 25-27; Spokane, WA. Pullman, WA: Washington State University: 93-104.

Black, Hugh C.; Hooven, Edward F. 1974. Response of small-mammal communities to habitat changes in western Oregon. In: Black, H.C., ed. Proceedings wildlife and forest management in the Pacific Northwest; 1973 September 11-12; Corvallis, OR. Corvallis, OR: Oregon State University: 177-186.

Black, Hugh C.; Hooven, Edward F. 1977. Effects of herbicide-induced habitat changes on pocket gophers in southwestern Oregon. In: Proceedings, 29th annual California weed conference; [date unknown]; Sacramento, CA. California Weed Conference: 119-127.

Boyd, R.J. 1987. Vegetation management and animal damage. In: Proceedings, animal damage management in Pacific Northwest forests; 1987 March 25-27; Spokane, WA. Pullman, WA: Washington State University: 55-58.

Buchner, Richard; Rorabaugh, Jim. 1979. The mountain pocket gopher and some implications for timber management. [Location of publisher unknown]: U.S. Department of Agriculture, Forest Service, Eldorado National Forest. 36 p.

Burton, Douglas H., and Black, Hugh C. 1978. Feeding habits of Mazama pocket gopher in south-central Oregon. Journal of Wildlife Management. 42(2): 383-390.

Canutt, Paul R. 1970. Pocket gopher problems and control practices on National Forest land in the Pacific Northwest region. In: Dana, R.H., ed. Proceedings, 4th vertebrate pest conference; 1970 March 3-5; West Sacramento, CA. Davis, CA: University of California: 120-125.

Capp, John C. 1976. Increasing pocket gopher problems in reforestation. In: Siebe, C.C., ed. Proceedings, 7th vertebrate pest conference; 1976 March 9-11; Monterey, CA. Davis, CA: University of California: 221-228.

Chase, Janis D.; Howard, Walter E.; Roseberry, James T. 1982. Pocket gophers. In: Chapman, J.A.; Feldhamer, G.A., eds. Wild mammals of North America: biology, management and economics. Baltimore, MD: Johns Hopkins University Press: 239-255.

Christensen, Robin C. 1972. Raptor predation on pocket gopher populations by the use of hunting perches. Provo, UT: Brigham Young University. 87 p. M.S. thesis.

Crouch, G.L.; Hafenstein, E. 1977. Atrazine promotes ponderosa pine regeneration. Res. Pap. PNW-309. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 7 p.

Crouch, Glenn L. 1971. Susceptibility of ponderosa, Jeffrey, and lodgepole pines to pocket gophers. Northwest Science. 45(4): 252-256.

Crouch, Glenn L. 1979. Atrazine improves survival and growth of ponderosa pine threatened by vegetative competition and pocket gophers. Forest Science. 25(2): 99-111.

Cummings, Maynard W. 1948. Progress report of Grand Mesa pocket gopher-range research project. Denver, CO: U.S. Fish and Wildlife Service, Denver Wildlife Research Center. 20 p.

Dimock, Edward J., II. 1974. Animal resistant Douglas-fir: how likely and how soon? In: Black, H.C., ed. Proceedings, wildlife and forest management in the Pacific Northwest; 1973 September 11-12; Corvallis, OR. Corvallis, OR: Oregon State University: 95-101.

Downhower, Jerry F.; Hall, E. Raymond. 1966. The pocket gopher in Kansas. Misc. Pub. 44. Topeka, KS: University of Kansas, Museum of Natural History. 32 p.

Hall, Frederick C. 1974. Prediction of plant community development and its use in management. In: Black, H.C., ed. Proceedings, wildlife and forest management in the Pacific Northwest; 1973 September 11-12; Corvallis, OR. Corvallis, OR: Oregon State University: 113-119.

Hall, Timothy R.; Howard, Walter E.; Marsh, Rex E. 1981. Raptor use of artificial perches. Wildlife Society Bulletin. 9(4): 296-298.

Hansen, R.M.; Ward, A.L. 1966. Some relations of pocket gophers to rangelands on Grand Mesa, Colorado. Tech. Bull. 88. Fort Collins, CO: Colorado State University, Colorado Agricultural Experiment Station. 22 p.

Horton, Alan J. 1987. Animal damage prediction models in conifer plantations. In: Proceedings, animal damage management in Pacific Northwest forests; 1987 March 25-27; Spokane, WA. Pullman, WA: Washington State University: 29-35.

Howard, Walter E.; Childs, Henry E., Jr. 1959. Ecology of pocket gophers with emphasis on *Thomomys bottae mewa*. Hilgardia. 29: 277-358.

Hull, A.C., Jr. 1971. Effect of spraying with 2,4-D upon abundance of pocket gophers in Franklin Basin, Idaho. Journal of Range Management. 24: 230-232.

Keith, James O.; Hansen, Richard M.; Ward, A. Lorin. 1959. Effect of 2,4-D on abundance and foods of pocket gophers. Journal of Wildlife Management. 23(2): 137-145.

Kimbal, J.; Poulson, T.A.; Savage, W.F. 1970. An observation of environmental rodent control. Range Improvement Notes 15. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region: 8-9.

Leopold, A.S. 1966. Adaptability of animals to habitat change. In: Darling, F.F.; Milton, J.P., eds. Future environments of North America. Washington, DC: The Conservation Foundation. 767 p.

Marsh, Rex E. 1987. The role of anticoagulant rodenticides in pocket gopher control. In: Proceedings, animal damage management in Pacific Northwest forests; 1987 March 25-27; Spokane, WA. Pullman, WA: Washington State University: 87-92.

Radwan, M.A.; Crouch, G.L.; Harrington, C.A.; Ellis, W.D. 1982. Terpenes of ponderosa pine and feeding preferences by pocket gophers. Journal of Chemical Ecology. 8(1): 241-253.

Robinson, Weldon B.; Harris, Van T. 1960. Of gophers and coyotes. American Cattle Producer. October [not paged].

Steele, Robert; Geier-Hayes, Kathleen. 1987. The grand fir/blue huckleberry habitat type in central Idaho: succession and management. Gen. Tech. Rep. INT 228. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 66 p.

Steele, Robert; Geier-Hayes, Kathleen. 1989. The Douglas-fir/ninebark habitat type in central Idaho: succession and management. Gen. Tech. Rep. INT 252. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 66 p.

Tietjen, H.P.; Halvorson, C.H.; Hegdal, P.L.; Johnson, A.M. 1967. 2,4-D herbicide, vegetation and pocket gopher relationships, Black Mesa, Colorado. Ecology. 48: 634-643.

Tietjen, Howard P. 1973. 2,4-D, vegetation and pocket gophers. In: Turner, G.T.; Hansen, R.M.; Reid, V.H. [and others], eds. Pocket gophers and Colorado mountain rangeland. Bulletin 554S. Fort Collins, CO: Colorado State University, Agriculture Experiment Station. 90 p.

U.S. Department of Agriculture, Forest Service. 1988. Animal damage control handbook, FSH 2609.22. Portland, OR: U.S. Department of Agriculture, Forest Service. 367 p.

Volland, Leonard A. 1974. Relation of pocket gophers to plant communities in pine region of central Oregon. In: Black, H.C., ed. Proceedings, wildlife and forest management in the Pacific Northwest; 1973 September 11-12; Corvallis, OR. Corvallis, OR: Oregon State University: 149-166.

Volland, Leonard A. 1977. Relation of pocket gopher populations and damage potential to plant communities. Presented at U.S. Forest Service animal damage control training session; 1977 April 27-29; Sacramento, CA. [unpublished]. 8 p.

SECTION FOUR
SILVICULTURAL METHODS IN RELATION TO
SELECTED WILDLIFE SPECIES

Chapter 11
Mountain Beaver

STEPHEN L. CAFFERATA

Abstract

More serious damage to Douglas-fir plantations is caused by mountain beaver than by any other animal species in the Pacific Northwest. Mountain beaver cause patchy damage within stands by clipping seedlings, climbing young trees and clipping lateral branches and tops, barking the bases of saplings, and by undermining and barking roots. Significant mortality and growth loss are associated with this damage.

The mountain beaver is a rodent weighing 2 to 4 pounds with a number of unique characteristics. Among these are a low birth rate (single litter per year averages 2.5 young, with females generally not becoming pregnant until the second year after birth), relatively long life (5 to 6 years), and generally healthy condition. They are sensitive to high and low temperature extremes and need large quantities of water or succulent vegetation. They eat a broad variety of vegetation and are unique in their ability to live on sword fern and bracken fern. They range from sea level to 7,000 feet. In dryer climates, mountain beaver are most common in cool, wet draws and north slopes. They are frequently found on south slopes and near ridge tops in moister situations.

STEPHEN L. CAFFERATA is forestry manager, Willamette Area, Weyerhaeuser Company, Springfield, Oregon 97477.

The key strategy for controlling mountain beaver damage is to manage stands to maintain mountain beaver populations at low levels. This prevents the occurrence of devastating damage and allows steps to be taken that reduce increases in damage when it occurs. Silvicultural approaches can help maintain populations at low levels, but these approaches probably will not be sufficient and direct methods also will be needed where mountain beaver pressure is intense.

Silvicultural approaches to damage control are those methods that maintain sites anc stands in conditions that do not encourage the expansion of mountain beaver popula tions. Such methods include a consideration of harvest unit size and shape, site-preparation techniques, encouragement of predator populations, rapid postharvest regeneration with large transplant stock, stocking density, the timing of precommerci thinning, the level and timing of commercial thinning, and the method of logging.

Direct approaches to the control of mountain beaver damage are needed when populations are high, damage levels are unacceptable, or populations are increasing in spite of existing silvicultural techniques. Two basic approaches are possible: tree protection and direct population control. Tree protection is done with physical barriers that most commonly are plastic-mesh tubes placed around seedlings either after planting or at the nursery. The nursery-installed barriers are then planted with the tree. Populations are controlled either by trapping or with poison bait. Trapping is the most common method of direct control.

Most land managers use a combination of approaches. The most environmentally sound and cost-effective method of managing damage at acceptable levels during th life of the stand most commonly is an integrated approach. Stand monitoring must be continued to ensure that populations of mountain beaver never are allowed to build up to levels where they can do significant damage to stands at advanced ages.

A decision methodology is needed for selecting the best methods. Neither preventive nor corrective strategies are ideal. The former may require the expenditure of unneeded resources and the latter may be too late. More predictive ability is needed to refine management decisions.

Keywords: Mountain beaver, animal damage, vertebrate pest, mountain beaver control, animal damage control, pest control.

Biological Characteristics

The mountain beaver is a small mammal occupying a unique ecological niche in the Pacific Northwest (fig. 1). This burrowing species also is active aboveground. As the only surviving member of a primitive family of rodents, *Aplodontidae,* it frequently has been studied. It is restricted to the west side of the Cascades and the northern Sierra Nevada Mountains to the coast. It is commonly called mountain beaver, but it is not closely related to the beaver *(Castor canadensis).* Other common names include mountain boomer, boomer, whistler, mountain rat and (the Indian name) sewellel (Borrecco and Anderson 1980). Few people have ever seen a mountain beaver, and the name causes much confusion among the general public.

The mountain beaver is a barrel-shaped rodent. The adults are about 1 foot long and weigh from 2 to 4 pounds. The body is muscular with short legs. The front legs are well adapted for digging, with clawed toes. The snout has long vibrissae or tactile hairs, and the ears and eyes are small. The tail is short and furred and the fur generally is reddish brown. Color variation is one difference among the seven recognized

Figure 1—Photo of mountain beaver (Weyerhaeuser Company photo).

races, but it also occurs within populations (Godin 1964). All mountain beaver have a small white spot at the base of the ear. The feet are bare soled with five strong digits. Mountain beaver can hold and grasp objects with their front feet, and they sometimes feed while sitting on their haunches holding food in their front feet. This grasping ability also makes them agile climbers, and their tree climbing ability is well known. They have poor eyesight and have difficulty detecting stationary objects, but they can detect gross movements. The high eye position gives them poor depth perception. Hearing is confirmed, but its importance remains undetermined. Smell appears to be the most used sense of the mountain beaver, and it is used to find and select food as well as to detect danger and recognize other members of the species. The long vibrissae or tactile hairs also sense and guide the mountain beaver's movements and are very important for movement within burrows (Goslow 1964).

Life Cycle

Mountain beaver are solitary creatures, and they avoid contact with one another even when their home ranges overlap. Males are in breeding condition from mid-December to mid-April. Estrus occurs in females within a period of 5 to 7 weeks in February and March. All females in a population ovulate about the same time each year. Females generally do not become pregnant until the second breeding season after their birth. The gestation period is about 30 days. Birth occurs in late March to early April. Litter sizes usually are two to four offspring, and two to three young per litter is most common. The sex ratio is even. Nursing lasts about 2 months, and the young emerge from the burrow about 2 weeks later (in June). One litter is born per year. By 4 months, mountain beaver weigh 70 percent of their adult body weight. Yearling animals weigh about 90 percent of their adult weight. Research suggests that mountain beaver commonly live 5 to 6 years (Feldhamer and Rochelle 1982).

Population Dynamics

The time it takes for mountain beaver to reach breeding age, their single litter per year, and their small litter size means that populations of this species are more stable and less explosive than populations of many other rodent species. The comparatively long life span also contributes to population stability.

The solitary lifestyle and clean habits of mountain beaver, apparently, keep them disease free. They are hosts for parasites, including tape worms, fleas, mites, and ticks. Nests generally harbor various parasites, including the largest known flea (Feldhamer and Rochelle 1982).

Predators of mountain beaver are numerous and include most carnivores. Coyotes, bobcats, and great horned owls are principal predators. Golden eagles and many other small predators also prey on the rodent. Limited information exists on the effect of predators on mountain beaver population densities. DeCalesta and Witmer (1983) estimated that mountain beaver supplied 90 percent of the daily intake required of bobcats and coyotes on the Elliot State Forest in southwestern Oregon. This extrapolates to 200 mountain beaver per bobcat and 223 mountain beaver per coyote per year.

Specific data on population replacement rates for mountain beaver is not available. Rough estimates, however, indicate that significant replacement is possible. If 25 percent of the population is composed of mature females, then the population-increase potential without mortality would be 60 percent the first year. Mortality of adults and higher mortality of young prevents this from occurring. Replacement rates under different conditions are not known.

Key Requirements

Mountain beaver are vulnerable to hot and cold temperature extremes. They can maintain their normal body temperature under conditions that range from 25 to 86 degrees F. (Johnson 1971). This inability to effectively thermoregulate restricts them to specific climates and necessitates a burrow system that moderates temperature extremes. Their nest chamber is well insulated and allows them to maintain body temperature when resting.

Another unique characteristic of this species is a primitive kidney that limits the animal's ability to concentrate urine. It is one of the least efficient of mammals in terms of conserving water, and it must consume approximately one-third of its body weight in water daily. Mountain beaver, therefore, require available water or large quantities of succulent vegetation, and their burrow systems must be high in humidity (Johnson 1971).

Mountain beaver eat foliage and bark from a wide range of plant species. Sword fern and bracken fern (when available) comprise a large portion of the animal's diet (the former in winter). The mountain beaver's ability to digest and utilize these plants is unique in that the animal obtains more nutritional value from these species than do most other mammals, and mountain beaver are the only mammals that can subsist on these ferns. Pregnant and lactating females require high intakes of protein, and they switch to plants such as conifers and grasses that are richer in protein than the ferns (Voth 1968).

Mountain beaver utilize a wide variety of other plant species, including vine maple, red huckleberry, salal, Oregon grape, thimbleberry, salmonberry, elderberry, and miners lettuce. It is estimated that two and one-half times as much vegetation is cut and gathered as is eaten (Voth 1968). Some is used for nest material. Much is wasted. The typical foods of mountain beaver are low in nutritive value; therefore, the animal must spend three-quarters of its active periods gathering and eating food (Voth 1969). Table 1 shows the general categories of food in the mountain beaver diet. Mountain beaver, like other rodents and hares, eat their soft feces to recover the essential vitamins produced during the digestive process.

Table 1—General categories of food items in the diet of mountain beaver as determined from counts of epidermal fragments from fecal pellets

	Age and sex group[a]		
Vegetation category	Males and nonpregnant females[a] (N = 12)	Lactating females[a] (N = 3)	Juveniles[a] (N = 4)
Pteridophytes (ferns)	84.0	37.7	90.7
Conifers	3.4	33.9	0.0
Grasses	2.5	18.4	4.6
Forbs	1.9	4.8	2.6
Hardwoods	5.4	1.3	1.3
Mosses	1.0	3.5	0.9
Shrubs	1.1	0.0	0.0

[a] Numbers given are percentages of total for each age and sex group.
Source: Feldhamer and Rochelle 1982; adapted from Voth 1968.

Distribution

The present range of the mountain beaver extends south from southern British Columbia to central California. It extends from the Pacific coast east to the Cascade Range and the Sierra Nevada. The animal ranges from sea level to about 7,000 feet in elevation. It is most abundant in Oregon and Washington, where it is found in humid, densely vegetated areas, primarily at low elevations (Walker and others 1975). Mountain beaver require conditions where succulent vegetation is abundant and where relatively high humidity can be maintained in burrows (Voth 1968).

Populations generally are arranged in a clumpy distribution in draws and moist areas. North and east slopes are the most common locations in southerly, drier climates. In many instances, however, populations may be found living away from draws, on south slopes, and at high elevations in moister situations.

Mountain beaver populations are very low in dense conifer stands (Hooven 1973). Brushy openings in stands provide suitable habitat that often supports populations of the animal (Hooven 1977). After timber harvest, mountain beaver populations may increase rapidly, especially in preferred habitat types of fern, shrubs, and young hardwoods. Under these conditions, populations of three to six animals per acre are common. Populations of the animal in young stands are highly variable, but as many as nine animals per acre have been found in such stands.

Home Range and Activity

Mountain beaver spend their lives in home ranges that average less than 0.7 acre in size. They live in burrow systems that radiate from a central nest chamber (see fig. 2). Martin (1971) found that these chambers "were most frequently located at sites with good drainage, usually under small mounds, logs, uprooted stumps, logging slash, or thick vegetative growth." In addition to a nest chamber, mountain beaver build feeding, refuse, fecal-pellet, and earth-ball chambers. Nests are roughly circular, 20 to 24 inches in diameter, and 14 inches high. They are filled with up to a bushel of vegetation that provides insulation. The feeding chamber may be as large or larger than the nest chamber, and it also is used to store both wilted and fresh vegetation.

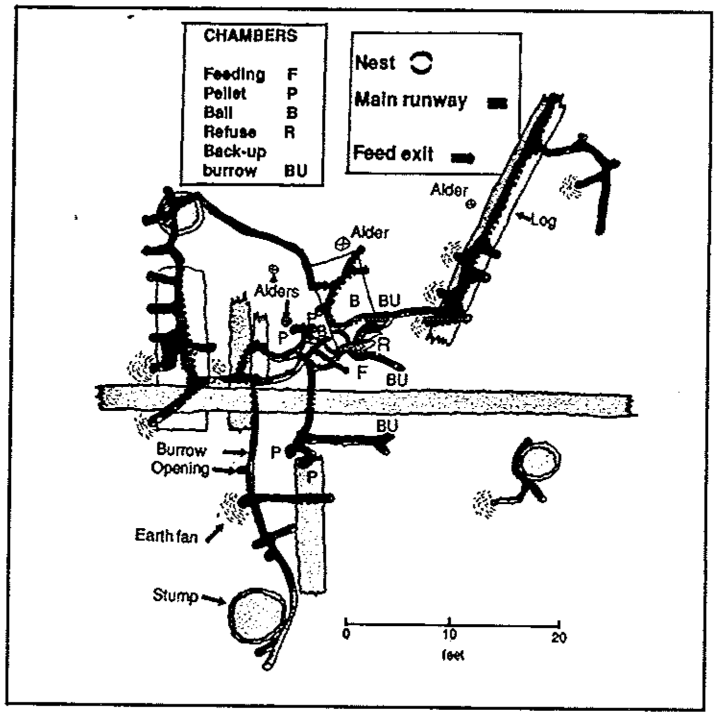

Figure 2—Underground tunnel system of a mountain beaver (Voth 1968).

Decayed plant material may be placed in a refuse chamber. Mountain beaver use the earth-ball chambers to store stones and compacted dirt that they use to block entrances to the nest and feeding chambers. The animal may trim its teeth on these items (Voth 1968).

Mountain beaver seldom range more than 80 feet from their nest chamber (Martin 1971). They primarily move through their shallow burrow system, which has numerous openings, for food-gathering purposes. The animals move short distances aboveground. They may consume vegetation aboveground, but they generally clip vegetation and move it to burrow openings or other caches where they either consume the vegetation or store it before moving it again to a more secure location. The feeding chamber is the most secure destination (Voth 1968).

Each animal has an individual nest and defends its territory. Their home ranges overlap, however, and they share some runways. Once established in nest sites, mountain beaver use them for extended periods (periods of more than 3 years have been recorded) (Martin 1971). They readily occupy the existing nest systems of other mountain beaver if the resident dies or departs (Goslow 1964).

Juveniles travel relatively long distances once expelled from the nest. Distances of one-third of a mile have been measured, and the animals may swim streams as they search for suitable nest sites. Males travel longer distances outside their home ranges during the breeding season. Martin (1971) tracked one animal that roamed 350 feet from its nest.

Mountain beaver are active during seven periods per day that are interspersed with resting periods. They are mostly active aboveground at night, but some foraging also occurs at dusk. Mountain beaver move about the burrows at all times (Ingles 1959, Voth 1968). Activity aboveground is curtailed during winter weather (Kinney 1971), and apparently little movement occurs during freezing weather. The animals tunnel under snow in winter and may tunnel to the surface and walk on the snow crust (Scheffer 1929).

Damage Identification and Presence

Evidence of feeding on conifer and hardwood plants is one of the key indicators of the presence of mountain beaver. Feeding occurs both aboveground and belowground. Aboveground, the animals clip plants measuring as much as 1 inch in diameter, and the diagonal clip is characteristic of rodents (see fig. 3). Mountain beaver also climb young trees and shrubs and clip lateral branches as well as terminal shoots as high as 20 or more feet. Basal barking of conifers occurs in trees of a wide range of diameters (3 to 16 inches at ground level), but this is most common in trees with diameters of 4 to 6 inches at ground level (fig. 4).

Figure 3—Clipped seedling–3/4 inch in diameter clipping (photo by Bob Anderson).

Figure 4—Basal barking and undermining of pole-size Douglas-fir (photo by Bob Anderson).

Mountain beaver cause belowground injury to conifers by uprooting or burying seedlings. They undermine and bark the roots of saplings. The latter two types of injury cause extensive damage in conifer stands of 10 to 20 years of age. Damage mainly occurs in and around burrow systems.

The existence of mountain beaver in an area can also be determined from the presence of shallow burrow systems of about 4 to 8 inches in diameter (Voth 1968). Fresh mounds of earth (kick outs) often may be found at burrow entrances. These may contain up to a cubic yard of earth and stones (Dalquist 1948). There may also be mounds of cut vegetation stacked at the entrances.

In freshly logged units with concentrations of heavy slash, mountain beaver have been reported moving under slash and brush. Burrow systems may be hidden under the slash in these situations, increasing the difficulty of detecting their presence (Doug Soules, personal communication).

Clipping of seedlings by mountain beaver can be confused with clipping by rabbits and hares. Rabbits and hares, however, seldom clip stems of more than 0.25 inch in diameter, and they frequently leave portions of their clippings at the base of the damaged tree. Round, flattened, ovoid droppings often are left in the area (Lawrence and others 1961). Mountain beaver, conversely, may clip stems of up to 1 inch in diameter, and their larger, cylindrical droppings (0.5 × 1 inch) never are left on the surface but are deposited in fecal chambers (Voth 1968).

Damage from mountain beaver and black bear occurs in sapling-size stands. Bear damage to the lower stems, characteristically, is indicated by bark strips left at the base of the tree and by long, vertical grooves caused by canine teeth scraping on exposed sapwood. Barking extends further up the stem, and bear remove large patches of bark. Mountain beaver pull the bark from the tree in strips and leave scattered horizontal tooth marks and irregular claw marks. Bark strips are not left at the base of the tree (Lawrence and others 1961).

Most mountain beaver damage of commercial importance occurs in stands of Douglas-fir. Severe damage to western hemlock, however, also occurs (Hoyer and others 1979), and damage has been observed on most conifer species growing in mountain beaver habitat.

Population density is difficult to determine and usually is estimated on the basis of field sign, which consists of burrow density, fresh "kick out" mounds of earth, clipped vegetation, and damaged trees and habitat. The prediction of population levels on the basis of counts of burrow entrances or other sign components so far has not been possible. Greater sign frequency usually correlates with more animals present. It also is important to consider home range size when making population estimates and to remember overlapping home ranges are common.

Severity of damage is easier to determine and normally is recorded in routine stand exams of young plantations. In a survey of forest managers in Washington, Oregon, and northern California in 1979, the Mountain Beaver Subcommittee, Northwest Forest-Animal Damage Committee found about 70 percent of the total problem was in new plantations.

Damage to sapling stands is not nearly as well understood as damage to young plantations, because these stands less frequently are visited and systematic information on mountain beaver damage or activity seldom is routinely recorded. In the same 1979 survey, forest managers reported 23 percent of their mountain beaver problem in stands of this age. Damage by mountain beaver is progressive unless damage-reduction measures are instituted. From a distance, dead trees may be confused with root-rot mortality or bear kills, and mountain beaver damage may not be identified for several years. Basal stem and root barking and the undermining of saplings may continue over several years, and levels of damage may differ by year. The reasons why damage in some years is greater than in other years is unknown.

Damage from mountain beaver is clumped in distribution. This creates nonstocked areas in stands rather than random mortality. These openings will continue to enlarge if mountain beaver activity continues as trees around the edges repeatedly are damaged or killed (Neal and Borrecco 1981).

Mountain beaver do more serious damage to Douglas-fir plantations than do any other animal species that cause damage in the Pacific Northwest. Of the types of damage, seedling clipping is the most serious. The survey by the Mountain Beaver Subcommittee, Northwest Forest-Animal Damage Committee (1979) reported damage by mountain beaver on more than a 0.25 million acres in Washington, Oregon, and northern California. It is probable that damage is greater than reported, as much damage goes undetected in older stands. Snow damage where trees fall over, for example, in some cases may be related to undermining and root girdling by mountain beaver.

Response to Habitat Change

Harvesting has the greatest influence on mountain beaver habitat. Low preharvest populations of mountain beaver in closed-canopy conifer stands frequently increase several fold as sparse-understory plant-communities develop into dense, herbaceous, vegetative cover of shrub and hardwood after clearcutting. Mountain beaver populations frequently are fairly high even before harvesting in more open stands of conifers with well-established understory plant communities and in hardwood and shrub-dominated stands. Motobu (1978) found 3.8 animals per acre in a recently harvested hardwood unit. These mountain beaver populations rapidly expand to high levels after harvesting. Heavy damage to plantations usually results from these high populations. Preharvest inspections of stands are used to determine both the presence and density of mountain beaver and the need for control.

Partial cuts, including commercial thinning and shelterwoods, also affect mountain beaver populations. As stands are reduced in density, more light reaches the forest floor and more understory vegetation develops. Many of these plant species are utilized by mountain beaver, and populations can expand in both area and density. This expansion may lead to more difficult damage control in new plantations established after final harvest. Commercial thinning is an example of a management regime that can increase mountain beaver populations. It is unlikely that the resulting increase in population would have an adverse impact on the residual stand. Regeneration after the final clearcut harvest could face a well-established population of mountain beaver with a network of burrow systems unless the stand has regained sufficient density to shade-out understory species.

Site Preparation

Site preparation after harvest consists of four general types and combinations. These are mechanical (hand and machine), chemical, burning, and logging only. Each preparation has unique impacts on the mountain beaver.

Logging generally has the effect of increasing populations (Hooven 1977). The type of logging system and the stand harvested determines specific effects. Ground skidding and high-lead logging may disrupt burrow systems more than full-suspension systems. Concentrations of slash can provide additional cover and potential nest sites. Destruction of existing vegetation from skidding generally causes vigorous resprouting and provides germination spots for early successional species. Most of these effects result in improved habitat, and populations respond with rapid increases. Damage to plantations usually follows.

Mechanical site preparation with tractors and brush blades has the most lasting impact on mountain beaver habitat. This method collapses burrow systems and uproots brushy species. Preferred brush species may be slow to re-establish as grass and forbs may densely establish. The method destroys suitable nest sites and greatly reduces populations. Reinvasion is slow, as mountain beaver seem to prefer to move through existing burrows in their search for new nest sites. They are highly vulnerable to predators in open scarified areas. Well-scarified areas frequently stay free of mountain beaver through plantation establishment, although they may become a problem in the sapling stand that follows. When slash piles are created during scarification and not burned or incompletely burned, mountain beaver frequently occupy these sites and damage trees near the piles. Some success has been achieved in alleviating this problem by creating numerous small piles no more than 10 to 15 feet wide and 4.5 feet tall (Tim Kosderka, personal communication). These piles, if kept small enough, apparently do not provide adequate nesting or cover habitat in scarified ground, and they break down quickly. Mechanical site preparation with spot scarifiers or backhoes is unlikely to significantly affect mountain beaver. Burrow system destruction is spotty and desirable plant species remain in adequate quantity. Minor impact on the mountain beaver population can be anticipated.

Broadcast burning on two brown-and-burn hardwood conversion units, and its effect on a population of mountain beaver, was studied by Motobu (1975). In a complete burn, where nearly all the slash was consumed, about half of the population was killed by the fire. Predators had good access to the site and were attracted by the burned carcasses. Coyote activity increased and caused further mortality in the population. There was no evidence of the mountain beaver leaving their home ranges within the burn for adjacent unburned areas, but they did move to unburned areas within their home range. The population re-established and later caused damage to the 15-year-old stand. In the less complete burn, where 20 percent of the area remained unburned, 80 percent of the population survived. The surviving individuals largely were found in unburned portions of the unit but still within their home ranges. The intensity of a burn, therefore, significantly affects a population and its ability to rebuild after a fire. Activity is reduced after a burn, and fresh evidence of the animals (such as burrowing and earth mounds) can be seen only after several weeks elapse. A population can exist on stored food with little or no signs of activity until the unit "greens up." After a burn, populations will rebuild rapidly to preburn or higher levels.

Brown-and-burn techniques increase fire intensity, especially where conifer slash is insufficient or where much green vegetation is present. Units are treated with herbicides, the vegetation is allowed to brown and dry, and then the unit is burned under warm, dry conditions. This technique also reduces postburn resprouting of brush species, and it results in more complete burns that would tend to increase population mortality. Hand slashing in heavy brush and burning after also increases the completeness of burns. Most broadcast burning after harvesting occurs under cool, moist conditions in the spring and without fire-enhancing treatments. This likely results in lower impacts on mountain beaver populations. Fifty-percent mortality probably is the upper limit in all but the most extreme cases.

Chemical site-preparation reduces competition to seedlings by suppressing existing species before planting. These chemicals selectively control forbs, grass, or various brush species. They may be used in combination for multiple species control. The duration of effectiveness varies with the chemical and the species. The objective of the treatment is to give the new seedlings a competitive advantage. Most treatments last one or two seasons. Normally, however, several species of plants that are resistant to the chemicals remain after treatment. New germinants and sprouts also form parts of the plant community. This technique, apparently, does not significantly affect mountain beaver populations. Some shifting among plant species in the animal's diet undoubtedly occurs.

Artificial Regeneration

Artificial regeneration either by planting or seeding after harvest can profoundly influence mountain beaver populations. Where dense stands can be established and brought to complete crown closure, mountain beaver populations can be virtually eliminated, providing damage to trees can be controlled until stand development is accomplished. Under such conditions, densities of understory plants are limited. This situation occurs in coastal areas where large numbers of natural hemlock become established and form dense stands. Stands, typically, are planted at a density that does not result in early, complete crown closure. Mountain beaver populations, consequently, remain in such stands for many years. The number of trees per acre necessary to achieve early crown closure depends on many factors, but it can be computed with stand-density diagrams described by Drew and Flewelling (1979).

Selection of planting stock also affects time to crown closure and the time when young trees are most susceptible to damage. Large transplant stock (20 to 40 inches tall) reduces these time periods. Large stock also is resistant to other problems (including vegetation competition and damage by other animal species, such as deer, elk, or hares) that can extend or increase the period when trees are susceptible to mountain beaver (fig. 5).

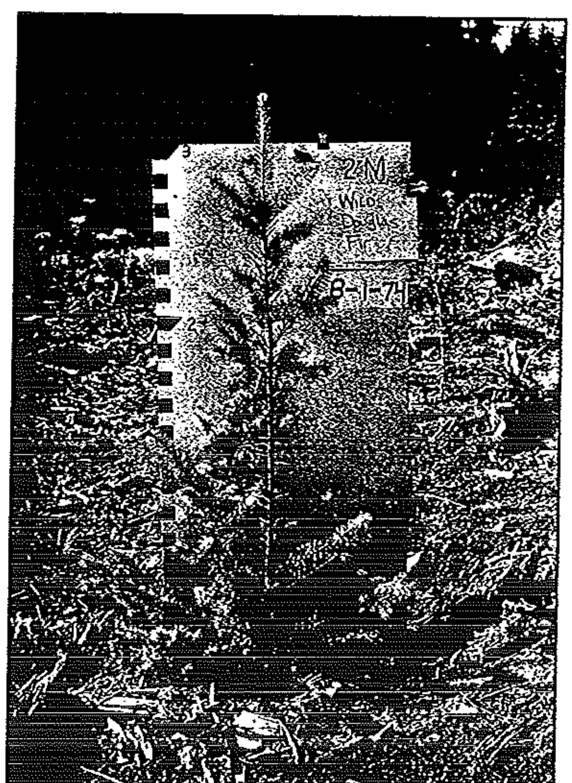

Figure 5—Large Douglas-fir seedling.

Release Treatments

Release treatments of various types (chemical and manual) suppress vegetation that competes with desirable conifer species. Most treatments are selective and, apparently, have little impact on mountain beaver populations. Some reports suggest that release treatments may encourage additional feeding on conifers as more desirable species are suppressed.

Grass has been seeded on the Alsea Ranger District to control brush, and sheep have been introduced to browse on brush and grass. This browsing keeps the grass at a palatable stage for elk. Mountain beaver do not extend their runways into the grass-seeded areas. Grazing sheep collapse the runways, and effective predators of mountain beaver (coyote and avian) focus their hunting activities in these areas, thus heightening mortality among mountain beaver (Virgil Morris, 1989, personal communication).

Stocking Control

Stocking control in sapling-size stands maintains growth rates of the most desirable trees. Mountain beaver in sapling-size stands usually are associated with openings. Damage primarily occurs around the edges of these openings, where the trees are growing within the mountain beaver home range. The openings may be caused by seedling clipping at a much earlier age. It is theorized that as the stand canopy begins to close, the understory vegetation thins out and becomes less abundant and desirable. Mountain beaver associated with these openings begin barking the stems and roots of saplings. This damage is progressive, and it maintains the openings as trees are killed. Trees that are not adjacent to active burrows seldom are damaged (Neal and Borrecco 1981, Hoyer and others 1979).

Stocking control in these stands changes stand composition and allows understory vegetation to redevelop. In theory, damage should decline as more food becomes available until the stand begins to close and again reduces the understory vegetation. Sapling trees, apparently, also become less susceptible to damage as they increase in size. Trees above 8 inches d.b.h. are unlikely to be damaged (John Todd, 1989, personal communication). Trees larger than this are damaged, but the frequency and impact of such damage are much less.

In practice, stand damage in sapling-size trees seems to be a recurring loss, and damage is higher in some years than in others. The difference from year to year is difficult to explain (Hoyer and others 1979). Damage to 40 percent or more of the stand has been documented (John Todd, 1989, personal communication) in clumpy distributions that have a very significant impact on timber yield. Delay of precommercial thinning until mountain beaver populations are reduced after stand closure or after trees reach less vulnerable sizes is a potential strategy to reduce damage.

Commercial Thinning

Commercial thinning effects should be similar to precommercial thinning. The degree of stand closure before thinning will determine the status of the mountain beaver population. If the stand is dense and closed with little or no understory vegetation, it is unlikely to harbor mountain beaver. More open stands may have a population of mountain beaver that could increase as the stand is thinned. It is unlikely that these animals will cause significant damage to the leave trees. Their major impact will come after final harvest and regeneration.

Damage Management Strategies

No single management technique works in all cases to reduce mountain beaver damage to acceptable levels. In many situations, a specific unit may require more than one management technique. The overall strategy must be to manage forest stands to maintain mountain beaver populations at reasonably low levels to avoid devastating damage. Specific techniques then can be employed to reduce damage and meet management goals within economic limits.

After mountain beaver populations grow to high levels (three or more animals per acre) great effort is required to reduce the populations. Rapid regeneration is critical to gain control of the site as quickly as possible. Techniques that work to reduce minor damage often are ineffective after populations reach high levels. Individual tree barriers, for example, may protect young seedlings, but large populations of mountain beaver clip the tops above the tube, undermine the plant, and bark the root. Where populations are maintained at moderate-to-low levels, this damage seldom becomes a problem. As stands with reduced mountain beaver populations achieve free-to-grow status (trees above brush—usually 4.5 feet high or higher), management directed at mountain beaver populations often is abandoned. This may lead to severe problems at age 10 to 20 years, when control not only is very difficult, but when the need for control is often discovered only after extensive damage already has occurred.

Management strategies must be designed and implemented to maintain populations at low levels throughout the life of the stand. This can be done best through habitat manipulation. In many instances, additional direct methods (including individual-tree barriers and population control techniques) also are required.

Root-rot pockets often form openings in stands with shrub and herbaceous vegetation. These often contain potential epicenters for expansion of mountain beaver populations. Specific plans must be made to establish stands of alternate species in root-rot pockets to create crown closure and prevent continuing mountain beaver problems.

Habitat Manipulation

Habitat manipulation to control damage from mountain beaver consists of maintaining the site and stand in a condition that does not encourage the expansion of populations. In even-age management, the size, shape, and location of the harvest unit can have a lasting impact on mountain beaver damage. Small and narrow units are highly susceptible to invasion from adjoining areas with populations of mountain beaver. A narrow unit adjoining a hardwood riparian area with a large population, for example, would be under constant pressure. Larger and more symmetrical units with less perimeter area aids in population control.

Habitat manipulation is a continuous process that requires the establishment of uniform stands free of openings or pockets of brush. Such openings can be important, even in stands 20 or more years old. Extra expenditures can be justified to eliminate these open areas in order to protect the surrounding stand.

Early canopy closure to reduce preferred food species helps ensure that populations do not rebuild and cause problems at later stages of stand development. Stand density control is an important part of this process. Precommercial thinning must be timed to discourage population buildup and damage. If populations are kept low, it is unlikely that commercial thinning will be followed by significant increases in mountain beaver populations. If animals are present at the time of commercial thinning, consideration must be given to the effect of thinning on the creation of mountain beaver problems for the next rotation. Prescriptions and timing should be adjusted if necessary.

Site preparation before regeneration is another opportunity to manipulate habitat. It may destroy nests and burrows, reduce cover, and control prime food species. If nests are located under stumps (as they often are), stump uprooting is necessary to destroy the nests. Mechanical scarification is very effective because it destroys burrow systems. Site preparation that exposes mountain beaver to increased predation by destroying runways and other cover can help to prevent population buildups.

Predator encouragement can help prevent population buildups and should be included in an overall strategy to maintain mountain beaver populations at low levels. Restricting the trapping of bobcats and coyotes and providing raptor roosts may encourage predation. Predators are not likely to control large populations of mountain beaver, but they may aid in reducing the abundance of the rodent.

Selecting the planting stock, the planting density, and the timing of planting relative to harvest are key decisions. Large transplant stock are less susceptible to mountain beaver damage and more resistant to mortality. Borrecco and Anderson (1980) examined 6,000 trees after 2 years in the field on 24 randomly selected plantations in western Washington. Mortality of clipped seedlings averaged 53 percent (±14 percent) for 2-0 nursery stock and 36 percent (±7 percent) for 2-1 seedlings. In addition, larger stock gains control of the site and reaches crown closure sooner, thus shortening the susceptible period and limiting the population buildup of mountain beaver. Larger stock that survive clipping also suffer less height reduction, as shown in fig. 6. Increased planting density also helps the stand attain crown closure sooner. Reducing the time interval between harvesting and planting similarly helps.

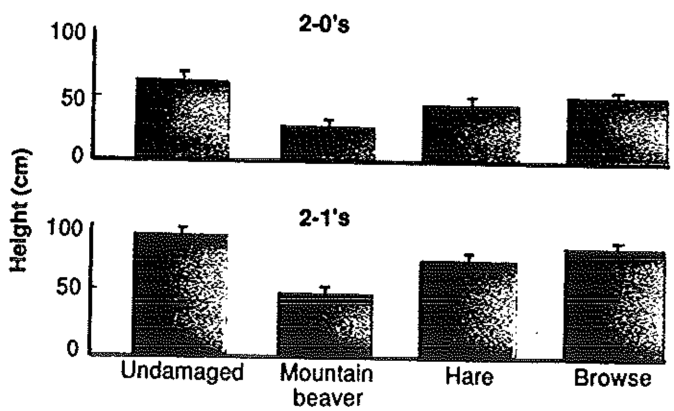

Figure 6—Mountain beaver damage and impact on the height of 2-0 and 2-1 nursery stock after 2 years in the field. Heights of undamaged seedlings are compared against the heights of seedlings damaged by mountain beaver, snowshoe hares, and deer (Borrecco and Anderson 1980).

Direct Damage Control

In most cases where mountain beaver populations are established, direct control of damage is necessary. Failure to do so results in tree mortality, thus creating openings and uneven stocking that not only adversely affects timber yield but also sustains mountain beaver populations that may cause significant damage later in the life of the stand.

Two approaches are possible: tree protection and control of the mountain beaver population. Trees can be protected either with repellents or with barriers that keep animals away from trees. To date, repellents have not been operationally effective against mountain beaver. Campbell and Evans (1988) have tested aversive conditioning by treating cull Douglas-fir seedlings with big-game repellent-powder (BGR-P) and placing them in mountain beaver systems. Subsequent planting of seedlings treated with BGR-P significantly reduced damage. More trials are needed before this approach can be recommended for operational applications, but it suggests that opportunities exist for creative new approaches. Campbell and Evans (1988) includes an excellent discussion of a variety of tests.

Fencing—Fencing to exclude mountain beaver from plantations primarily has been done for genetic-evaluation plantations and research areas. The fence must have 1-inch mesh at the bottom and must be buried to a depth of 2 to 3 feet. All animals within the fence must be eliminated, and careful fence maintenance is required, as well as monitoring for underground intrusion by mountain beavers. Mountain beaver, apparently, seldom climb over fences tall enough to exclude big game. This method of control, however, is not practical on an operational scale.

Individual tree protection—Individual tree protection with plastic-mesh tubes is a technique that protects seedlings from clipping by mountain beaver. This expensive technique can be cost effective in a variety of circumstances (fig. 7). Its primary use is in areas where direct population control is nearly impossible or prohibitively expensive. Tubes can be used effectively on edges of clearcuts and in draws and brushy pockets where problems are likely or where reinvasion is probable after direct population control. Tubes frequently are used in unburned units with heavy slash where trapping is ineffective. Replanting of areas where mountain beaver caused mortality to previously planted trees is another case where tubes potentially may be effective. Small units (under 30 acres) or narrow units often are most effectively protected by this means.

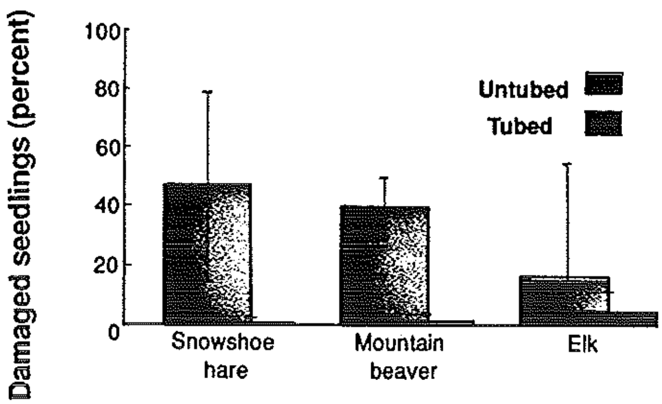

Figure 7—Mean percentage (and ranges) of damage by snowshoe hares, mountain beaver, and elk to young Douglas-fir seedlings protected by Vexar tubing compared with those left unprotected (untubed) (Borrecco and Anderson 1980).

Tree tubing, as it frequently is called, is not always effective. Tubes are clipped through and pushed under by mountain beaver that then clip seedlings inside the tubes. Mountain beaver climb the tubes and clip seedlings off at the top of the tubes. In one instance, 14 years of repeated top clipping of an individual tubed seedling was observed. Specific individuals, apparently, learn to chew through or climb tubes, because this type of damage often is localized around a specific mountain beaver's home range, and neighboring systems often do not show any evidence of either type of direct interaction with the tubes. Damage of this type usually is not extensive and normally can be expected to be less than 5 percent after 1 year.

Burying of tubed trees by mountain beaver also may occur where trees are planted in active burrow entrances, but undermining and root barking of tubed trees are the most serious damage. Where populations are unchecked, this damage can occur after stands are well established and thought to be out of danger. Populations of mountain beaver must be limited to low levels to avoid this type of damage, whether or not the trees are protected with tubes.

Significant resources have been expended to develop a tube that will degrade quickly enough to avoid constricting the growth in diameter of seedlings. Tube color affects degradation rate and can be prescribed and ordered for specific life spans. In practice, dense herbaceous vegetation and seedling crowns on high sites prevent light from reaching the tubing, thus greatly extending degradation times. Some foresters have gone to the expense of removing tubes from seedlings to avoid anticipated constriction problems. The expanding bole of the seedling, however, actually stretches the tube, making the plastic filaments thinner and thinner until they ultimately break, and the tube does no harm to the young trees. This generally occurs when the trunk is 5 to 7 inches in diameter. Trees that grow out of the side of the tube incorporate the tube in the wood, and it is unlikely that this will result in later problems.

Protective tubes can be installed on seedlings either before or after planting. The most common method is installation of rigid tubes on seedlings with a second crew after planting. Single crews also may plant the tree and then install the tube. Specific diameter, mesh size and angle, and length must be prescribed to fit the tree species and stock size to be protected. Tubes normally are ordered in nested groups for ease of handling and shipping. When installed, the individual tubes must be anchored to the ground and supported. Various anchoring techniques are used, but the most common technique involves weaving a bamboo staff or dowel through the tube into soil. Laths attached to tubes with twist ties also have been used, but they are subject to breaking at ground level, and this pulls the seedling over. Large stock, such as transplants, can provide much of the support for the tube. Length of tube, mesh diameter, and shape are critical to reducing tube leader interaction if tubes significantly longer than seedlings are installed (Campbell and Evans 1975). Tubes significantly taller than the seedlings must be installed vertically to prevent seedlings from growing through the sides of the tubes. Tubes taller than 18 to 24 inches are not necessary for operational reduction of mountain beaver damage. Rigid tubes, typically, are nested in groups of 10 tubes made of polypropylene. Each tube measures 3.25 inches in diameter (±0.5 inch), has 14 to 17 strands of 50-mil thickness, is 18 inches long, and has a life span of 24 to 30 months.

A second approach to the installation of tubing is to install the tubes on the seedlings at a centralized location, frequently the nursery. With this approach, a softer plastic-twill material closely matched to seedling height is placed over the seedling. The softer material takes up much less space than a rigid tube. Tubed seedlings then are placed in standard seedling bags for shipment to the field. Planters bag up the tubed seedlings and plant them normally but with 1 to 2 inches of the tube in the soil to anchor them. This technique is only suitable for sturdy transplant stock, because the seedling must provide support for the tube. Typical twill-tube specifications are 1.75 inches inside diameter, 14 strands of 50-mil thickness arranged in a diamond pattern, 18 inches long, and a life span of 24 to 30 months. These tubes also are made of polypropylene and polyethylene.

Tubing installed at the nursery has the advantage of much lower cost, and it ensures that all planted seedlings receive protection. The main disadvantage of pretubing is the added difficulty of planting seedlings vertically upright and at the proper depth. Ensuring that soil is compacted properly around the seedling's roots and around the tube in the planting hole also is very critical. Some additional mortality can be expected. Proper spacing of seedlings often is improved because the tubed seedlings are more visible to the planters.

Proper timing for the installation of pretubing is important. Tubing should be delayed until just before planting to reduce storage. Handling during tubing must be controlled to minimize the impact of root drying and exposure. Additional mortality of approximately 10 percent can be expected with this approach because of the extra handling and planting errors.

Direct population control—Direct population control is done either by trapping or poison baiting. Trapping is the most common and widespread technique for controlling mountain beaver damage (Mountain Beaver Subcommittee, Northwest Forest Animal Damage Committee 1979). Crews normally place Victor 110 Conibear kill traps (two to three traps per mountain beaver system) in main runways (figs. 8 and 9).

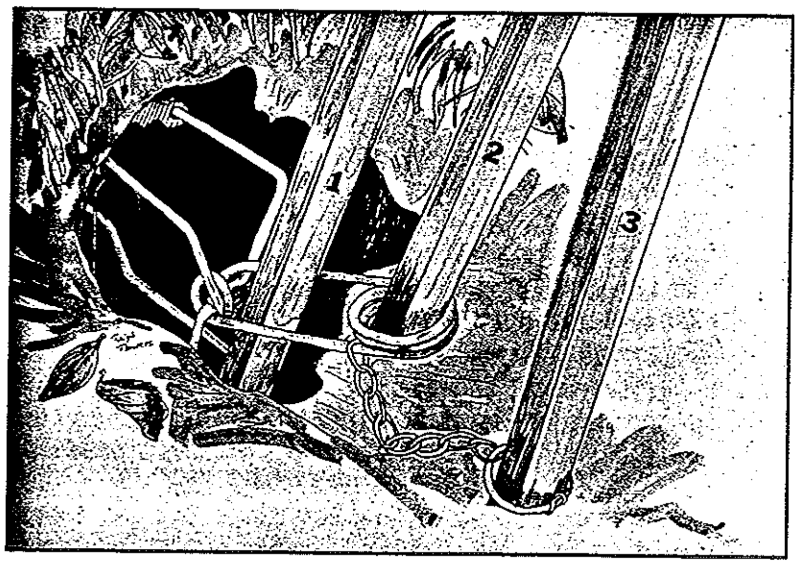

Figure 8—Conibear trap set showing placement of the third stake in the ring at the end of the trap chain.

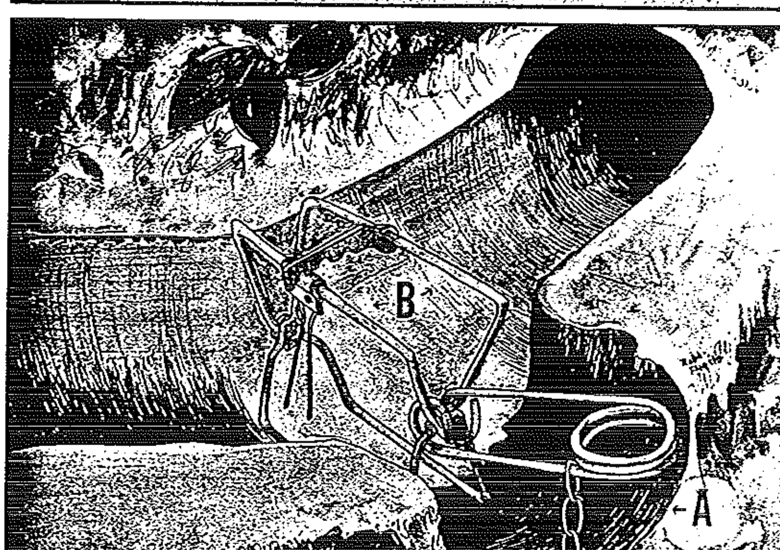

Figure 9—Conibear trap in typical burrow with a cutaway view showing the trap introduced through the feed exit (A) and placed across the main runway (B).

As many as 20 to 25 traps may be set per acre; however, 8 to 10 traps usually are sufficient. Traps generally are checked once or twice during a 5-day period before they are moved. Daily checking is not required with kill traps. Trapping on new units should be done as close to the time of planting as possible to minimize reinvasion time (Motobu and Jones 1977). Trapping, optimally, is done in the winter when vegetative cover is minimized. Trapping during cold, dry periods is ineffective because animal movement is minimal. Buffer areas of 300 feet may be trapped around plantation units to reduce reinvasion; however, this frequently is not done, and it is of questionable operational value.

Units need to be reasonably free of slash for effective trapping so that animals are forced to live in burrow systems that can be found consistently and set with traps. Broadcast burning is a technique that greatly enhances trapping effectiveness and reduces labor. At least a 6-week interval after burning is needed to locate active systems before trapping (Motobu and Jones 1977). Units must be monitored for reinvasion and retreated by trapping or baiting before significant damage occurs. Rapid reinvasion has been observed in some cases. Larger units with less border per planted acres are the units that can be trapped most effectively. Small units and long narrow units, or units adjacent to heavy population areas, require a continuous trapping effort. A small proportion of nontarget animals may be taken by trapping, including rabbits, hares, woodrats, skunks, mice, weasels, mink, and, occasionally, others (Motobu and Jones, 1977). Proper trap placement, trigger positioning, moving traps after five nights, and the timing of trapping can minimize impacts on nontarget species. Spring trapping also should be avoided.

Mountain beaver have been poisoned in a variety of ways over the years. One registered, restricted, and prepared strychnine bait presently is available for use in Oregon by licensed applicators (Orco Boomer-Rid Mountain Beaver Bait SLN Reg. No. OR-840029). Operational use of this material has been limited, but tests show it can be effective (Schaap 1986). Recent tests conducted by Campbell and Evans (1989) and Campbell and Engeman (1990) have shown very little effect on nontarget animals. The most recent test showed poor results but was done in March with spring plant flushing. Additional testing is planned to continue registration.

Baiting must strictly follow label instructions and state law. It consists of identifying the main runways of a mountain beaver system and placing from three to five pellets of bait deep within the system (preferably 2 or more feet deep) and well below ground level in several locations in main runways. Feeder tunnels, excavation openings, and deadend runways must be avoided. Where systems are extensive and overlapping, three to four bait stations per system are adequate. Isolated systems may require five to eight stations. All stations must be underground where they are neither visible nor easily accessible from outside the burrow. Baiting should be done at least 2 weeks before planting and during the winter when available food is low. Baiting should not be done during freezing weather, heavy rain, or after new growth in the spring.

Units must be carefully monitored for resurgence of activity, and methods of direct control should be implemented before population buildup or significant damage occurs. Other direct methods of population control, such as slash burning and predator encouragement, are not adequate to sufficiently control populations or alleviate damage if used alone.

Combination approaches—Most land managers use a combination of approaches among and within units. The objective is to manage damage at acceptable levels during the life of the stand. The most cost-effective and environmentally sound method of doing this, in most cases, requires a mix of approaches, including habitat manipulation and either individual tree protectors or direct population control (or both). The control strategy should start with preharvest assessments that lead to site specific silvicultural prescriptions, including unit design, site preparation, choice of planting stock, vegetation management, and direct strategies of damage control. Stand monitoring must continue to ensure that populations do not build up and cause significant damage as the stands mature.

Decision Methodology

Decision methodology is needed to develop the most environmentally sound and cost-effective methods of achieving and maintaining target stocking levels. Two approaches, generally, can be taken. The first approach is an anticipatory or preventative strategy. The second approach is a corrective or postdamage strategy. Managers employ both methods, although the second approach may be either planned or unplanned. Decisions must be based on the projected costs and benefits of alternative courses of action. Costs of alternative approaches are relatively easy to forecast. Benefits are much more difficult to forecast, and the margin of error is great. The most reliable source of information on the consequences of alternative treatment strategies is the experience gained from similar situations in nearby locations. Such results can be factored in and compared against new approaches.

Monitoring is mandatory to determine damage and population levels. Annual checks often are needed during the first few years, but monitoring intervals may lengthen at older ages. More frequent monitoring also is needed at precommercial thinning time. Mountain beaver behavior is unpredictable, and midcourse corrections in the damage-control strategy may be required. No forester wants to invest dollars for mountain beaver control after sustaining significant damage and would rather prevent damage. Damage must be managed throughout the life of the stand, and this must be done by maintaining populations at acceptable levels.

Research Needs

Listed below are some examples of research needed to improve methods for controlling damage from mountain beaver.

- Most research work on mountain beaver has been concentrated in the coastal areas, and research in the Cascades is needed to confirm basic biology and habits. Mountain beaver frequently are found in the Cascades in unexpected places, and damage is less predictable than in coastal areas.
- More understanding of mountain beaver damage in sapling-sized stands is needed to predict when and where damage will occur, why it occurs in some stands and not in others, and how it is affected by practices such as precommercial thinning.
- More information on the influence of predators on mountain beaver populations would be valuable.
- Additional knowledge is needed of the response of mountain beaver to silvicultural treatments and other habitat manipulation.
- More data are needed on the response of mountain beaver to methods of direct control. Areas of concern include birth rate, survival impacts, and sources and timing of reinvasion.

- Information is needed on how the amount of slash present on a site affects burrow and nesting patterns.
- Research on toxicants presently and potentially available is needed.
- Alternate strategies are needed to control damage with lower costs and in an environmentally sound manner.
- Predictive ability on the consequences of alternative control strategies over time is needed.

Literature Cited

Borrecco, John E.; Anderson, Robert J. 1980. Mountain beaver problems in the forests of California, Oregon and Washington. In: Clark, Jerry P., ed. Proceedings, 9th vertebrate pest conference; 1980 March 4-6; Fresno, CA. Davis, CA: University of California: 135-142.

Campbell, Dan L.; and Engeman, R.M. 1990. Field efficacy data collection for continued registration of ORCO Boomer-Rid mountain beaver *(Aplodontia rufa)* bait. II: Operational field efficacy study. Progress Report. Olympia, WA: Forest Animal Research. 5 p.

Campbell, Dan L.; Evans, James. 1975. "Vexar" seedling protectors to reduce wildlife damage to Douglas-fir. Wildlife Leaflet 508. U.S. Department of Agriculture, Fish and Wildlife Service. 11 p.

Campbell, Dan L.; Evans, James. 1988. Recent approaches to controlling mountain beavers *(Aplodontia rufa)* in Pacific Northwest forests. In: Crabb, A. Charles; Marsh, Rex E., eds. Proceedings, 13th vertebrate pest conference; 1988 March 1-3; Monterey, CA. Davis, CA: University of California: 183-187.

Campbell, Dan L.; Evans, James. 1989. Field efficacy data collection for continued registration of Orco-Boomer Rid mountain beaver *(Aplodontia rufa)* bait. Job completion report. Olympia, WA: Forest Animal Damage Control Research Station. 22 p.

Dalquest, Walter W. 1948. Mammals of Washington. In: University of Kansas Publications, Museum of Natural History; Lawrence, KS: University of Kansas, Vol. 2: 1-444 p.

deCalesta, David S.; Witmer, Gary. 1983. Impacts of bobcats on mountain beaver. Final Report. Project ORE-FS-144-P. Corvallis, OR: Department of Forest Science, Oregon State University. 54 p.

Drew, T.J.; Flewelling, James W. 1979. Stand density management: an alternative approach and its application to Douglas-fir plantations. Forest Science. 25: 518-532.

Feldhamer, George A.; Rochelle, James A. 1982. Mountain beaver *(Aplodontia rufa)* In: Chapman, Joseph A.; Feldhamer, George A., eds. Wild mammals of North America: biology, management, and economics. Baltimore, MD: Johns Hopkins University Press: 167-175.

Godin, Alfred J. 1964. A review of the literature on the mountain beaver. Spec. Sci. Rep.-Wildl. 78. Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife. 52 p.

Goslow, George E., Jr. 1964. The mountain beaver–*Aplodontia rufa*. Arcata, CA: Humboldt State College. 74 p. M.A. Thesis.

Hooven, Edward F. 1973. Effects of vegetational changes on small forest mammals. In: Hermann, Richard K.; Lavender, Denis P., eds. Even-age management: Proceedings of a symposium; 1972 August 1; Corvallis, OR. Corvallis, OR: School of Forestry, Oregon State University. 75-97.

Hooven, Edward F. 1977. The mountain beaver in Oregon: Its life history and control. Res. Pap. 30. Corvallis, OR: Forest Research Laboratory, School of Forestry, Oregon State University. 20 p.

Hoyer, Gerald E; Anderson, Norman; Riley, Ralph. 1979. A case study of six years of mountain beaver damage on Clallam Bay western hemlock plots. DNR Note 28. Olympia, WA: Washington Department of Natural Resources. 5 p.

Ingles, Lloyd G. 1959. A quantitative study of mountain beaver activity. American Midland Naturalist 61(2): 419-423.

Johnson, Sheldon Robert. 1971. The thermal regulation, microclimate and distribution of the mountain beaver *Aplodontia rufa pacifica* Merriam. Corvallis, OR: Oregon State University. 164 p. Ph.D. dissertation.

Kinney, J.L. 1971. Environmental physiology of a primitive rodent. Eugene, OR: University of Oregon. 181 p. Ph.D. dissertation.

Lawrence, William H.; Kverno, Nelson B.; Hartwell, Harry D. 1961. Guide to wildlife feeding injuries on conifers in the Pacific Northwest. Portland, OR: Western Forestry and Conservation Association. 44 p.

Martin, Paul. 1971. Movements and activities of the mountain beaver *(Aplodontia rufa).* Journal of Mammalogy. 52 (4): 717-723.

Motobu, DiAnne. 1978. Effects of controlled slash burning on the mountain beaver *(Aplodontia rufa).* Northwest Science. 52(2): 92-99.

Motobu, DiAnne; Jones, Marvin. 1977. Trapping guidelines for mountain beaver. Technical Report 042-4101/77/20. Centralia, WA: Weyerhaeuser Western Forestry Research Center. 28 p.

Mountain Beaver Subcommittee, Northwest Forest-Animal Damage Committee. 1979. Survey of mountain beaver damage to forests in the Pacific Northwest, 1977. DNR Note 26. Olympia, WA: Department of Natural Resources. 16 p.

Neal, Fred D.; Borrecco, John E. 1981. Distribution and relationship of mountain beaver to openings in sapling stands. Northwest Science. 55(2): 79-86.

Schaap, Wiger. 1986. Efficacy of Boomer-Rid in controlling mountain beaver. Discussion paper for OFIC meeting; 12 June 1986; Corvallis, OR. Corvallis, OR: Oregon State University. 10 p. [mimeo]

Scheffer, Theo H. 1929. Mountain beavers in the Pacific Northwest: their habits, economic status, and control. Farm Bull. 1598. Washington, DC: U.S. Department of Agriculture. 18 p.

Voth, Elver Howard. 1968. Food habits of the Pacific mountain beaver, *Aplodontia rufa pacifica* Merriam. Corvallis, OR: Oregon State University. 263 p. Ph.D. dissertation.

Walker, E.P. [and others]. 1975. Mammals of the world. 3d ed. [Rev.] J.L. Paradiso, Baltimore, MD: Johns Hopkins Press. 2 vol.

SECTION FOUR
SILVICULTURAL METHODS IN RELATION TO
SELECTED WILDLIFE SPECIES

Chapter 16
Deer and Elk

JAMES A. ROCHELLE

Abstract

This chapter discusses the biology and habitat relations of deer and elk and how they are impacted by forest management practices in relation to browsing damage and forest regeneration. Silvicultural techniques currently used to reduce the amount of impact of deer and elk browsing are discussed and modification of silvicultural approaches commonly used to reduce damage are suggested. Prompt establishment of large, vigorous planting stock and thorough site preparation immediately after completion of timber harvest is proven strategy for reducing deer and elk damage and impacts on seedling growth. This chapter identifies research needed to support the development of improved management tools and to evaluate the influences of new silvicultural approaches currently being applied in relation to the occurrence and control of deer and elk damage.

Keywords: Deer, elk, animal damage control, Pacific Northwest, silviculture.

Introduction

Most reforestation surveys in the Pacific Northwest indicate deer and elk are the most widespread causes of damage. The primary reasons for this are the extensive occurrence of deer and elk on forest land and the fact that woody vegetation, including conifer foliage, is a frequent component in the diet of these species. Essentially all forest land in the Pacific Northwest is occupied by deer, elk, or both.

JAMES A. ROCHELLE is manager, Environmental Forestry Research, Weyerhaeuser Company, WTC 2H2, Tacoma WA 98477.

Natural or management-caused changes in forest ecosystems have important implications for deer and elk because of strong historical, ecological, and nutritional linkages. The responses of deer and elk to these changes have similar implications for the forest manager attempting to produce a new forest stand. An understanding of deer and elk responses to the habitat changes brought about by forest management is a prerequisite to the development of silvicultural approaches to addressing the problem of damage to forests.

This chapter deals with two species of deer: white-tailed and mule, including the black-tailed subspecies. It also deals with two subspecies of elk: Roosevelt and Rocky Mountain. Discussion throughout this paper deals with deer and elk generically, except in cases where specific or subspecific characteristics are sufficiently different to require a distinction.

Biology of Deer and Elk

Distribution and Populations

Black-tailed deer occur throughout the area west of the Cascade Range from northern California to central British Columbia. East of the Cascades and throughout the Intermountain region, mule deer occur widely, and their ranges overlap with those of white-tailed deer in many areas. White-tailed deer are the most common and widely distributed deer in North America, occurring in 45 of the 49 states and most of the Canadian provinces. The range of Roosevelt elk extends from California to southern British Columbia and is confined primarily to the coastal areas, except where transplanting has extended their range. Rocky Mountain elk, originally found in the Great Plains and Intermountain West, now also occur widely on the western slope of the Cascades, largely as a result of transplanting efforts.

On a regional scale, populations of deer and elk have been fairly stable in recent years. The number of black-tailed deer observed in the 1940s and 1950s fluctuated widely in association with the conversion of old-growth forests to managed stands over extensive areas, but those fluctuations have leveled off in response to the more subtle and dispersed habitat changes associated with second-growth management. After a period of widespread extirpation in the early part of the century, populations of white-tailed deer have expanded to an estimated level of 15 million in North America, and they appear to have leveled off in recent years (Hesselton and others 1982). General declines in populations of mule deer occurred across the west in the late 1960s and early 1970s. Causes for those declines were not clearly defined, but additional emphasis on habitat relations in recent years has resulted in expanded management efforts and some rebuilding of populations (Mackie and others 1982). In the absence of large wildfires, such as those that occurred widely in the early part of this century, elk populations also have stabilized regionally at levels that most biologists consider fairly high. Extensive transplanting of elk by state agencies has contributed to increasing populations in some areas.

Movement Patterns and Home Range

Migratory and resident behaviors are demonstrated by each of the deer and elk species and subspecies considered in this paper. Depending on the particular subpopulation and the habitat and climatic conditions where they occur, extensive migrations between summer and winter ranges are fairly common in Rocky Mountain elk and mule deer. Roosevelt elk and white-tailed and black-tailed deer more commonly display resident behaviors in which the same area is occupied throughout the year. Local elevational shifts or lateral shifts from one part of the home range to another are further variations observed in both deer and elk. The primary factor influencing movement patterns appears to be the seasonal availability of suitable habitats.

Size of home ranges differs between and within species and subspecies of deer and elk. Movements and home-range size differ, in general, among individual animals with the same general habitat; males use larger areas and move more widely than females, particularly when rutting movements are included. Movements and home-range size increase as distances between food, cover, and water sources increase. They also increase with decreasing complexity or diversity of habitats. Nonmigratory species like white- and black-tailed deer typically have small home ranges on the order of 320 acres for females and 640 acres for males. Home-range sizes vary seasonally, particularly for males during the breeding season. Home ranges of Roosevelt elk typically are on the order of 1,000 to 6,000 acres. Rocky Mountain elk occupy similar-sized seasonal ranges often separated by some distance of transitory range. Seasonal home ranges of mule deer range from 100 to 800 acres, and distances of several miles between summer and winter ranges have been measured in some locations.

Factors Influencing Population Levels

Population levels of deer and elk vary on a local scale in response to a number of factors, of which the most important include habitat conditions and intensity of legal and illegal hunting. Predation also can have significant effects in localized situations. In most cases, these factors operate in concert to determine the level of the individual population.

Hunting, historically, is the variable that best lends itself to management control. Political opposition to the taking of female deer and elk often has limited the effectiveness of hunting to control populations. General opposition to hunting of all kinds, furthermore, is increasing nationally. An increased emphasis is being placed on "quality" hunting in many areas of the Pacific Northwest. This usually entails limited-entry hunts, often in walk-in areas, with some type of antler-point restrictions or regulations requiring the use of archery or other special equipment. The result of these programs is that fewer animals are taken, and lower levels of population reduction are achieved.

Habitat changes can take the form of permanent loss to factors like urban or highway development or conversion to noncompatible use, such as some types of agriculture. Other modifications can either improve or degrade the value of the habitat. Forest management's role is one of habitat modification, and it can result in changes that are beneficial, detrimental, or neutral to the big game species of interest. It is through this vehicle of habitat change that forest management can influence population levels and use of local areas. The following discussion examines in detail the mechanisms through which specific silvicultural practices influence deer and elk populations, use of habitat, and damage to forest regeneration.

Characteristics of Deer and Elk Damage to Forest Regeneration

Broad-scale surveys in the Pacific Northwest have consistently listed damage by deer and elk as the most widespread form of animal damage (Black and others 1979). The similarity of deer and elk damage often prevents specific assignment of cause of damage; however, the wider distribution of deer suggests they are the most prevalent cause.

Several types of damage are caused by deer and elk; however, the most widespread and economically important type is browsing of planted seedlings during the first several years after planting. Other less common and less important types of damage include trampling of newly planted seedlings by elk, and bark removal from saplings through feeding or antler rubbing by both deer and elk.

The growth and survival impacts of deer and elk browsing on seedlings vary with a number of factors. The most important of these are timing, intensity and frequency of browsing, the site conditions under which the seedling is growing, and the size and physiological vigor of the browsed seedling itself.

An infrequent, but particularly serious type of damage is caused by elk pulling newly planted seedlings out of the ground. This activity results in mortality of the pulled seedlings, and it often is severe enough to necessitate replanting. A much more common form of damage is browsing, which removes the terminal shoot of the seedling. This type of feeding seldom results in direct mortality, and a single occurrence of browsing on a healthy tree often has negligible effects on subsequent growth. The severity of growth-loss increases with browsing that removes most of the foliage from the seedling, with repeated browsing in consecutive years or seasons, with browsing in addition to damage by other wildlife species, and with browsing on seedlings of small size and low vigor or when the seedling is subject to severe competition from other vegetation. Under these circumstances, seedling growth may be suppressed to the point that the tree is unable to develop as a normal component of the stand and either drops out or contributes less than the expected volume at harvest.

The proportion of the stand with severe damage is a critical determinant of the economic impact of the damage. Heavy browsing on 25 percent of the trees in a plantation of 600 trees per acre scheduled for precommercial thinning, for example, is not likely to justify costs to control the damage, especially if browsing is evenly distributed across the plantation. The level of damage necessary to justify a damage-control treatment is a function of a number of factors specific to the landowner or manager, and it largely is based on expected economic return. The difficulty in predicting long-term growth effects of browsing damage that occurs early in the life of the stand obviously complicates the decision-making process.

Habitat Relations

Foraging Patterns and Diets of Deer and Elk

The literature of food habits and feeding patterns of deer and elk is voluminous, indicating the amount of research and the variation observed among different populations. The diets of deer and elk overlap to a wide degree, and the diets of both groups largely are determined by forage availability. Being ruminants, both deer and elk rely on microbial populations in their stomachs to digest the complex carbohydrates making up the plant tissues in their diets. The amount of vegetation that can be ingested is determined by the size of the rumen and the digestibility of the forage consumed (which controls the rate at which plant material is passed through the rumen). The smaller rumen of deer (as compared to elk) dictates a high rate of forage turnover, which in turn requires the utilization of easily digestible forage. Deer, consequently, exhibit very selective feeding behavior compared to larger herbivores.

Availability is the primary determinant of food habits; therefore, geographic and seasonal differences in deer and elk diets are common. General forage types consumed by both deer and elk in western Washington and Oregon, for example, and examples of species within those types are listed below:

Spring—Forbs, grasses, and new growth on shrubs and trees. Examples are velvet grass, false dandelion, sedges, trailing blackberry, Douglas-fir. Diet reflects a transition from winter to summer foods.

Summer—Forbs, grasses and shrubs (leaves, twigs and fruit). Examples are fireweed, dandelion, trailing blackberry, vine maple, thimbleberry, red huckleberry, sedges, and legumes.

Fall—Shrubs, forbs and grasses. Examples are trailing blackberry, red huckleberry, thimbleberry, red alder, fireweed, dandelion, sedges and legumes. Shrubs increase in importance, and fruits commonly are utilized at this time.

Winter—Winter-active grasses and forbs, shrubs, and conifers. Examples are trailing blackberry, sedges, false dandelion, salal, red huckleberry, Oregon grape, Douglas-fir, western redcedar and western hemlock.

A general distinction between deer and elk is that deer primarily are browsers and feed largely on woody vegetation, while elk are grazers that mainly utilize grasses and other herbaceous plants. Availability, however, remains the key determinant, and the above generalization frequently does not hold.

Deer and elk utilize conifers differently both seasonally and in different geographic areas. During spring and early summer, Douglas-fir is preferred by black-tailed deer in some parts of western Washington and Oregon. In other areas, it is consumed only in winter when its availability is high relative to other forages. East of the Cascade Range, browsing on conifers more typically is a winter occurrence in response to reduced availability of other forage. Snowfall greatly affects forage availability. Conifers often protrude above the snow, for example, and heavy damage can occur under these circumstances. Where deer and elk are migratory, damage often is most pronounced on migration routes between summer and winter ranges.

Key Factors Affecting Habitat Use

Deer and elk, like other animals, require space, water, food, and cover. The degree to which these components are represented and distributed throughout the forested area largely determines the productivity of the habitat and has a major influence on the occurrence of deer and elk damage in the regenerating forest.

Deer and elk require an area of adequate size to carry out their daily activities of feeding, resting, traveling, breeding and raising young. As discussed earlier, home ranges are the on-the-ground manifestation of this requirement for space, and the variations observed in migratory behavior and size of home range reflect the way these needs are met.

Deer and elk obtain from forage the energy they need to maintain a constant body temperature, carry out daily activities, grow, accumulate energy reserves and reproduce. Forage areas recently have been defined (Witmer and others 1985) as vegetated areas with less than 60-percent canopy-closure of trees and tall shrubs combined. These conditions most commonly occur in recent cutovers and young plantations up to the open pole-sapling stage; in some cases, thinned stands and shelterwood areas also qualify.

Water is obtained to varying degrees from the forage consumed, but most animals require free water on a regular basis. Availability of water is an important factor influencing home-range characteristics, particularly in the drier eastern parts of the region and in late summer when elk and deer activity in riparian areas and wetlands increases.

Deer and elk use cover for hiding, shelter, and to conserve energy. Hiding cover and thermal or sheltering cover are two types widely recognized by biologists. Hiding cover is defined as any vegetation capable of hiding 90 percent of a standing adult deer or elk at 200 feet or less. This includes some shrub stands and all forested stand conditions with stem density adequate to hide animals. Topographic features provide hiding cover in some instances. Thermal cover is defined as a forest stand that is at least 40 feet in height with tree-canopy cover of at least 70 percent. These stand conditions are achieved in closed sapling-pole stands and by all older stands, unless canopy cover is reduced below 70 percent. A third type, optimal cover, is of particular importance where heavy snowpacks may make cutover areas inaccessible to deer (Witmer and others 1985). Optimal cover provides snow interception as a result of overstory branch structure and an intermediate canopy, and it contains small openings and a shrub and herbaceous layer. These features result in reduced snow depths compared with cutover areas, and litterfall and rooted vegetation provide a source of forage (Rochelle 1980). Optimal cover usually occurs in stand conditions of mature sawtimber or old-growth.

Forest Management Influences on Deer and Elk Habitat

Road construction and use—Direct influences on deer and elk habitat from road construction include the removal of a portion of the habitat base, either permanently in the case of primary roads or temporarily in the case of secondary roads. Road use can have direct effects through mortality resulting from vehicular collisions with deer or elk. Indirect effects of roads, particularly road use, are of more significance to the use of habitat by deer and elk. There are examples of deer and elk adapting to regular flows of traffic like those associated with logging, but public access for hunting or other recreational pursuits tends to have a disruptive effect on the use of habitat by deer and elk. The disturbance associated with road use can result in higher metabolic rates and greater energy needs of deer and elk, and otherwise acceptable feeding and resting areas, consequently, may not be used. Roads also can facilitate legal and illegal hunting that directly affects harvest levels of deer and elk.

The degree to which roads and their associated traffic affect deer and elk and their use of habitat is determined by a number of factors. One of the most important factors is the cover condition adjacent to the road: the level of disturbance is inversely related to the amount of cover present. The type of road and its level of use also are key influences. The majority of forest roads are secondary roads, and in the absence of log-hauling activity, they are used only intermittently. The disturbance associated with use of this type of road is substantially different than that associated with primary roads (Witmer and others 1985). Use of roads in steep topography creates larger areas of disturbance than on more level ground because of the greater visual distances involved. Roads that are closed to vehicular traffic do not disturb deer and elk and often are used by the animals for foraging, travel lanes, and bedding sites.

Timber harvest, site preparation, and regeneration—Most forest harvesting in the Pacific Northwest is by clearcutting, with significant exceptions in the pine and mixed conifer forest in the eastern part of the region, where several forms of selective harvest often are employed. Removal of all or a portion of the forest stand has both immediate and lasting effects on habitat. Clearcutting, much like natural disturbances, such as wildfire or windthrow, reinitiates the process of plant succession. Invasion of forage plants and resprouting of existing species results in dramatic improvements in both the quantity and quality of forage. This condition persists for a period of 10 to 20 years, depending on the productivity of the site and the regeneration practices employed. It is during this period of high use that deer and elk damage regenerating stands.

The utilization of this enhanced forage supply is influenced by the type and extent of site preparation. Where large amounts of slash remain and broadcast burning and scarification are not practiced, access by deer and elk to portions of the harvest unit may be impeded temporarily. The soil disturbance caused by site preparation also may prolong the productive forage period by removing residual vegetation and allowing invasion of desirable herbaceous species.

The timing and density of conifer planting significantly affects the period of high forage production in a cutover area. Planting within one or two years of harvest with high stocking densities (>500 trees per acre) will shorten the productive period compared with delayed regeneration at lower densities. Site productivity and quality of the planting stock also influence forage-production patterns.

Competition control—Herbicide applications sometimes are used to reduce competition between plantation trees and other vegetation on the site. Red alder, vine maple, bigleaf maple, salmonberry, ceanothus, and grasses are among the most common competitors. The effects of the treatment can be either positive or negative with regard to forage. The initial decline in forage quantity often is followed by sprouting of woody plants and expansion of species not affected by the treatment. Removal of dense shrub cover also may improve deer and elk access to the site. Release of the conifers from competition also has the effect of shortening the period of high forage production.

Precommercial thinning, or stocking control, in which a portion of the plantation is removed to promote growth of the remaining trees, also affects the deer- and elk-habitat characteristics of the stand. The temporary reduction in canopy density allows some forage plants to persist by extending the time the stand remains in an open condition. Heavy accumulations of thinning slash can interfere with animal movement, reducing access to the site for several years.

Fertilization—Application of nitrogen fertilizer at the time of stocking control and at selected intervals during the life of the stand is a practice commonly applied on some forest ownerships. All the vegetation on the site receives fertilizer; therefore, significant improvements in forage production, quality, and palatability are possible (Rochelle, 1979). Fertilization also enhances the growth of the forest stand; therefore, the length of the period of improved forage conditions may be reduced, depending on tree density, degree of crown closure at time of fertilization, and timing of subsequent thinning.

Commercial thinning—Removal of a portion of the stand to extract commercial value and control levels of in-stand competition is practiced to varying degrees in the Pacific Northwest. Forage quantity and quality usually are improved by this treatment. The degree of thinning depends on previous treatment history, density, and number of trees removed. Commercial thinning, depending on thinning intervals, can help maintain forage production throughout the managed stand rotation.

Population Responses of Deer and Elk to Forest Management

The preceding discussion indicates that deer and elk interact with forest management in multiple and complex ways. This section summarizes the basic relations that determine the status of deer and elk on a particular area of forest land.

Hunting, predation, and other direct influences play a role in regulating the numbers of deer and elk on forest land; however, they operate on the populations that result from the inherent productivity of the habitat. The number of animals that potentially can be produced from an area, therefore, largely is determined by the interaction of this basic productivity with factors like forest management that modify habitat.

Forest management activities have a major influence on deer and elk populations at the local and regional scale as the result of the patterns of forest succession that accompany the harvest and subsequent development of the forest (fig.1). As with wildfire, volcanic eruptions, or other disturbances, forest harvests are followed by a period characterized by an abundance of high-quality forage for deer and elk. Historic, as well as current population trends, largely are a result of this process. The influence of subsequent management practices largely depends on how they increase or decrease the actual forage base, its nutritional quality, or the degree to which it is available to deer and elk. The availability and use of this forage base is a function of the distribution of harvest units in time, space, and in relation to each other and to cover. To the degree that energy conservation by deer and elk is affected, the relative balance of forage and cover also affects population productivity. Overall levels of use of habitat are affected by the amount of human disturbance, which largely is a function of road use as modified by the presence or absence of suitable cover.

Alternative management approaches, such as the New Forestry advocated by Franklin (1989), affect deer and elk habitat to the degree they affect the basic relations described above. Many of the anticipated benefits of new forestry are yet to be demonstrated and are not specifically targeted to deer and elk habitat; however,

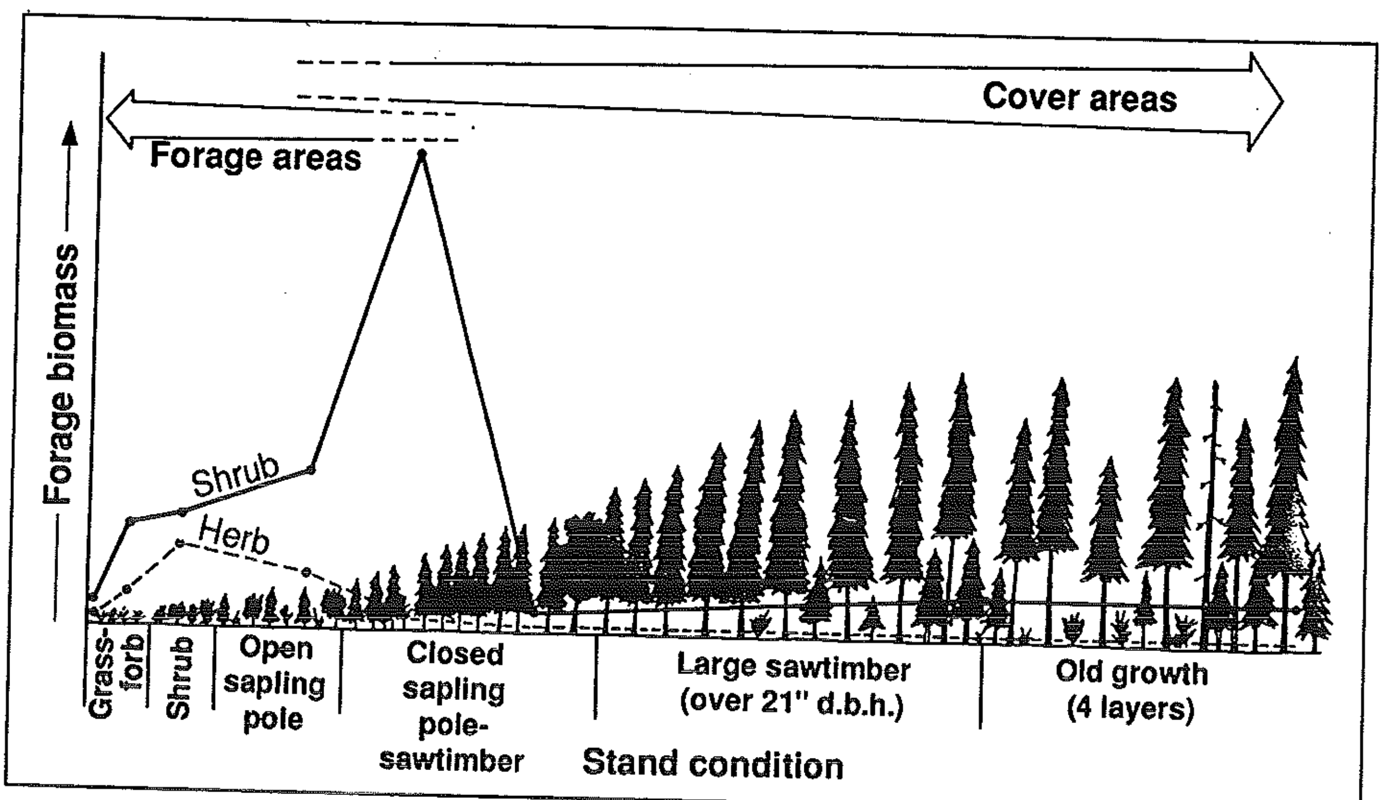

Figure 1—Relation of forest stand condition (or seral stage) to deer and elk forage and cover areas (biomass curves adapted from Long 1976, Witmer and others 1985).

some likely results of the implementation of this approach can be advanced. Partial cutting, as recommended for some situations, slightly reduces forage production while retaining cover in the form of residual trees. The effect of this practice on the productivity of deer and elk habitat is not likely to be significant, either positively or negatively, and it largely depends on the proportion of trees removed (or retained). Harvest units created with 'feathered' or otherwise irregular margins result in additional habitat edge and may increase utilization of forage in clearcuts by augmenting cover in proximity to food. Partial cutting provides additional edge that potentially may increase the frequency and intensity of browsing on seedlings because of more complete foraging activity in harvest units. This practice was not conceived with deer and elk habitat in mind; however, the largest influence of new forestry on deer and elk probably results from the concentration of timber harvests in larger blocks as opposed to the extensive dispersal of staggered clearcut blocks recommended previously. After natural or human-caused, large-scale disturbances, historically, deer and elk populations have displayed both rapid increases and decreases in response to the changed forage availability. This sometimes is referred to as the "boom and bust" phenomenon. Increased levels of browsing damage have accompanied the increased populations. The scale on which concentration of harvest units is implemented in New Forestry largely will determine the degree to which increased damage results.

Managing Deer and Elk Damage

The number of deer or elk present per unit area of regenerating forest in relation to the amount of available, nutritionally adequate, and palatable forage normally is directly related to the amount of browsing damage. In recognition of this relation, prevention and control of damage have focused on approaches that directly or indirectly influence the number of animals in the area, affect the palatability or availability of forage, or reduce the deleterious survival or growth impacts to the seedling if browsing does occur. Management of deer and elk damage is likely to be most successful with a combination of two or more of these approaches.

Direct Control Methods

This section briefly notes some of the possible methods of direct control. A number of publications detailing these techniques are available through university extension offices and other sources.

Population reduction—The positive relation between density of animals and tree damage has been clearly demonstrated for black-tailed deer (Hines 1973) as has the role of hunting in reducing deer numbers and damage (Crouch 1980). In many areas, more animals could be removed and hunting pressure often is available to do so, but political considerations often prevent implementation of this approach. Reliable and defensible data on the levels and trends of damage is a critical piece of information needed to support more liberal harvests of animals, including antlerless deer.

Mechanical and chemical barriers—Area fencing or physical barriers on individual trees have been shown to be effective in preventing or reducing deer and elk damage. Many different materials, designs, and applications of physical barriers have provided varying levels of effectiveness. Cost is a major deterrent to the widespread use of this approach. A variety of chemical repellents, likewise, have been developed and used with varying levels of success. Cost and the need for repeated treatments are major obstacles to extensive use of repellents.

Silvicultural Approaches to Managing Deer and Elk Damage

As opposition to hunting as a means of damage control increases and as the number of chemical tools available declines, habitat manipulation with silvicultural methods is becoming a more important option for addressing animal damage. This section discusses ways of applying the range of existing silvicultural tools with the goal of preventing or reducing browsing damage by deer and elk and suggests that combinations of these methods, frequently, are the most effective strategies. The approaches outlined in this section may conflict with other deer- and elk-management goals, such as optimizing populations or habitat use; however, those tradeoffs are not addressed here. These goals must be balanced elsewhere, in the context of the biological, legal, political, and economic objectives and constraints associated with the management of particular areas of land.

Timber harvest— As distance from cover increases, the utilization of forage areas by deer and elk declines (fig. 2). Circular or square configurations of the harvest unit create the minimum amount of edge in relation to harvest area. Maximizing the area of the harvest unit also should reduce the intensity of browsing across the unit. In some instances, deer and elk populations may increase after several years in response to the improved forage conditions. Planting as soon after harvest as possible, therefore, is a critical step to enable seedlings to become established and develop the height growth that will reduce the growth impacts of browsing. Building on this approach, blocking-up harvest units to further reduce the amount of edge in relation to plantation area should further disperse browsing pressure, at least temporarily. This again points up the need for immediate regeneration.

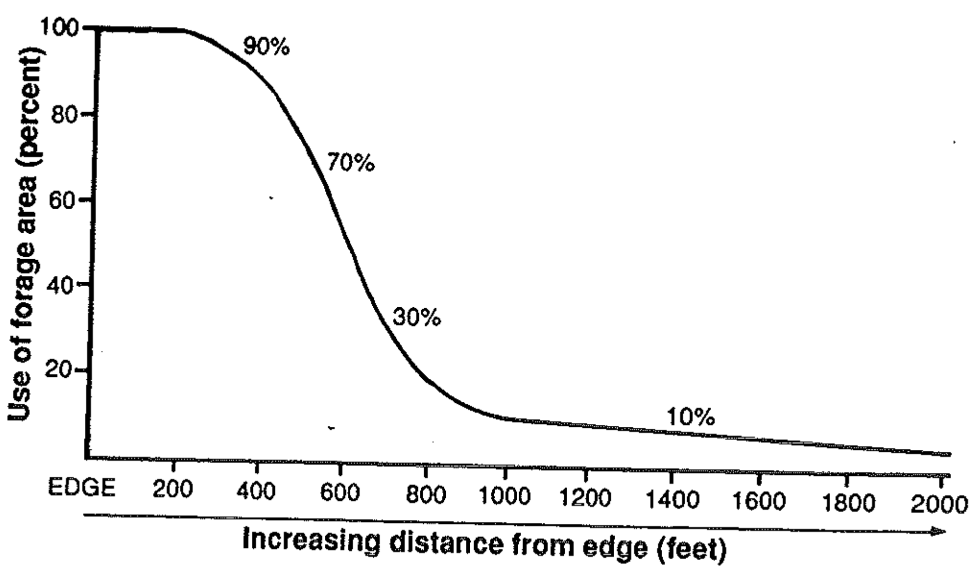

Figure 2—The generalized influence of distance to edge on deer and elk use of forage areas (derived from Hanley 1983, Harper and Swanson 1970, Willms 1971, Witmer 1981, Witmer and others 1985).

Location of harvest units relative to surrounding conditions also can help reduce damage. Populations of deer and elk normally are low in mature sawtimber or old-growth stands relative to younger areas; therefore, clearcuts placed in larger areas of older forest should sustain less feeding pressure and seedling damage than those placed in areas of mixed-age classes, including younger forests. The ability to exercise this option, clearly, declines as harvesting in an area proceeds and as the ratio of forage to cover areas becomes more favorable to deer and elk.

Other factors that interact with open areas include the overall level of forage available and the occurrence of human activity. Where forage abundance is low, the distances animals travel from cover is larger. Merrill and others (1983) documented the extremely large forage areas that elk used in the absence of human disturbance in the Mount St. Helens blast zone.

Road construction and use—Placement of roads normally is a function of engineering considerations, and little flexibility in road location is possible. Engineering and economic considerations also largely dictate road densities. Where flexibility exists for an equivalent amount of road use, however, placement of roads to maximize the area visible from the road results in maximum reduction in damage by deer or elk. Enhanced traffic levels on roads passing through areas that sustain deer and elk damage also may reduce damage, particularly if road use increases during the period when damage occurs. Increased road densities also may reduce levels of deer and elk damage (fig. 3), but this probably is not practical solely for the purpose of damage control. Road closures in damage areas, conversely, may result in increased levels of damage. These observations probably apply only to primary roads that constitute a fairly small portion of the total mileage of forest roads (Witmer and others 1985).

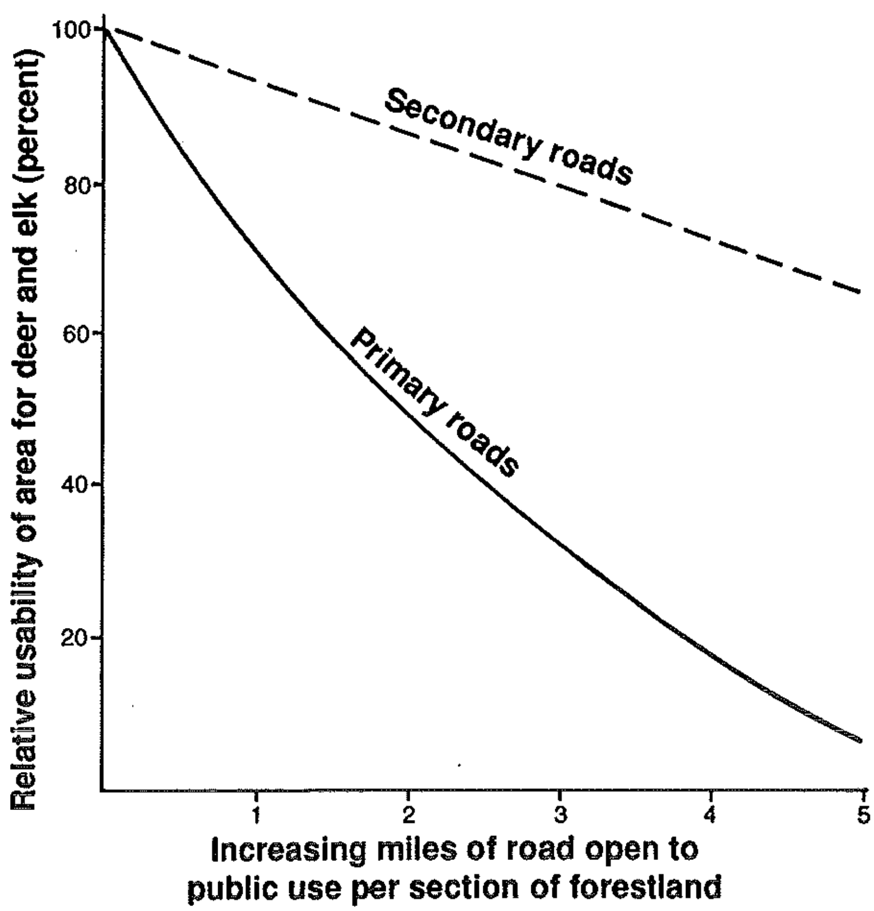

Figure 3—Generalized influence of increase in open-road density on otherwise usable deer and elk habitat (derived from Willms 1971, Witmer 1981, Witmer and others 1985).

Site preparation and regeneration—The condition of the harvest site with regard to slash concentrations and the amount of desirable forage on the site can have a major influence on the levels of use by deer and elk. Retention of large amounts of scattered slash or slash piled in windrows may impede deer and elk access to an area, but it also may enhance rodent and hare populations and associated damage. Clean site preparation with broadcast burning or scarification temporarily removes desirable forage plants, reduces vegetative competition with the planted seedlings, and reduces the attractiveness of the area for deer and elk. These conditions are short-lived and rapidly lose effectiveness as the time between site preparation and planting increases. If areas around the plantation support high densities of deer or elk, then seedlings planted on very clean sites may be browsed as a result of their high exposure.

Quality of planting stock increasingly is recognized as a critical determinant of regeneration success. Seedlings with high vigor that quickly become established after planting and grow rapidly in height beginning in the first growing season are one of the most effective tools available for dealing with deer and elk browsing. This effectiveness is further enhanced if large stock (1-1, 2-1) are planted. Large seedlings with high vigor planted immediately after thorough site preparation can sustain low to moderate levels of browsing with minimal effects on survival and growth. Severe browsing also is less likely to cause mortality of trees with these characteristics.

Vegetative manipulation—Modification of the quantity, species composition, and nutritional value of vegetation within the regeneration area operates in several ways to reduce levels and effects of browsing damage. Treatments to prevent development of preferred forage species may reduce damage by reducing the use of the plantation, but they may have the opposite effect if surrounding areas support high populations of deer or elk. Hines (1973) reported increased browsing of Douglas-fir by black-tailed deer when the availability of preferred forage was reduced in the presence of high deer numbers.

Forage seeding with either native or agricultural plant species is an alternative approach that has been widely used, but its effectiveness is poorly documented. Grasses and forbs, usually including legumes, are the plants most commonly seeded (table 1). Becker (1989) reviewed published work-to-date and concluded that seeding can substantially increase amounts and quality of forage but found little evidence of a reduction of browsing damage by deer and elk. Increased damage observed in some instances, apparently, was related to seeded forage that attracted additional animals to the treated areas.

Fertilization to improve nutritional quality and palatability of forage plants can shift feeding pressure from plantation trees but also may attract additional animals to the site and result in increased damage. Fertilization of natural and human-made openings, such as fields and rights-of-way, can concentrate deer and elk feeding and may draw animals away from specific damage areas on a limited scale (Brown and Mandery 1962). Increased incidence of deer or elk collisions with vehicles could be a negative result of right-of-way seeding.

Control of competing vegetation indirectly influences damage by mitigating the growth impacts of browsing by deer and elk, and it can be more cost-effective than direct

Table 1—Forage species of proven value for use in western Oregon and Washington

Forage species	References
Orchardgrass, ryegrass, white clover, birdsfoot trefoil (wildlife mix No. 2)	Smith 1980
Perennial and annual ryegrass, orchardgrass, tall fescue, white and subterranean clover	Mereszczak and others 1981
Catsear, hawksbeard, fleabane, hawkweed, phacelia and redstem fireweed	Campbell and Evans 1978 Campbell and Johnson 1981
Many species of grass, legumes, shrubs and trees, cereal grains, lupine, sedges	State of Oregon 1980[a] State of Washington 1983[a]

[a] An especially useful reference.
Source: Witmer and others 1985.

protection with repellents or physical barriers because of the consistent, positive growth response it provides (Gourley and others 1989). Vegetation control also can improve deer habitat by changing forage species composition without increasing browsing damage on seedlings (Borrecco 1972). In instances where much of the other vegetation is removed, damage levels on plantation trees may increase, especially with high populations of animals before treatment (Boyd 1987).

Silvicultural planning—Some of the most effective steps that can be taken to manage damage by deer and elk fall into categories of administration or planning. Most of them fall into the common sense category and are part of the job of forest management. They require little extra effort or expense. At the risk of offending some readers, some of these steps are listed below:

- Utilize experience gained previously, from adjacent areas, previous years, and previous managers in anticipation of damage and planning operations.

- Know your territory or area, what species are present, when they are present, and when damage occurs. With migratory deer and elk, regeneration activities sometimes can be timed to avoid tree-animal interactions during the immediate post-planting period. Extra effort to ensure trees are firmly planted can reduce elk pulling if it is anticipated.

- Work together with your state agency biologist to understand trends in animal numbers and tree damage. Support of the local biologist is essential to obtain support for special hunts that reduce population in damage areas.

- Spread the word, through hunting maps or other means, about locations of severe damage and associated hunting prospects. Use road management to make damage areas accessible to hunters and to concentrate hunting pressure.

- Insist on quality planting stock and use the largest seedlings available and consistent with operational constraints. The track record for achieving successful reforestation with this combination is well established.

- Monitor your regeneration areas to track damage levels and determine needs for competition control or other treatments. Record successes and failures to provide future direction. As discussed above, silvicultural treatments that change forage availability may either increase or decrease damage, depending on other local factors.

Research Needs to Support Silvicultural Control of Deer and Elk Damage

Landscape Scale Interactions of Deer, Elk, and Forestry

Silvicultural practices and their relation to the other resources of the forest, including wildlife, increasingly are being considered on a landscape, watershed, or some equally large geographic scale. This is particularly applicable for species like deer and elk, whose home ranges are large and normally include stands of differing silvicultural status, including unmanaged conditions. It is this combination of features that determines population levels, patterns of habitat use, and occurrence of damage. Planning silvicultural activities that consider the potential for browsing damage requires a better understanding of the response of deer and elk in space and time, especially with regard to feeding patterns.

Prediction of Deer and Elk Damage

Our knowledge of deer and elk responses to changes in food, cover, and human disturbance continues to increase, but our ability to anticipate where and at what intensity browsing will occur is limited. A quantitative method for assessing the likelihood that deer and elk will use a specific site at a level that will interfere with regeneration success would be valuable in guiding silvicultural or other methods of damage control. This need perhaps is best addressed as a component of determining landscape-level interactions of deer, elk, and forestry.

Vegetation Manipulation

Planted conifers sometimes and in some locations are a preferred forage item, but their use more often is related to the overall availability of forage on the site. Enhancing forage levels and quality in order to increase the difference in palatability between seedlings and other available forage warrants additional research, but that research should consider the responses of deer and elk populations and the need for control. The full potential of selective manipulation of vegetation with herbicides to achieve both competition control and forage composition objectives has yet to be fully explored. The possible dual benefits of damage reduction and enhancement of seedling growth make this approach particularly attractive from an economic perspective.

Influence of Alternative Silvicultural Approaches

New Forestry, riparian zone management, retention of specific habitat components like snags and large woody debris, and other modifications of traditional management approaches are being applied in varying degrees on public and private forestland. These practices have potentially broad implications for silviculture, wildlife, and their interactions (including damage). Programs to assess the results of these different approaches should include levels of deer and elk damage as criteria for evaluation.

Road Management

Human activity on roads negatively affects deer and elk use of habitat and leads to road-management programs designed to reduce or eliminate road use. This suggests that enhancement of levels of human activity on roads could reduce the use of particular areas by deer and elk at times of damage occurrence. Many factors limit the feasibility of this approach, but they should not preclude further testing to determine if there are specific situations where it might have potential.

Summary

The widespread occurrence of deer and elk damage to forest regeneration in the Pacific Northwest has been amply documented. On the plus side, deer and elk browsing normally is not a significant cause of seedling mortality. Deer and elk also are highly desired components of Northwest forests, and significant, ongoing management efforts are directed at maintaining and, usually, enhancing their populations. Attempts to satisfy population and silvicultural objectives on the same land base create some unique management challenges, particularly in light of the well established relation of animal numbers to occurrence of damage. In many instances, these objectives are not compatible, and tradeoffs are necessary. The most acceptable solutions are those with the least detrimental impact on either goal and those that satisfy other societal demands, like hunting, in contrast to reducing habitat quality.

Deer and elk, because of their high profile, have received substantial attention from researchers. These research efforts provide a relatively good level of understanding of the relation of these animals to forest habitat. This knowledge suggests a number of approaches to damage control, many of which are being applied. Examples of some of the more common sense but extremely effective tools available include thorough site preparation, immediate establishment of plantations after logging, and the utilization of large, high-quality planting stock. Combined with other treatments, such as control of competing vegetation, these standard forestry activities go a long way toward reducing browsing, or its impact, to acceptable levels.

Among the research opportunities that exist (and there undoubtedly are many more than those listed above), reducing damage through manipulation of vegetation on a broad or landscape scale and on a site-specific basis is likely to be one of the more fruitful areas of research. As the use of alternative silvicultural approaches expands, moreover, their animal-damage implications must be assessed.

Literature Cited

Becker, J.M. 1989. Forage enhancement in the Pacific Northwest: improving elk habitat and forest regeneration. Seattle, WA: University of Washington, College of Forest Resources. 55 p. M.S. thesis.

Black, H.C.; Dimock E.J., II; Evans, J.; Rochelle, J.A. 1979. Animal damage to coniferous plantations in Oregon and Washington. Part 1: a survey, 1963-1973. Res. Bull. 25. Corvallis, OR: Forest Research Laboratory. Oregon State University, School of Forestry. 45 p.

Borrecco, J.E. 1972. The response of animals to herbicide-induced habitat change. Corvallis, OR: Oregon State University. 92 p. M.S. thesis.

Boyd, R.J. 1987. Vegetative management and animal damage. In: Baumgartner, D. M.; Mahoney, R.L.; Evans, J. [and others], eds. Animal damage management in Pacific Northwest forests; 1987 March 25-27; Spokane, WA. Pullman, WA: Cooperative Extension, Washington State University: 55-58.

Brown, E.R.; Mandery, J.H. 1962. Planting and fertilization as a possible means of controlling distribution of big game animals. Journal of Forestry. 60: 33-35.

Campbell, D.L.; Evans, J. 1978. Establishing native forbs to reduce black-tailed deer browsing damage to Douglas-fir. In: Howard, Walter E., ed. Proceedings, 8th vertebrate pest conference; 1978 March7-9; Sacramento, CA. Davis, CA: University of California: 145-151.

Campbell, D.L.; Johnson, L.E. 1981. Guide for collecting and seeding native forbs for wildlife in Douglas-fir clearcuts. Wildlife Leaflet 513. Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service. 13 p.

→ **Crouch, G.L. 1980.** Post-season hunting to reduce deer damage to Douglas-fir in western Oregon. Res. Note PNW-349. Portland, OR: U.S. Department of Agriculture, Pacific Northwest Forest and Range Experiment Station. 6 p.

Franklin, J. 1989. Toward a new forestry. American Forests. 95(11-12): 37-44.

Gourley, M.; Vomocil, M.; Newton, M. 1987. Mitigating deer browse damage—protection or competition control? In: Baumgartner, D.M.; Mahoney, R.L.; Evans, J. [and others], eds. Animal damage management in Pacific Northwest forests; 1987 March 25-27; Spokane, WA. Pullman, WA: Cooperative Extension, Washington State University: 113.

Hanley, T. 1983. Black-tailed deer, elk, and forest edge in a western Cascades watershed. Journal of Wildlife Management. 47: 237-242.

Harper, J.A.; Swanson, D.O. 1970. The use of logged timberland by Roosevelt elk in southwestern Oregon. In: Proceedings of the 50th annual conference of Western Association of State Game and Fish Commissioners; 1970 July 13-16; Victoria, BC. [Place of publication unknown]: [Publisher unknown]: 318-341.

Hesselton, W.T.; Hesselton, R.A.; Monson 1982. White-tailed deer *(Odocoileus virginianus).* In: Chapman, J.A.; Feldhamer, G.A., eds. Wildlife mammals of North America: biology, management, and economics. Baltimore, MD: Johns Hopkins University Press: 878-901.

→ **Hines, W.W. 1973.** Black-tailed deer populations and Douglas-fir reforestation in the Tillamook Burn, Oregon. Game Rep. 3. Corvallis, OR: Oregon Department of Fish and Wildlife, Research Division. 59 p.

Long, J.M. 1976. Forest vegetation dynamics within the *Abies amabilis* zone of a western Cascades watershed. Seattle, WA: University of Washington. 175 p. Ph.D. dissertation.

Mackie, R.J.; Hamlin, K.L.; Pac, D.F. 1982. Mule deer *(Odocoileus hemionus).* In: Chapman, J.A.; Feldhamer, G.A., eds. Wild mammals of North America: biology, management, and economics. Baltimore, MD: Johns Hopkins University Press: 862-877.

Mereszczak, I.M.; Krueger, W.C.; Vavra, M. 1981. Effects of range improvement on Roosevelt elk winter nutrition. Journal of Range Management. 34: 184-187.

Merrill, E.H.; Taber, R.D.; Raedeke, K.J. 1983. Elk populations in the northwest section of the Mt. St. Helens blast zone. Prog. Rep. (mimeo). Centralia, WA: Weyerhaeuser Company, Western Forestry Research Center. 49 p. [+ figures and appendices].

Rochelle, J.A. 1979. Effects of forest fertilization on wildlife. In: Gessel, S.P.; Kenady, R.M.; Atkinson, W.A., eds. Proceedings, forest fertilization conference; 1979 September 25-27; Seattle, WA. Inst. For. Resour. Contrib. 40. Seattle, WA: University of Washington, College of Forest Resources: 163-168.

Rochelle, J.A. 1980. Mature forests, litterfall and patterns of forage quality as factors in the nutrition of black-tailed deer on northern Vancouver Island. Vancouver, BC: University of British Columbia. 295 p. Ph.D. Dissertation.

Smith, S.P. 1980. Forage seedling for elk management. Corvallis, OR: U.S. Department of Agriculture, Forest Service, Siuslaw National Forest. 3 p.

State of Oregon. 1980. The Oregon interagency guide for conservation and forage plantings. Portland, OR: State of Oregon, Oregon State University and Oregon Department of Fish and Game; U.S. Department of Agriculture, Forest Service and Soil Conservation Service; U.S. Department of the Interior, Bonneville Power Administration and Bureau of Land Management. 84 p.

Washington State Rangeland Committee. 1983. The interagency guide for conservation and forage plantings. Misc. Publ. 0058. Pullman, WA: Washington State University, Cooperative Extension. 70 p.

Willms, W.D. 1971. The influence of forest edge, elevation, aspect, site index, and roads on deer use of logged and mature forest, northern Vancouver Island, BC. Vancouver, BC: University of British Columbia. 184 p. M.S. thesis.

Witmer, G.W. 1981. Roosevelt elk habitat use in the Oregon Coast Range. Corvallis, OR: Oregon State University. 104 p. Ph.D. dissertation.

Witmer, G.W.; Wisdom, M.; Harshman, E.P. [and others]. 1985. Deer and elk. In: Brown, E.R., ed. Management of wildlife and fish habitats in forests of western Oregon and Washington. Part 1: chapter narratives. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region: 231-258. Chapter 11.

Chapter Seven

Application Equipment and Calibration

Chal Landgren

Appendix 5

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Application Equipment and Calibration

Chal Landgren

Within the forest environment, pesticide users encounter a variety of application and equipment options. These range from helicopters through the treatment of individual stumps with hand held applicators. Each type of application equipment or technique has unique considerations for application and calibration. These will be the focus of this chapter. Applications discussed include helicopter and fixed-wing aircraft, ground based foliar and soil, basal bark, hack-n-squirt, thinline and cut stump. Use this summary in conjunction with PNW320 Calibrating and Using a Backpack Sprayer, which provides more detail.

Helicopters

Helicopters apply the majority of the forest herbicide volume used in the Pacific Northwest. Given this high use rate, it is important for managers and landowners to understand helicopter application.

In most cases, managers are users of services and will depend on the pilot-applicator to have detailed understanding of the calibration and functioning of the equipment. Land managers are not expected to be experts in the operation of aircraft. Managers should understand key considerations for planning the project, identify what needs to be communicated to the pilot, and understand the limitations of equipment.

Helicopters are versatile. Their ability to operate in steep terrain and spray close to the canopy makes them ideally suited for many applications.

This versatility does have limits. On small areas, the expense of moving a helicopter in and out may prove high on a per acre basis, unless it is shared by nearby landowners.

Some difficulties also arise on steep terrain in achieving uniform distribution. Along steep contours, the upslope side of the flight pattern becomes more concentrated than the downhill side. When pilots fly helicopters uphill, their "rotor wash" creates a somewhat narrower spray swath pattern than found on flatter ground. The reverse is true when pilots fly downhill.

Pilot skill and knowledge is critical when operating in the forest environment. Most helicopters carry payloads between 50 and 100 gallons of mix, fly in the range of 45 to 55 mph, and apply 10 to 15 gallons of mix per acre. The combinations of nozzle types, boom configurations and spray mix options demand close communication between the landowner and spray applicator.

Some key items that the landowner and manager must keep in mind when using helicopter services follow:

• How many acres are included in the spray units? What is the distance between units? How is access? How much ferrying distance is involved? Payment, pesticide purchase, and feasibility of using the helicopter will depend on these determinations.

• How can the boundaries of the spray unit be clearly communicated to the pilot? Use current aerial photographs, large colored markers, local landmarks, and pre-fly the units to outline the limits of spray application.

• Have you explained buffer strip needs and areas of concern clearly to the pilot? You must mark or point out stream buffers, local water supply sources, and boundary buffers to the applicator before spraying begins.

• Have you allowed sufficient lead time to accomplish the project? Spraying often occurs within a narrow window of time. Leave adequate lead time to obtain the necessary permits, to communicate with nearby landowners, to locate water sources for tanker refill, to identify landing sites, and to accomplish many of the details critical to a good job.

• How critical is uniform spray distribution? If uniform distribution is essential, you may consider having the helicopter "double spray" the area, using half the pesticide on each application.

Fixed-Wing Aircraft

Fixed wing aircraft are used on occasion, but the need for large landing strips and problems of quick maneuvering in steep terrain limit usage to flatter areas near local airports or to insecticide applications over large areas.

Ground Based Foliar and Soil Applications

How it's done

The operator typically is spraying vegetation at chest height or above. Drift onto other workers or back onto the applicator can be a concern. Monitor wind direction, location of nearby workers, and nontarget vegetation.

Application equipment

Treatments may be made by backpack sprayer, tractor mounted sprayer, all terrain vehicle (ATV), hose pulling from tank sprayer, or any of a variety of methods and equipment.

Nozzles and calibration

Often, a percent dilution in water is the method of calibration when using foliar herbicides. Percent dilutions will change depending on situations. For example, some recommendations suggest a "spray to wet" application. This requires spraying a fairly large volume of water on a per clump or per acre basis. Other applications require spraying only a very light "misting." Both may provide good coverage, but the volume of water applied varies significantly. As always, the amount of active ingredient applied must be within labeled recommendations.

In situations where the target vegetation is more uniform, calibration may be based on a per acre recommendation. Extension publication PNW320, *Calibrating and Using a Backpack Sprayer* illustrates detailed examples of calibration using a per acre recommendation or a percent dilution.

Grass control

When using any herbicides, consider how your application technique affects distribution of the spray mixture. For example, let's assume you are controlling grasses with a soil applied herbicide among small trees. In this situation, some applicators apply the herbicide in a circle pattern around each tree using flat fan or flooding type tips. This technique concentrates herbicide in the inner portion of the circle (nearest the tree). In the inner area of the circle, the spray wand moves more slowly. At slower speeds, herbicide concentration increases, and tree damage could result. An application technique having a more uniform spray distribution, such as a strip or rectangular pattern, would work better, keeping the tree in the center of the spray pattern.

Basal Bark Applications

How it's done

Apply the herbicide mix to the base of the target tree or brush. Usually, coverage is required all around the stem from the ground to a height of 12" to 15." Where moss, leaves or other stems obscure the bark, remove these obstacles. This is especially important with thicker bark and hard-to-kill species.

In some situations, diesel oil or oil substitutes will serve as the carrier for the herbicide. Particularly with diaphragm type sprayers, check that the diaphragm material is designed for use with diesel. If it is not, obtain the proper diaphragm.

Application equipment

In forest situations, the backpack sprayer is the equipment of choice. This includes the ready-to-use, closed system sprayers.

Nozzles

Hollow cone herbicide type nozzles or adjustable cone spray tips that operate with low volume output at 20 to 40 psi are commonly used.

Calibration

Most of the bark applications use a percent dilution in a carrier. For example, a 5% Garlon-4 ®(triclopyr) mix in diesel would contain 6.4 ounces (.05 multipied by 128 ounces per gallon) of Garlon-4® in each gallon of diesel.

The spray volume applied will vary. Some treatments call for a "low volume basal" application. This method applies spray as if in a light painting; just enough to know application has occurred. The "high volume basal" applications continue until the spray begins to thoroughly wet and run down the bark.

The "low volume" method uses a higher concentration of active ingredients and may entail somewhat lower labor costs by reducing the time involved in refilling. The high volume method may provide better coverage.

Hack-and-Squirt Applications

How it's done

The idea in this type of application is to deliver chemical just beneath the bark and into the tree sapwood. As the bark is opened the chemical comes in contact with the sapwood, where it moves throughout the tree. The spacing of the cuts and the amount of chemical needed in each cut will vary depending on the species being controlled, time of year, and the type and concentration of herbicide used. Apply the chemical immediately after the cut is made.

Application equipment

A variety of devices are available to accommodate this technique. At one end of the spectrum, a hand axe can be used to open the bark; then chemical is placed into each hack mark. Injection cylinders both make the cut and contain herbicide for injection into each cut. Hypo-Hatchets also are available that deliver a measured dose with each hatchet slice. A new device called the EZject® presses cartridge shells filled with herbicide in contact with the wood.

Calibration

The herbicide often is applied in concentrated form, sometimes undiluted. As little as 1 ml of herbicide per cut is used. Use extra caution in dealing with concentrated herbicides.

Some application tools have pre-set measuring options to deliver a metered dose as the cut is made. Check these to be sure tools are working properly and operators know about equipment maintenance and use.

If the herbicide application is a separate task, various measuring and application devices have been used. These must measure accurately down to 0.5 or 1 ml. Some applicators have tried syringes used in administering livestock injections, as well as spray bottles. The applicator must precalibrate the amount of spray delivered with each trigger pull. And, each trigger pull must be consistent. The spray device also must be durable, as it is subject to frequent abuse in forest situations.

Thinline and Streamline Applications

How it's done

Apply a fine stream of concentrated herbicide to the bark of target vegetation. Place the herbicide close to the base of the tree or brush above obstructing leaves or moss that might block the stem. On brush with larger (greater than thumb width) stems, or on trees with particularly thick bark, be careful to apply the stream of chemical completely around each stem. Often the applicator must hit the stem from two to three spots to surround each brush clump or stem.

Application equipment

Use of backpack sprayers or smaller spray bottles that produce a consistent thin stream of spray is common. Special "ultra low volume" wands and trigger sprayers like Pow-a-Spray® devices are useful in delivering a fine metered stream spray with minimum waste or wand drip.

Nozzles

Applicators often use a very small orifice plate. In these applications the swirl plate is absent. Adjustable cone tips with small orifices are also used. Check valves behind the tips help to minimize the amount of material that may drip from the wand after the applicator closes the trigger grip.

Calibration

Large clumps of brush or trees may receive from 30 to 60 ml (1 to 2 ounces) or more, per clump. Amounts vary depending on a host of factors, including the type of vegetation, season of application, and bark thickness. The calibration process must determine how to accurately apply small amounts of herbicide in a brief time period.

Typical calibration times spray delivery into a graduated cylinder or other measuring device. For example, let's assume that in using a Uni-jet 0 degree® straight stream nozzle tip, it takes 30 seconds at 20 psi to apply 50 ml of spray. In the field, we want to apply 50 ml of spray all around the stem. We then should take 30 seconds (the amount of time needed to apply 50 ml) to move around each stem or clump while spraying.

The thinline and streamline methods differ in the width of the application band and in the number of sides treated. The thinline treatment is typically a narrow band (up to 2" in width), applied from multiple sides. The streamline treatment may be a 3" to 4" band sprayed from only one side of the tree or brush. Some users do not make these distinctions and consider stream and thinline type treatments as the same. Ask precisely what is meant when these or other techniques are described. This is particularly important as it relates to the amount of herbicide to apply, i.e., how wide is the band, how many sides are treated, or how concentrated is the herbicide.

Since the spray often is applied undiluted, use small amounts of material and aim the spray carefully. This is critical for two reasons. First, an overdose of the herbicide concentrate could damage nontarget species. Second, herbicide is too expensive to waste.

Cut Stump Treatment

How it's done

Shortly after the brush or tree is cut (within 30 minutes) apply herbicide in a ring around the outer portion of the stump. To minimize sprouting, keep stump height as close to the ground as feasible.

Amine or water soluble herbicide formulations commonly are used in this treatment.

Calibration

Apply herbicide in a concentrated form. Squirt or squeeze bottles containing the material are common application devices. On large stems only the outer 3 inches of the sapwood require treatment.

Chal Landgren is an Extension Forester with the Oregon State University Extension Service, stationed in St. Helens, Oregon.

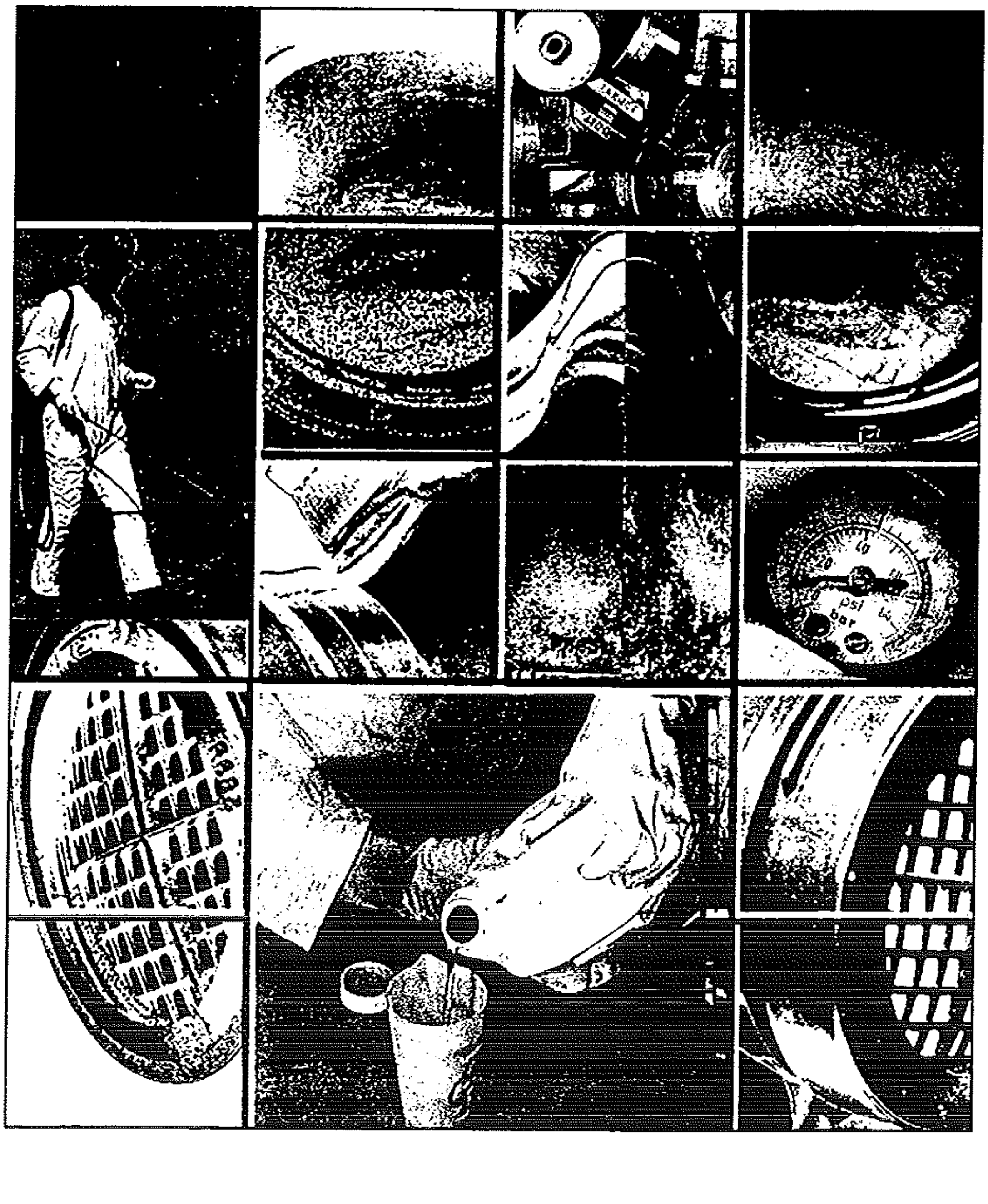
Appendix 5

Forest Environment Pesticide Study Manual

Calibrating and Using Backpack Sprayers, PNW320, by C.G. Landgren. Revised 1996. Reprinted courtesy of Pacific Northwest Extension Publications.

PNW 320
Revised April 1996

CALIBRATING AND USING
BACKPACK SPRAYERS



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Ordering information

If you would like additional copies of PNW 320, *Calibrating and Using Backpack Sprayers*, send $1.50 per copy to:

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Corvallis, OR 97331-2119

Contents

Use pesticides safely!

- Wear protective clothing and safety devices as recommended on the label. **Bathe** or shower after each use.
- Read the pesticide label—even if you've used the pesticide before. **Follow closely** the instructions on the label (and any other directions you have).
- **Be cautious** when you apply pesticides. **Know** your legal responsibility as a pesticide applicator. You may be liable for injury or damage resulting from pesticide misuse.

Calibrating and Using Backpack Sprayers

C.G. Landgren

Backpack sprayers are extremely versatile tools. Unfortunately, many users fail to calibrate their sprayer, and know little about available accessories. The consequences of improper sprayer use can be severe—dead crops, wasted money, or poor pest control.

But be warned: To successfully calibrate and use your sprayer, you'll need to work through some examples, take some time, and. . . practice. It isn't complicated, but it will demand effort on your part.

This publication will help you understand how to use and calibrate a backpack sprayer. It has four parts: (1) What is a backpack sprayer? What are appropriate uses? (2) Sprayer characteristics and accessories, (3) Nozzle components, and (4) Calibration and operation.

This publication also can be used in combination with a video (VTP-017) of the same title. Viewing the action often helps make the calculations more understandable. (See *For more information*, page 19.)

What is a backpack sprayer? What are appropriate uses?

A backpack (or knapsack) sprayer consists of a tank, a pump, and a spray wand with one or more nozzles (Figure 1). The small size, transportability, and ease of use make the sprayer a versatile tool.

You can spray many acres with a backpack sprayer; however, the effort of carrying the spray mix and walking over each area you spray takes its toll on your strength and enthusiasm.

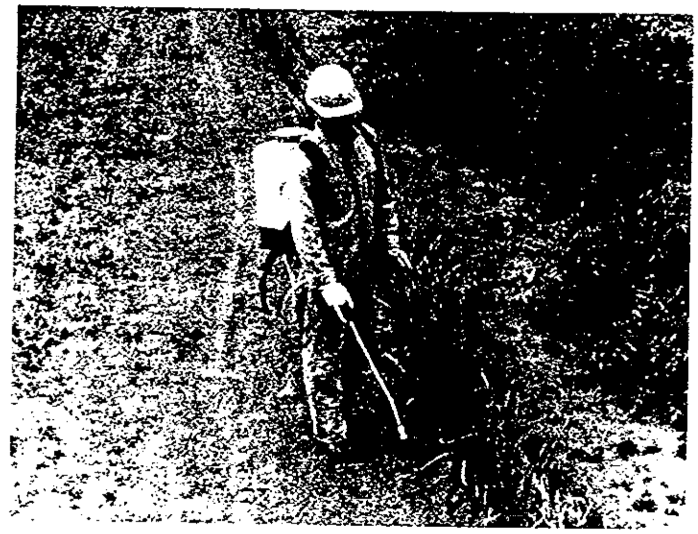

Figure 1.—Backpack sprayer application.

To provide some perspective, many backpack applicators consider 4 to 5 acres of broadcast spraying (the entire area sprayed) as a full day's effort. A helicopter, in contrast, may spray the same area in a matter of seconds. Appropriate tasks for backpack sprayers then tend to be:

1. Small acreages and spot spraying
2. Hard-to-reach locations
3. Spraying jobs where larger sprayer units (tractors, helicopters, etc.) are unavailable

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Chal G. Landgren, Extension agent, Columbia County, Oregon State University. This publication, prepared in cooperation with Extension specialists at the University of Idaho and Washington State University, replaces OSU publication EC 962.

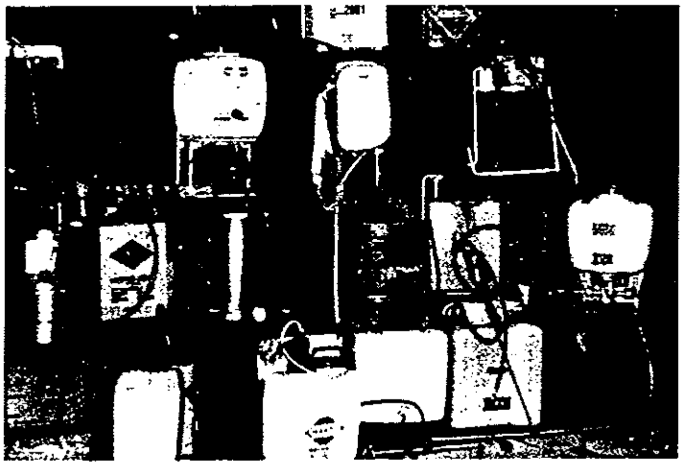


Figure 2.—A wide variety of sprayer types is available.

Sprayer characteristics and accessories

You'll find a wide array of sprayers and accessories on the market (Figure 2). The next five sections outline some key differences among the sprayers commonly sold: types of pumps, pressure regulation, availability of nozzles and booms, sprayer tank volume, and other features.

Types of pumps

Both piston and diaphragm pumps are available. The piston type generally is capable of developing higher pressures, around 90 psi (compared to around 40 psi for common diaphragm types). The piston rings on these pumps wear and lose pressure after extensive use, particularly with abrasive wettable powder herbicides.

Diaphragm pumps are simpler mechanically, which may mean less maintenance. If you use one, be sure the diaphragm material is resistant to the chemical or solvent you plan to use. Diesel oil, for example, may degrade some diaphragms.

Pressure regulation

Proper calibration demands a constant uniform pressure. Some sprayers have built-in valves to regulate pressure. Others have pressure gauges on the handle. Either type is acceptable as long as you maintain uniform pressure.

Availability of nozzles and booms

Before you buy, be sure the sprayer can accept different spray tips, booms, shielded spray wands, and other accessories. The greater the number of attachments you can use, the more versatile your sprayer.

Spray booms, for example, increase the area you spray during each pass through the field. This saves you time and effort and can improve coverage uniformity. Booms are available in many configurations. They may be oriented vertically for spraying along the height of trees or horizontally for field spraying.

Sprayer tank volume

Sprayer capacities range from 2 to 5.5 gallons. You can decide how much weight you want to carry (water weighs 8.3 pounds/gallon). The tank should have an easy-to-read volume gauge printed or embossed along the side.

Other features

There are a number of additional features that are important in selecting a sprayer. Here are some:

1. The pumping lever should be in a comfortable position. Consider, too, a sprayer with a reversible lever (one that you can use left- or right-handed).
2. The wand and hand grip should be comfortable and easy to remove and clean.
3. The sprayer should balance comfortably and solidly on your back. The straps should be comfortable when you're carrying a 25- to 70-pound weight. The sprayer should be stable when it sits on the ground.

4. Hoses should be durable and reinforced, with secure attachment to the tank.
5. In-line screens are available in some models (usually in the handle). These help to reduce clogging at the nozzle.
6. The filling hole should be large, with a tight-fitting lid—to prevent spray liquid from spilling on you when you bend or walk.

Nozzle components

Typically, a nozzle is composed of four items—spray tip, screen (strainer), cap, and nozzle body (Figure 3).

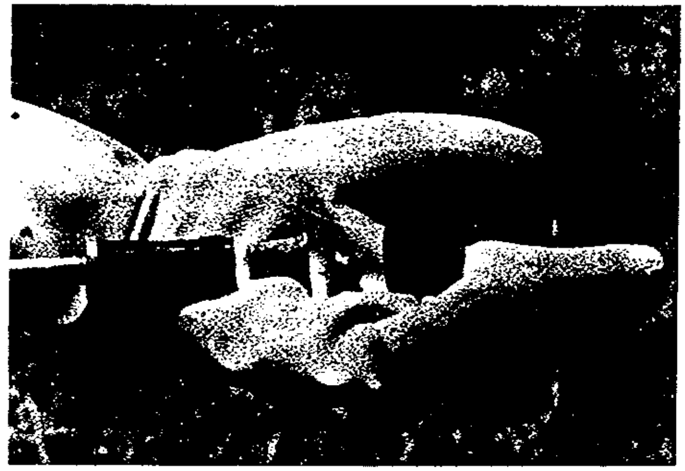


Figure 3.—Typical nozzle assembly.

Spray tip

The spray tip is the most important nozzle accessory for your sprayer. It breaks the liquid into droplets of the correct size, forms the spray pattern, and directs the droplets. Unfortunately, most users pay little attention to the spray tip and know little about alternative tips.

Nozzle tips are designed for various uses, crops, and spray pressures. Table 1 shows some of those most useful for backpack sprayers.

Tips are made from a variety of materials. Table 2 compares the durability of various spray-tip materials. Tips made of harder materials may cost more initially, but their longer wear life often results in lower long-run costs.

For example, tests indicate that with bronze tips, the flow rate increased by 8 percent after 50 hours of use with a 2,4-D herbicide in water. More abrasive formulations, like wettable powders, will cause even more rapid wear. As a general rule, if tip output varies by 10 percent above or below rated capacity, replace it.

Screens (strainers)

Screens are needed in advance of the spray tips to reduce clogging. The smaller the tip opening, the finer the screen mesh needed to protect the tip. Nozzle tips such as an XR8001 (Spraying Systems) require a 100-mesh screen, but larger nozzle openings such as an XR8004 need only 50-mesh. The manufacturer will recommend the screen mesh size you need.

Screens are available that also function as check valves. These prevent nozzle dripping when the line pressure drops below a certain level (you select the level, from 5 to 40 psi). These do cause a pressure drop of 5 to 10 psi at the nozzle, and they require careful cleaning and storage for proper functioning.

Calibration and operation

Important variables

The amount of spray you apply to an area will depend on four variables: your walking speed, the pressure you select, your spray swath width, and the nozzle tip you've chosen. *If you change any one of these, you change the amount of spray you apply.*

This is why, with broadcast spraying, it's impossible to say, "Always add 2 ounces of the pesticide per gallon of water." You could be spraying 10 times too much or 10 times too little, depending on your

Table 1.—**Common backpack sprayer nozzle tips, uses, and examples.**

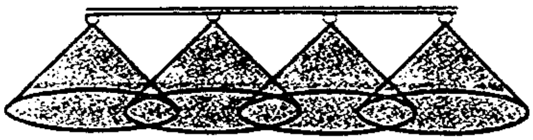
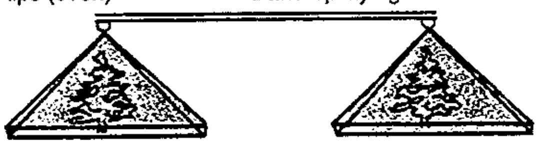
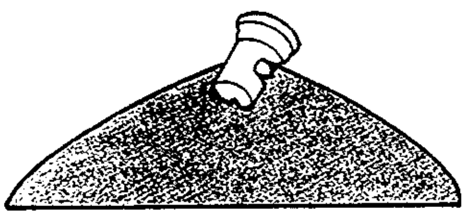
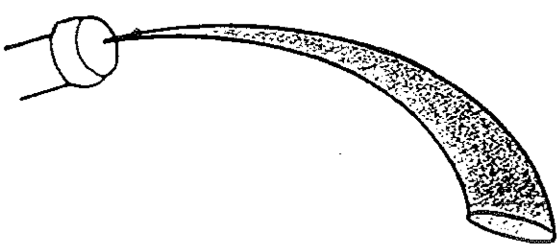
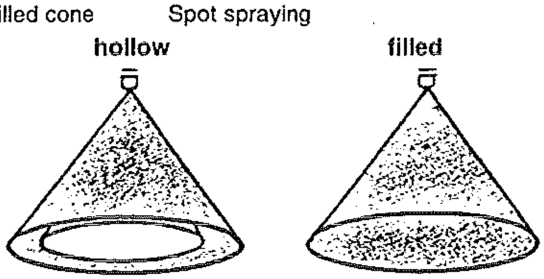
Tip	Use	Remarks and examples
Flat tips (overlap)	Boom spraying with multiple nozzles 	These tapered tips are designed for at least 30 percent overlap of each nozzle in the spray pattern. *Manufacturers* include Delevan, Hardi, and Spraying Systems. Tips are designated (usually on the tip itself) by spray angle and gallon per minute (gpm) output at a specified pressure. *Example:* Spraying Systems Co. tip XR8002. This code has three parts: • The first two letters "XR" denote an "Extend Range" tip. These maintain spray distribution over a range of pressures (15–60 psi). • The first two numbers indicate the spray angle (80 = 80°). Tips are available from 25° to 150°. • The second two numbers indicate gpm output (02 = 0.2 gpm, at 40 psi). Tips are available from 0.06 to 2 gpm outputs.
Flat tips (even)	Band spraying 	Tips deliver an even spray, edge to edge. *Manufacturers:* same as for overlap flat tips. *Example:* Delevan tip 95-3E. This code has three parts: • The first two numbers indicate the spray angle (95 = 95°). • The second number indicates gpm output (-3 = 0.3 gpm, at 40 psi). • The final letter(s) indicate a special feature (E = even output, edge to edge).
Flooding or impact	Broadcast spraying 	Flooding tips are useful in situations where a wide spray swath is needed and a boom can't be used. Spray droplets often are larger than those with flat tips, and some spray uniformity may be sacrificed. *Manufacturers:* Delevan, Hardi, Imperial Chemical Co. (ICI), Spraying Systems. *Examples:* ICI makes a series of 4-color-coded nylon tips. Depending on the tip used, they provide swath widths from 2 to 7 feet when held 20 inches above the ground.
Adjustable cone	Spot spraying, bark applications 	Adjustable cone tips can be set to spray a straight stream or coarse cone. These are especially useful in spot-spraying clumps of brush up to 20 feet away. They also have uses in straight stream or basal drench bark applications.
Hollow and filled cone	Spot spraying 	These tips operate in the 15- to 300-psi range. There is a wide variety of tips and uses in this category.

Table 2.—**Wear comparison of common spray tips.**

Material	Life compared to brass
Plastic or nylon	0.7 to 1 time
Stainless steel	4 to 6 times
Hardened stainless	8 to 15 times
Ceramic	70 to 120 times
Tungsten carbide	150 to 200 times

situation. You simply *must* calibrate your sprayer before adding pesticide.

Before going through step-by-step examples of calibration for broadcast, band, and spot spraying, let's discuss how walking speed, pressure, nozzles, and swath width interact.

Walking speed. If you double your walking speed while maintaining pressure and swath width, you'll apply half as much spray. For example, if your walking speed is 1 mph and you spray 20 gallons per acre, at 2 mph you'd apply only 10 gallons per acre. At 2 mph, then, you'd require more pesticide per gallon (that is, a greater concentration) to apply the same amount of pesticide per acre.

Pressure. If you change the pressure while you spray, you change output. Suppose you changed pressure from 15 to 30 psi at 4 mph, with an 8002LP nozzle; this would change your output from 15 to 21 gallons per acre.

Nozzle tip selection. The proper tip will depend on the situation (see Table 1). Tips are available that cover a wide range of output volumes, spray widths, and pressures.

Most backpack sprayers come with a single flat fan nozzle. Attempting to use this one nozzle tip in, for example, a 4-acre broadcast application, wastes operator time and usually results in poor application uniformity. Check with nozzle tip suppliers about booms, flooding tips, or other options.

Swath width/nozzle height. Tips are designed for use within certain heights and pressures. Within these ranges, some tips deliver narrow bands; others, like flooding tips, provide swath widths up to 7 feet. The wider each swath width, the less time the operator spends walking up and down fields.

The height at which you hold the spray tip above the target influences the swath width. Suggested spray heights vary by tip type. Flat tips commonly have suggested heights in the 17- to 28-inch range. Flooding tips do not have suggested heights. Spraying as close to the target as is practical minimizes drift and operator contact.

The spray height you select needs to be maintained during calibration and field application—otherwise your output per acre changes. Some operators have tried using height stakes or weighted drop strings to maintain a constant height. These aids may be useful reminders while practicing.

Calibrating for broadcast spraying

Broadcast spraying requires a uniform application over the entire area you plan to spray. To accomplish uniform application, you must establish some standard application practices regarding pressure, walking speed, nozzle-tip selection, and height.

Uniform pressure. Nozzle pressure on backpack sprayers is maintained by hand pumping. Try for a constant pressure that is easily maintained while walking/pumping. With broadcast spraying, tips designed to operate in the 15–40 psi pressure range often will be the tip of choice for this application (i.e., low pressure, extended range, and FloodJet® tips).

Constant walking speed. In broadcast spraying, walking speed must be constant, regardless of slope or terrain conditions. This constant walking speed should be one that you can comfortably maintain over the entire time you intend to spray. It also must be the same speed at which you calibrate the sprayer.

Table 3.—**Converting the time (seconds) needed to walk 100 feet to miles per hour (mph).**

Sec/100 ft	Mph
68	1.0
45	1.5
34	2.0
27	2.5
23	3.0
19	3.5
17	4.0
15	4.5
14	5.0

$$\text{Mph} = \frac{\text{distance (ft)} \times 60}{\text{time (sec)} \times 88}$$

Be aware, too, that most people tend to slow down when they spray, to make sure they apply enough herbicide. *This is wrong!* You must apply herbicides at the correct rate, or you may injure your crop.

There are various methods of achieving a consistent walking speed—for example:

- Counting paces to a steady tempo
- Using a stopwatch along a measured distance, such as a plantation row
- Developing a cadence between steps and pumping strokes

One common aid in achieving consistency is to periodically retime your walking speed over a 100-foot distance. Table 3 converts the time it takes to walk 100 feet into miles per hour (mph). Knowing your walking speed also will be helpful when you select a nozzle tip.

***Selecting a nozzle tip*.** The nozzle tip you select depends on your spraying need and the amount of pesticide and carrier you choose to apply per acre. In general, applying 10 to 20 gallons/acre of carrier and pesticide is adequate, but check the pesticide label to be sure.

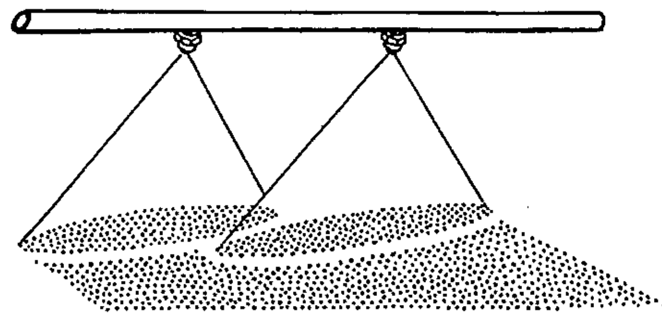


Figure 4.—Check your coverage before spraying. (Nozzle pattern should overlap when you use flat fan tips—if not, correct before proceeding.).

Also keep in mind that it's generally better to change nozzle(s) to alter spray volume than to change walking speed or pressure.

Let's assume you need to find a tip that will provide around 10 gallons/acre at 2.5 mph walking speed and 15 psi. There are two ways to do this—use a formula or use a spray catalog. Appendix A gives examples of both methods.

Using either method, you will find that nozzle output should be around 0.15 gallon/minute. Most tips are coded to indicate output/minute at various pressures. For example, a Spraying Systems 80015LP tip with a 50-mesh filter screen will give 0.15 gallon/minute at 15 psi and would be an appropriate tip for your needs.

***Steps in calibration*.** There are different ways to calibrate sprayers. This method is one that may be easier with backpack sprayers. You'll need a tape measure, and you may find a calculator convenient:

1. Select the spray tip or boom that provides the desired output (see Appendix A).
2. Add water, and spray the ground or dry pavement as if you were spraying your field. Now check the spray pattern for uniformity (and proper spray pattern overlap if you're using a boom). Adjust nozzle spacing and/or height until you achieve the desired pattern. Be certain you're getting uniform coverage before you proceed! (Figure 4.) Check fittings and hoses for leaks.

Try to calibrate in the same field or under the same conditions as where the spray application will occur.

3. If all is well, add exactly 2 gallons of water to the tank. (Note: You can use any amount of water, but remember to substitute your figure whenever you see "2 gallons" in the example that follows Step 9.)
4. Mark your starting spot.
5. Spray the water as if you were actually spraying your field. Remember, you must maintain:
   - Constant pressure
   - Constant walking speed
   - Consistent height of the nozzle or boom over your spray target
6. When the water is gone, stop and mark the spot.
7. Measure the area you sprayed and calculate square feet (length of swath x width).
8. Calculate how much of an acre you covered:

$$\frac{\text{number of ft}^2\text{ you sprayed}}{43{,}560\text{ ft}^2\text{/acre}} = \text{acres sprayed}$$

9. Calculate how many gallons/acre you sprayed:

$$\frac{\text{2 gal sprayed}}{\text{acres sprayed}} = \text{gal/acre}$$

Example. Let's say you sprayed two rows of Christmas trees with 2 gallons. Rows were 5 feet apart, and each row was 580 feet long. The area sprayed was:

$$2\text{ rows x }5\text{ ft/row x }580\text{ ft} = 5{,}800\text{ ft}^2$$

Now, calculate gallons/acre, in two steps:

First, to find the acres you sprayed with 2 gallons, divide the square feet you sprayed by the number of square feet in an acre:

$$\frac{5{,}800\text{ ft}^2\text{ sprayed}}{43{,}560\text{ ft}^2\text{/acre}} = 0.13\text{ acre}$$

Next, divide 2 gallons by 0.13 acre, to find your gallons/acre rate:

$$\frac{2\text{ gal}}{0.13\text{ acre}} = 15\text{ gal/acre}$$

With the above walking speed, nozzle(s), pressure, and swath width, you sprayed 15 gallons/acre. That's a very important number. You'll need it to determine the amount of pesticide to add per gallon. You also can see that if you fill the sprayer with 5 gallons each time, it will require 3 tankfuls of pesticide and carrier (often water) to cover 1 acre completely.

A quick check. There is a way to quickly check your calibration results. It is based on the amount of time it takes to spray a 340 square foot area. It works because 340 square feet is 1⁄128 of an acre (remember, there are 128 ounces in a gallon, so ounces collected convert directly to gallons per acre). The steps are as follows:

1. Measure out a 340 square foot area to spray (e.g., 5 ft x 68 ft). It's best to make this a convenient width for your nozzle/height configuration and to flag the beginning and ending points.
2. Spray the 340 square foot area, and time yourself. Do this several times, until you have consistent results.
3. Next, insert the spray tip into a measuring device graduated into ounces. Spray into the measuring device for the same time required to spray the 340 square feet (Step 2). Remember to match the pressure used in Step 2.
4. Now, read the number of ounces you sprayed into the measuring device. The number of ounces you collect converts to gallons per acre of output. For example, let's say it took you 45 seconds to spray the 340 square foot area. You then collected the spray from the nozzle for 45 seconds in the measuring device. In that time,

you collected 10 ounces of water. Since you sprayed 1⁄128 of an acre, the ounces you collected represent a 10-gallon-per-acre output.

Remember—pressure, walking speed, nozzle tips and swath width must remain unaltered during the actual spraying.

How much pesticide to add?

Pesticides are sold as liquids, emulsifiable concentrates, wettable powders, flowables, and other forms, to be mixed with water or other carriers. Each product label contains use instructions, safety precautions, use restrictions, application rates, and conditions for application.

Application rates are listed on the package, most commonly in pounds per acre or amount of liquid per acre. Given a choice, it usually is easier to apply liquid than dry formulations.

Conversion table. You may find these conversion values handy when mixing pesticides.

Table 4.—**Conversion values for measuring pesticides.**

Liquid (volume)	Oz	Dry (weight)	Oz
teaspoon	0.17	gram	0.035
tablespoon	0.5	pound	16
cup	8	kilogram	35
pint	16		
quart	32		
liter	34		
gallon	128		

Liquid pesticides. Let's assume you need to apply 1 quart (32 oz) of the herbicide Roundup® (48 percent ai glyphosate) per acre.

You calculated previously that you'll apply 15 gallons of spray solution (pesticide plus water) per acre. To determine how much herbicide to add per gallon of spray, divide the 32 ounces of product by your 15 gallon/acre output:

$$\frac{32 \text{ oz Roundup}^{®}\text{/acre}}{15 \text{ gal/acre}} = 2.13 \text{ oz Roundup}^{®}\text{/gal}$$

Table 5.—**Required ounces of product per gallon of spray mix by output/acre and target product amount.**

Sprayer output (gal/acre)	Target amount of product/acre					
	1 pt (16 oz)	1 qt (32 oz)	1.5 qt (48 oz)	2 qt (64 oz)	3 qt (96 oz)	1 gal (128 oz)
7	2.3	4.6	6.9	9.1	13.7	18.3
10	1.6	3.2	4.8	6.4	9.6	12.8
12	1.3	2.7	4.0	5.3	8.0	10.7
15	1.1	2.1	3.2	4.3	6.4	8.5
17	0.9	1.9	2.8	3.8	5.6	7.5
20	0.8	1.6	2.4	3.2	4.8	6.4
25	0.6	1.3	1.9	2.6	3.8	5.1

Each gallon of solution in the sprayer must include 2.13 ounces of this particular Roundup® formulation. If you are filling the sprayer to 5 gallons, you add 10.7 ounces of Roundup® (5 x 2.13) per 5-gallon sprayer.

Table 5 shows another method of determining the amount of liquid product to add per gallon. The two items you need to know are, again, sprayer output and the amount of liquid product to apply per acre. In this case, locate the number that matches up with the column indicating 1 quart of product and the row showing 15 gallons of sprayer output. If you do this, you'll find the 2.1 ounces/gallon calculated above.

Spraying trees. At times, backpack sprayers are used to spray trees or shrubs for insect or disease problems.

Pesticide recommendations commonly are given in two ways. One is an amount of product to apply per acre. Another is an amount of product per 100 gallons of carrier, with the assumption that the 100 gallons covers an acre.

The difficulty in calibration is that your target is now vertical (trees and shrubs), rather than horizontal (the ground). The recommendations for the amount of product to apply are based on a horizontal acre and assume the trees or target crop is average size and age and the entire area is sprayed, not just a tree here and there.

Since the recommendation is based on an amount applied per acre, calibration is similar to past examples, except that now you are spraying the tree rather than the ground. Here's an example.

Situation. Your Christmas trees have aphids, and you need to apply 1.5 pints of an insecticide per acre. These aphids occur on the new growth so you need to cover the new growth with spray mix. You have 1,200 trees/acre ranging in size from 4 to 7 feet.

Follow these steps:

1. Pick out a row or area where the trees represent the "average" tree height and spacing for your field.
2. Fill the sprayer with a known volume of water. (Let's assume 3 gallons.)
3. Spray the trees as you would with the spray mix, trying for adequate coverage for the target pest.
4. After spraying the 3 gallons of water, count the number of trees you sprayed. (Let's say you sprayed 120 trees.)
5. Next, determine what part of an acre you sprayed with 3 gallons.

$$\frac{120 \text{ trees}}{1{,}200 \text{ trees/acre}} = 0.10 \text{ acre}$$

6. Determine your gallon/acre output by dividing volume by area.

$$\frac{3 \text{ gal}}{0.10} = 30 \text{ gal/acre}$$

7. Finally, determine how to divide the 1.5 pints (24 oz) for the acre application.

$$\frac{24 \text{ oz/acre}}{30 \text{ gal/acre}} = 0.8 \text{ oz/gal}$$

Each gallon of water in the spray solution should contain 0.8 ounces of insecticide.

It is important to note that this example assumes that the trees are uniformly spaced over an acre, that the entire area is occupied with trees, and that you need to spray each tree. It also is important to remember that the 1.5 pints/acre of insecticide represents the maximum recommended amount that can or should be applied for any acre.

If the trees do not occupy the entire area or you do not need to spray all the trees in an acre, the amount of pesticide you need to apply per unit area is reduced proportionally to the untreated area.

Dry pesticides. Pesticides formulated as wettable powders, dispersible granules, or other dry forms require similar calculations. For example, the label for Aatrex® Nine-O® may state that 2.5 pounds of the product should be applied per acre for a particular use.

To determine the amount of product to add to water, first convert pounds to ounces:

2.5 lb x 16 oz/lb = 40 oz

Next, divide the 40 ounces by your sprayer output rate per acre:

$$\frac{40 \text{ oz}}{15 \text{ gal/acre}} = 2.7 \text{ oz/gal}$$

For a 5-gallon sprayer, add 13 ounces (5 x 2.7 ounces) of product.

The best way to measure 2.7 oz is with a scale. If a scale isn't available, you can measure dry herbicides with liquid measuring utensils and use a weight-to-volume conversion, which calculates the weight of a given volume of product per cup or tablespoon.

Example. From the calculations above, you want to have 2.7 ounces of product (Aatrex® Nine-O®) in each gallon. Remember, these are dry ounces. For this product, you know there are 4 dry (weight) ounces per cup (calculated from prior usage).

This is a specimen label which was not prepared by Ciba-Geigy Corporation. Ciba-Geigy Corporation is not responsible for the accuracy of the information contained herein. As labels are subject to revision, always carefully read and follow the label on the product container.

Princep® Caliber 90®

HERBICIDE

For weed control in certain crops.

ACTIVE INGREDIENT:

Simazine: 2-chloro-4.6-bis (ethylamino)-s-triazine.	90%
INERT INGREDIENTS:.	10%
TOTAL	100%

EPA Reg. No. 100-603/EPA Est. 100-LA-1

Princep Caliber 90 is a water dispersible granule.

KEEP OUT OF REACH OF CHILDREN

CAUTION

See additional precautionary statements and directions for use.

DIRECTIONS FOR USE AND CONDITIONS OF SALE AND WARRANTY

IMPORTANT: Read the entire Directions for Use and the Conditions of Sale and Warranty before using this product. If terms are not acceptable, return the unopened product container at once.

Figure 5.—A sample label for Princep® showing the percent active ingredients.

Knowing this, you can develop a conversion from weight to volume.

$$\frac{2.7 \text{ oz (dry)/gal}}{4 \text{ oz (dry)/cup}} = 0.68 \text{ cup or } 5.4 \text{ liquid oz/gal}$$

This allows the operator to use volume/liquid measuring devices, rather than a scale. You can develop similar weight/volume conversions for other products.

With some dry products (and even some liquids), sprayer output can change when you apply pesticides since you're no longer spraying just water. A thicker solution may pass through the tips more slowly. To check for this, it's often useful to respray the area of your original calibration test—assuming it's part of the field you wish to spray.

Start at the same spot you began in calibrating, and spray the area with the same amount (2 gallons in the example) of water and pesticide. You should finish very close to the same spot. If you don't, recalculate the area you sprayed, and adjust your calculations for your next batch.

Some dry formulations, such as wettable powder and water-dispersible granules, settle in the spray tank. Since few backpack sprayers have recirculating pumps and built-in agitators, it's very important to keep these products mixed. Two helpful suggestions: jostle the tank while you walk; stop now and then to give the backpack a good shake.

Active ingredients vs. product. Some herbicide guides list suggested rates on the basis of active ingredients (ai) per acre rather than as an amount of product to apply per acre. The reason is that the same herbicide can have a number of different formulations and concentrations.

To calculate the amount of product to apply per acre, divide the application rate (in active ingredient per acre) by the *decimal form* of the percent active ingredient for the product you are using:

$$\frac{4 \text{ lb ai/acre}}{0.9} = 4.4 \text{ lb Princep® Caliber 90® WPG}$$

Figure 5 illustrates a product label and shows how the percent active ingredient is depicted for use in the above calculation. Appendix B has other examples of these calculations.

Be certain you're clear on this point: Is the recommendation you're using based on active ingredients or product amount? An incorrect assumption could cause crop damage or reduced effectiveness.

Calibration for band spraying

Band spraying involves treating a crop row or band rather than the entire area. The steps are identical to calibrating for broadcast spraying (page 8). Keep in mind that you base application rates on the area treated. The 15 gallons/acre of spray in the example on page 10 may cover several field acres in a banding application, depending on the width of the band.

Calibration for spot spraying

Spot spraying is common on clumps of brush or weeds that are scattered or difficult to walk through. Sprayer calibration often is done on a "spray until wet" basis. In other words, you spray until the vegetation appears to be covered by a light rain.

When "spraying to wet," you'll likely apply between 30 and 75 gallons/acre, depending on how you define "wet" and the amount of foliage to cover. Remember, spray solution that drips off foliage is wasted.

Herbicide rates for spot spraying typically are given as a percentage dilution. For example, a typical recommendation for blackberry control might be to apply a 2 percent solution of Roundup® (48 percent ai glyphosate) in the fall.

To mix a 2 percent solution, multiply 0.02 x 128 (ounces in 1 gallon) to get 2.6 ounces per gallon. In a 5-gallon sprayer, mix 13 ounces of Roundup® (5 x 2.6 ounces). Table 6 lists various product amounts per volume by herbicide recommendation.

Spot spraying devices, such as the Meter Jet™, that deliver a metered volume of spray solution also are available. The area sprayed with this metered volume is determined by the tip size and height of the tip above the target. Again, calibration is based on the spray volume per unit area. Since the use of the Meter Jet™ is increasing, let's run through an example.

Situation. Let's assume you are having a problem with grass surrounding 3-year-old Douglas-fir seedlings. You want to control the grass just around each tree, not over the entire area. You have a recommendation that you need to apply 3 quarts of Velpar-L product per acre. You have a Meter Jet™ using a Full Jet FL-8VS tip, and will apply 14 ml of spray mix (water and Velpar-L) in a 4' diameter circle around each tree.

Table 6.—**Amount of product per volume for various herbicide recommendations.**

Herbicide recommendation (%)	Amount herbicide (oz) to add to:		
	1 gal	3 gal	5 gal
1%	1.3	4	6
2%	2.6	8	13
3%	3.8	11	19
4%	5.1	15	26
5%	6.4	19	32

Solution. First, determine the total volume of spray mix needed to spray, for example, 300 trees. Here you multiply the volume per tree by the number of trees.

14 ml x 300 trees = 4,200 ml

Next, since it often is easier to measure in ounces, convert ml to ounces (34 oz per 1,000 ml) in the following way:

(4,200 ml ÷ 1,000 ml/l) x 34 oz/l = 142 oz

Now that you have calculated the spray mix needed for 300 trees (142 ounces), you can move on to calculate the area. The formula for the area of a circle is (π) x (radius squared). Your spray circle had a 4-foot diameter. The radius is one-half the diameter. So, the area for 1 tree is:

(2 ft radius)^2 x 3.14 = 12.56 sq ft

The area occupied by 300 trees is:

300 x 12.56 = 3,768 sq ft

Since your spray mix recommendation is based on an acre, you need to determine how much of an acre 300 trees represent. As in past examples, there are 43,560 square feet in an acre.

$$\frac{3{,}768 \text{ sq ft}}{43{,}560 \text{ sq ft/acre}} = 0.087 \text{ acres}$$

Finally, combine your spray volume with the spray area calculation and find that your application rate is 12.8 gallons/acre.

$$\frac{142 \text{ oz}}{0.087 \text{ acre}} = 1{,}632 \text{ oz/acre}$$

or

$$\frac{1{,}632 \text{ oz/acre}}{128 \text{ oz/gal}} = 12.8 \text{ gal/acre}$$

So, in that 12.8 gallons (1,632 oz) of spray mix you need 3 quarts of Velpar (96 oz). So, each gallon in the sprayer should contain 7.5 oz of Velpar-L product.

$$\frac{96 \text{ oz}}{12.8 \text{ gal}} = 7.5 \text{ oz of Velpar-L per gal}$$

One last caution in using the Meter Jet™. Remember that height is critical. Hold the tip the same height above the target (ground) on each tree.

Operating hints

Here are some useful operating tips. Following them will help you do a more proficient spray job.

Keep records. Complete records help you duplicate successful spraying jobs and avoid repeating mistakes. Record these especially (and other notes you think might help in the future): spray tips used, date of spray application, pressure, spray mixture, weather (during spraying and for 24 hours after), and stage of weed and crop growth.

Remember to do this job immediately after you spray—and after results are evident, make notes on your impressions for future reference.

Clean your nozzle(s). Have an old toothbrush or other fine brush, clean water, gloves, and pliers handy. Clean the tip and screen after your first two tankfuls, and thereafter as needed. Use only a soft brush or compressed air to clean the tip opening.

Maintain correct boom or nozzle height. Keeping the nozzles at the calibrated height above your target is critical. The wand or boom tends to drop as the applicator tires. This should be avoided.

Agitate pesticides. All pesticides must be mixed thoroughly and agitated in the tank to ensure uniform coverage. Some products (such as wettable powders) tend to settle. Others (such as emulsifiable concentrates) tend to separate. When you spray these products, jostle or agitate the tank with a brisk sidestep to keep the solution well mixed.

Clean your tank. Thoroughly clean and triple-rinse your sprayer after use. Useful cleaners are water and ammonia (6 ounces of household ammonia per tank), commercially prepared tank-cleaning compounds, and trisodium phosphate (2 fluid ounces TSP per tank). Ammonia is recommended for cleaning after spraying 2,4-D.

When you use oil-based herbicides like 2,4-D esters, rinse the sprayer first with a light oil (diesel oil or kerosene).

Cleaning is especially critical if you plan to use the same sprayer for insecticide and herbicide sprays. In fact, many users have two sprayers—one for insecticides and one for herbicides, because total cleaning sometimes is difficult.

Review current label. The product label contains a wealth of information, from safety data to application tips. Read it carefully, refer to it often, and heed the advice. Especially be aware of toxicity classification and needed protective gear.

Use protective or safety clothing/gear. In many ways, backpack sprayer users are in closer contact with the pesticide than tractor operators are. Frequent refilling and mixing, walking over sprayed surfaces, etc. *means you must be very careful.*

Rubber boots and gloves, and eye protectors, are a must. Your product label may specify additional protection, such as respirator, rain gear, or face shield.

Use liquids when possible. Most liquids mix easier and stay mixed longer. Powders and granules tend to require more agitation and can clog nozzles and screens more easily.

Keep a safe distance between adjacent applicators. To minimize possible contact, it is wise to keep some distance between adjacent applicators.

Investigate accessories and have a supply of tips. Much of the versatility of backpack sprayers comes in the use of accessories such as booms, shields and the various tips available. Investigate options and consider their use where appropriate.

Conclusions

Accurate calibration is vital. The fact that your neighbor adds a certain amount of herbicide per gallon and gets good results is no reason for you to expect the same.

You might walk more slowly; you might have different nozzles; or you might use greater pressure. You simply *must* calibrate for your conditions.

Remember: You control these factors:

1. **Pressure.** If you increase the spray pressure, you increase output.
2. **Walking speed.** If you slow down, you increase output per acre.
3. **Swath width/nozzle height.** Your output (gal/acre) may change with different nozzle tips, nozzle heights, and swath widths. It often is best to first establish walking speed and pressure and then change your tip selection to achieve a desired output.

It's critical that you clearly understand the suggested application rates. Are they based on the amount of actual product you should apply, or on the amount of active ingredients? Is the product you're applying the same as the product on which the recommendation was based?

Above all, work safe and work smart. Don't rush and neglect important details. As you spray, periodically check yourself to verify accurate application.

Appendixes

A. Selecting a nozzle

Using a catalog. Nozzle catalogs are very helpful in making your first selection of tips. This doesn't save you from the need to calibrate each tip, but it does help determine which tips will get you "in the ballpark" of where you want to be in terms of application rates.

For example, consider Table 7. Again, let's assume that your pressure is 15 psi, your walking speed will be constant at 2.5 miles per hour, and you want to spray 10 to 20 gallons of spray per acre.

Table 7 doesn't cover speeds as low as 2.5 miles per hour at 15 psi, but you can see that for each drop of 1 mph in speed, there's a 2- to 3-gallon/acre increase in the spray amount you apply.

Using this logic, at 2.5 mph and 15 psi, the 80001LP tip would deliver around 9 gallons per acre. The 80015LP would deliver around 14 gallons per acre. You selected the 80015LP nozzle on that basis. Table 7 also suggests you need a 50-mesh screen behind your nozzle tip.

Using formulas. To determine gallons sprayed per minute, multiply gallons per acre times square feet per minute. Divide your answer by the number of square feet in an acre:

$$\text{spray tip gal/min} = \frac{\text{gal/acre x ft}^2\text{/min}}{43{,}560\ \text{ft}^2\text{/acre}}$$

To determine square feet per minute, multiply spray width times walking speed (mph) times 5,280 ft/mile. Divide your answer by 60 min/hour:

$$\text{ft}^2\text{/min} = \frac{2.5\ \text{mph x } 2.5\ \text{ft x } 5{,}280\ \text{ft/mile}}{60\ \text{min/hour}}$$

$$= 550\ \text{ft}^2\text{/min}$$

Table 7.—**Low pressure flat fan spray tips**[a].

Tip no. fix (strainer & screen size)	Liquid pressure (psi)	Capacity 1 nozzle (gpm)	Gal/acre 20" spacing 4 mph	Gal/acre 20" spacing 5 mph
8001LP-SS (100-mesh)	15	.10	7.4	5.9
	20	.12	8.6	6.9
	30	.14	10.5	8.4
80015LP-SS (50-mesh)	15	.15	11.1	8.9
	20	.17	12.9	10.3
	30	.21	15.8	12.6
8002LP-SS (50-mesh)	15	.20	14.9	11.9
	20	.23	17.2	13.7
	30	.28	21.0	16.8

[a]Excerpted with permission from a chart in Spraying Systems Co. Catalog #44 (1993), page 25.

Using these values, you determine spray tip gallons/ minute:

$$\frac{10\ \text{gal/acre x } 550\ \text{ft}^2\text{/min}}{43{,}560\ \text{ft}^2\text{/acre}} = \text{spray tip gal/min}$$

$$= 0.13\ \text{spray tip gal/min}$$

Thus, a spray tip delivering around 0.13 gallon/ minute at 15 psi is the answer. Again, the 80015LP tip would be appropriate.

B. Calculating herbicide mixtures for small quantities

The following examples should help you when you mix small quantities of herbicides. Assume that your calibrated application rate of carrier (water) is 15 gallons/acre—but remember to use your actual calibrated application rate, not this assumed rate.

Liquid products (Velpar). How much per gallon do you add if you want to apply 3 quarts of product per acre? First, convert 3 quarts to ounces:

3 qt/acre x 32 oz/qt = 96 oz/acre

Next, knowing your calibrated application rate, determine how much product to add per gallon of final spray mix:

$$\frac{96 \text{ oz/acre}}{15 \text{ gal/acre}} = 6.4 \text{ oz Velpar/gal mix}$$

2,4-D. Here, let's assume your herbicide guide reads, "Add 2 pounds of acid equivalent (ae) per acre." (Because there are several 2,4-D formulations, most weed control guides state acid equivalent rather than amount of product or active ingredients.)

Read the 2,4-D product label. It will state the concentration of product in pounds of acid equivalent/gallon. Let's assume yours is 3.75 pounds acid equivalent/gallon. How much do you add per gallon?

First, determine gallons of product for one acre:

$$\frac{2 \text{ lb ae/acre}}{3.75 \text{ lb ae/gal}} = 0.53 \text{ gal product/acre}$$

Next, convert to ounces:

0.53 gal/acre x 128 oz/gal = 68 oz/acre

Now, to find the amount of product to add per gallon, divide 68 oz/acre by 15 gal/acre:

$$\frac{68 \text{ oz/acre}}{15 \text{ gal/acre}} = 4.5 \text{ oz/gal}$$

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Published and distributed in furtherance of the Acts of Congress of May 8 and June 30, 1914, by the Oregon State University Extension Service, Washington State University Cooperative Extension, the University of Idaho Cooperative Extension System, and the U.S. Department of Agriculture cooperating.

 Published November 1987; Revised April 1996. $1.50/$1.50/$1.50

References

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References

Alfaro, René I. 1988. Pest damage and its assessment. *Northwest Environment Journal.* 4:279-300.

Anonymous. 1992. *Washington Forest Practices, Rules and Regulations.* Title 222 AC. Washington Forest Practices. Board and Department of Ecology. 129 pp.

Anthony, R.M., V.G. Barnes Jr., and J. Evans. 1978. "Vexar" plastic netting to reduce pocket gopher depredation of conifer seedlings. *In:* Howard, W. E., ed. *Proceedings 8th Vertebrate Pest Conference*; University of California, Davis. pp. 138-144.

Arno, S.F. 1980. Forest fire history in the Northern Rockies. *Journal of Forestry,* 78:460-465.

Auclair, N.D. and J.A. Bedford. 1994. Conceptual origins of catastrophic forest mortality in the western United States: a test of the Pyne fire hypothesis. *Journal of Sustainable Forestry,* (in press).

Baker, F.A. 1988. The influence of forest management on pathogens. *Northwest Environmental Journal.* 4:229-246.

Baker, W.L. 1992. Effects of settlement and fire suppression on landscape structure. *Ecology* 73:1879-1887.

Barbosa, Pedro and M.R. Wagner. 1989. *Introduction to forest and shade tree insects.* Academic Press, Inc. San Diego, CA. 639 pp.

Baumgartner, D.M. (ed.). 1973. *Management of lodgepole pine ecosystems.* Symposium Proceedings held at Washington State University, October, 1973. 825 pp.

Baumgartner, D.M., R.G. Krebill, and Gordon F. Weetman (eds.). 1984. *Lodgepole pine the species and its management.* Symposium Proceedings held at Spokane, WA and Vancouver, B.C. 1984. 381 pp.

Baxter, Dow V. 1967. *Disease in Forest Plantations.* John Wiley and Sons, Inc., New York.

Biggar, J.W. and Seiber, J.N. (eds.) 1987. *Fate of Pesticides in the Environment.* Agricultural Experiment Station, Division of Agriculture and Natural Resources Publication 3320, University of California Press. Oakland. 157 pp.

Boyce, J. S. 1961. *Forest pathology.* McGraw-Hill, New York. 572 pp.

Brodie, D., H.C. Black, E.J. Dimock, J. Evans, C. Kao, and J.A. Rochelle. 1979. *Animal damage to coniferous plantations in Oregon and Washington, Part II. Economic evaluation.* Oregon State University, Corvallis, OR. 24 pp.

Brookes, Martha H., R.W. Campbell, J.J. Colbert, R.G. Mitchell, and R.W. Stark (eds.). 1987. *Western spruce budworm.* U.S.D.A. Forest Service Technical Bulletin 1694. 198 pp.

Brooks, M. H., R. W. Stark, and R. W. Campbell. 1978. *The Douglas-fir tussock moth: A synthesis.* U.S.D.A. Forest Service Technical Bulletin 1585. Washington, D.C. 331 pp.

Brown, J.K. 1983. The "unnatural fuel buildup" issue. Pages 127-128 *In:* Lotan, J.E., et al., eds. *Proceedings—symposium and workshop on wilderness fire.* U.S.D.A. Forest Service, Intermountain Research Station General Technical Report INT-182. Ogden, UT.

Brown, A.W.A. (ed.) 1978. *Ecology of Pesticides.* John Wiley and Sons. New York. 525 pp.

Burdon, J.J. 1991. Fungal pathogens as selective forces in plant populations and communities. *Australian Journal of Ecology,* 16:423-432.

Cafferetta, S.L. 1992. Mountain beaver. *In:* Black, H.C. (ed.) *Silvicultural Approaches to Animal Damage Management in Pacific Northwest forests.* U.S.D.A. Forest Service General Technical Report PNW-287. pp. 231-251.

Campbell, D.L. and J. Evans. 1975. *"Vexar" seedling protectors to reduce wildlife damage to Douglas-fir.* U.S.D.I., Fish and Wildlife Service, Wildlife Leaflet 508: 11 pp.

Campbell, D.L. and J. Evans. 1978. Establishing native forbs to reduce black-tailed deer browsing damage to Douglas-fir. *In:* Howard, W.E. (ed.), *Proceedings 8th Vertebrate Pest Conference*; Sacramento, CA. University of California, Davis. pp. 145-151.

Campbell, D.L. and J. Evans. 1988. *Evaluation of seedling protection materials in western Oregon.* U.S.D.I. Bureau of Land Management, Technical Note OR-5. Portland, OR. 14 pp.

Campbell, D.L. and L.E. Johnson. 1981. *Guide for collecting and seeding native forbs in Douglas-fir clearcuts.* U.S.D.I. Fish and Wildlife Service, Wildlife Leaflet 513: 13 pp.

Campbell, D.L., J.P. Farley, and R.M. Engeman. 1992. Field efficacy evaluation of pelleted strychnine baits for control of mountain beavers (*Aplodontia rufa*). Pages 335-339 *In:* Borecco, J.E. and R.E. Marsh (eds.) *Proceedings 15th Vertebrate Pest Conference,* University of California, Davis.

Campbell, D.L., J.P. Farley, P.L. Hegdal, R.M. Engeman, and H.W. Krupa. 1992. Field efficacy evaluation of diphacinone paraffin bait blocks and strychnine oat groats for control of forest pocket gophers (*Thomomys* spp.). Pages 299-302 *In:* Borecco, J.E. and R.E. Marsh, (eds.) *Proceedings 15th Vertebrate Pest Conference,* University of California, Davis.

Capizzi, J., G. Fisher, H. Homan, C. Baird, A. Antonelli, and D. Mayer. 1985. *Pacific Northwest Insect Control Handbook.* Extension Systems of Oregon State University, Washington State University, and the University of Idaho. 316 pp.

Chapman, J. A. 1974. *Ambrosia beetles: Guidelines to population estimates near dry land log-storage areas and damage hazard assessment.* Canada Forest Service Information Report BC-X-103. Pacific Forest Resources Center, Victoria, B.C. 4 pp.

Condrashoff, S. F. 1962. *Douglas-fir needle midges: Pests of Christmas trees in British Columbia.* Forest Entomology and Pathology Branch, Canadian Department of Forestry. Forest Entomology Laboratory, Vernon, B.C. 5 pp.

Condrashoff, S. F. 1968. Biology of *Steremnius carinatus* (Coleoptera: Curculiondiae), a reforestation pest in coastal British Columbia. *Canadian Entomology* 100:386-394.

Condrashoff, S. F. 1969. *Steremnius carinatus* (Boheman), a weevil damaging coniferous seedlings in British Columbia. Forestry Branch Information Report BC-X-17. Department of Fisheries and Forestry. Forest Research Laboratory, Victoria, B.C. 6 pp.

Cumming, M. E. P. 1959. The biology of *Adelges cooleyi* (Gill.) (Homoptera: Phyloxeridae) on spruce. *Canadian Entomology* 94:395-408.

Davis, D. D. and H. D. Gerhold. 1976. Selection of trees for tolerance of air pollutants. Pages 61-66 *In: Symposium proceedings: Better trees for metropolitan landscapes.* U.S.D.A. Forest Service General Technical Report NE-22. Northeastern Forestry Experimental Station, Upper Darby, PA.

Edmonds, R.L. 1991. Organic matter decomposition in Western United States forests. Pages 118-128 *In:* Harvey, A.E. and L.F. Neuenschwander, comps. *Proceedings-Management and productivity of western montane forest soils.* U.S.D.A. Forest Service Intermountain Research Station, Ogden, UT.

Evans, J. 1987 Identification of forest animal damage in the Pacific Northwest. Pages 25-26 *In:* Baumgartner, D. (and others), eds. *Symposium Proceedings Animal Damage Management in Pacific Northwest Forests.* Spokane, WA. Washington State University.

Evans, J., G.H. Matschke, D.L. Campbell, P.L. Hegdal, and R.M. Engeman. 1990. Efficacy data for registration of strychnine grain baits to control pocket gophers (*Thomomys* spp.). Pages 82-86 *In:* Davis, L.R., and R.E. Marsh (eds.) *Proceedings: 14th Vertebrate Pest Conference.* University of California, Davis.

Foster, R. E. and G. W. Wallis. 1974. *Common tree diseases of British Columbia.* Forest Bureau Publication 1245, 2nd ed. Department of Fisheries and Forestry, Ottawa. 116 pp.

Franklin, Jerry F. and C.T. Dyrness. 1973. *Natural Vegetation of Oregon and Washington.* Reprinted 1988, Oregon State University Press, Corvallis, OR.

Fryxell, R. 1965. Mazama and Glacier Peak volcanic ash layers: relative ages. *Science* 147:1288-1290.

Furniss, M. M., R. W. Clausen, G. P. Markin, M. D. McGregor, and R. L. Livingston. 1981.

Effectiveness of Douglas-fir beetle anti aggregative pheromone applied by helicopter. U.S.D.A. Forest Service General Technical Report INT-101. Intermountain Forest and Range Experimental Station., Ogden, UT. 6 pp.

Furniss, R.L. and V.M. Carolin. 1977. *Western forest insects.* U.S.D.A. Forest Service Miscellaneous Publication 1339. Washington, D.C. 654 pp.

Gast, W.R., D.W. Scott, C. Schmitt, et al., 1991. *Blue mountains forest health report—"new perspectives in forest health."* U.S.D.A. Forest Service, Pacific Northwest Region, Portland:, OR, Special Report.

Geist, J.M., and P.H. Cochran. 1991. Influences of volcanic ash and pumice deposition on productivity of western interior forest soils. Pages 90-94 *In:* Harvey, A.E., and L.F. Neuenschwander, comps. *Proceedings—Management and productivity of western mountain forest soils.* U.S.D.A. Forest Service, Intermountain Research Station, Ogden, UT.

Graham, R.T., J.L. Kingery, and L.A. Volland. 1992. Livestock and forest management interactions. Pages 351-364 *In:* Black, H. C. (ed.) *Silvicultural Approaches to Animal Damage Management in Pacific Northwest forests.* U.S.D.A. Forest Service General Technical Report PNW-287.

Grizzle, R.E. 1994. Environmentalism should include human ecological needs. *Bioscience* 44:263-268.

Haak, R.A. and J.W. Byler. 1993. Insects and pathogens, regulators of forest ecosystems. *Journal of Forestry* 91:32-37.

Habeck, J.R. and R.W. Mutch. 1973. Fire-dependent forests in the northern Rocky Mountains. *Quantitative Research* 3:408-424.

Hadfield, J. S. 1985. *Laminated root rot: A guide for reducing losses in Oregon and Washington forests.* U.S.D.A. Forest Service, Pacific Northwest Region, Portland, OR. 13 pp.

Hadfield, J. S., D. J. Goheen, G. M. Filip, G. L. Schmidt, and R. D. Harvey. In press. *Root diseases of Oregon and Washington conifers.* U.S.D.A. Forest Service, Pacific Northwest Region, Portland, OR.

Hadfield, J. S., Donald J. Goheen, Gregory M. Filip, Craig L. Schmitt, and Robert D. Harvey. 1986. *Root Diseases in Oregon and Washington Conifers.* U.S.D.A. Forest Service Pacific Northwest Region, Forest Pest Management, Portland, OR.

Hagle, S.K., G.I. McDonald and E.A. Norby. 1989. *White pine blister rust in northern Idaho and western Montana: alternatives for integrated management.* General Technical Report INT-419. U.S. D. A. Forest Service, Intermountain Research Station, Ogden, UT. 35 pp.

Hamel, D. R. 1983. *Forest management chemicals: A guide to use when considering pesticides for forest management.* U.S.D.A. Forest Service Agriculture Handbook 585. U.S. Government Printing Office, Washington, D.C. 645 pp.

Hamm, Philip B., Sally J. Campbell, and Everett M. Hansen. 1990. *Growing Healthy Seedlings.* Special Publication No. 19. Forest Research Laboratory, Oregon State University, Corvallis, OR.

Hansen, E. M., D. J. Goheen, P. F. Hessburg, and J. J. Witkosky. 1985. Biology and management of blackstain root disease in Douglas-fir. *In: Proceedings: Symposium on Verticicladiella diseases of conifers.* American Phytopathology Society, Reno, NV.

Harvey, A.E., M.J. Larsen, and M.F. Jurgensen. 1979. *Fire-decay: interactive roles regulating wood accumulation and soil development in the Northern Rocky Mountains.* Research Note INT-263. U.S.D.A. Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT. 4 pp.

Harvey, A.E., G.I. McDonald, and M.F. Jurgensen. 1992. Relationships between fire, pathogens, and long-term productivity in northwestern forests. Pages 16-22 *In:* Kaufman, J.B., et al., coord. *Fire in Pacific Northwest ecosystems: exploring emerging issues.* Portland, OR. Jan. 21-23, 1992, Corvallis, OR, Oregon State University.

Harvey, A.E., J.M. Geist, G.I. McDonald, and others. 1993a. Biotic and abiotic processes in eastside ecosystems: the effects of management on soil properties, processes and productivity. Pages 101-173 *In:* Hessburg, P.F., comp. *Eastside forest ecosystem health assessment-Volume III.* U.S.D.A. Forest Service, Northwest Forest and Range Experiment Station, Portland, OR.

Harvey, A.E., G.I. McDonald, M.F. Jurgensen, and M.J. Larsen. 1993b. Microbes: drivers of long-term ecological processes in fire-influenced cedar-hemlock-white pine forests of the Inland Northwest. *In:* Baumgartner, D.A., comp. *Symposium proceedings, Interior cedar-hemlock-white pine forests: their ecology and management.* March 2-4, 1993; Spokane, WA, (in press).

Harvey, A.E. 1994. Integrated roles for insects, diseases and decomposers in fire dominated forests of the Inland Western United States: Past, present and future forest health. *Journal of Forest Sustainability,* (in press).

Heinselman, M.L. 1978. Fire intensity and frequency as factors in the distribution and structure of northern ecosystems, Pages 7-57 *In:* Mooney, H.A., et al. *Fire regimes and ecosystem properties.* Proceedings of the Conference, December 11-15, 1978, Honolulu, HI. U.S.D.A. Forest Service General Technical Report WO-26, Washington D.C. 593 pp.

Hepting, George H. 1971. *Diseases of Shade Trees of the United States.* U.S.D.A. Forest Service Handbook No. 386.

Hessburg, P.F., R.G. Mitchell and G.M. Filip. 1993. Historical and current roles of insects and pathogens in eastern Oregon and Washington forested landscapes. Pages 486-535 *In:* Hessburg, P.F., comp. *Eastside forest ecosystem health assessment-Volume III.* U.S.D.A. Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, OR.

Hoff, R.J. and S. Hagle. 1990. Diseases of whitebark pine with special emphasis on white pine blister rust. Pages 179-190 *In:* Schmidt, W.C., and K.J. McDonald, comp. *Proceedings—Symposium on whitebark pine ecosystems: ecology and management of a high-mountain resource.* U.S.D.A. Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT.

Howard, P.H. (ed.) 1991. *Handbook of Environmental fate and Exposure Data. Volume III-Pesticides.* Lewis Publishers, Chelsea, MI. 684 pp.

Hoyer, G. 1983. *Douglas-fir leader and upper stem damage in plantations of the western slope of Washington's coastal mountains.* DNR Rep. 44. Department of Natural Resources, Olympia, WA. 29 pp.

Innes, J.L. 1993. *Forest health—its assessment and status.* CAB International, Wallingford, Oxon OX10 8DE, UK 677 pp.

Jarosz, A.M., J.J. Burdon and W.J. Muller. 1991. Long-term effects of disease epidemics. *Journal of Applied Ecology,* 26:725-733.

Johnson, Warren T. and Howard H. Lyon. 1976. *Insects that feed on trees and shrubs.* Comstock Publishing Associates, Cornell University Press. Ithaca, NY. 556 pp.

Keane, R.E. and S.F. Arno. 1993. Rapid decline of whitebark pine in western Montana: evidence from 20-year remeasurements. *Western Journal of Forest Management* 8:44-47.

Kingery, J.L. and R.T. Graham. 1987. Cattle grazing and forest animal damage interaction. Pages 114-132 *In:* Baumgartner, D. (and others), eds. *Symposium Proceedings Animal Damage Management in Pacific Northwest Forests.* Spokane, WA. Washington State University.

Knapp, W.H. and J.D. Brodie. 1992. The process of managing animal damage. Pages 365-375 *In:* Black, H.C., (ed.) *Silvicultural Approaches to Animal Damage Management in Pacific Northwest Forests.* U.S.D.A. Forest Service, General Technical Report PNW-287.

Koepsell, Paul A. and Jay W. Pscheidt. 1993 (Updated annually) *Pacific Northwest Plant Disease Control Handbook.* Extension Systems of Oregon State University, Washington State University, and the University of Idaho. 347 pp.

Lee, C. and P.J. Peters 1976. Neurotoxicity and behavioral effects of thiram in rats. *Environmental Health Perspectives.* 17:35-43.

Lohle, C. 1988. Forest decline: endogenous dynamics, tree defenses, and the elimination of spurious correlation. *Vegetatio* 77:65-78.

Mannion, Paul D. 1981. *Tree Disease Concepts.* Prentice Hall, Inc. Englewood Cliffs, NJ.

Marsh, R.E. and R.W. Steele. 1992. Pocket gophers. Pages 205-230 *In:* Black, H.C. (ed.) *Silvicultural Approaches to Animal Damage Management in Pacific Northwest Forests.* U.S.D.A. Forest Service General Technical Report PNW-287.

Martin, C. 1988. Interactions among fire, arthropods, and diseases in a healthy forest. Pages 87-91 *In: Healthy forests, healthy world.* Proceedings of the 1988 Society of American Foresters national convention; October 16-18, 1988, Rochester, NY. Washington DC, Society of American Foresters.

McDonald, G.I. 1991. Connecting forest productivity to behavior of soil-borne diseases. Pages 129-144 *In:* Harvey, A.E. and L.F. Neuenschwander, comps., *Proceedings—Management and productivity of western montane forest soils.* U.S.D.A. Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT.

McDonald, G.I., R.J. Hoff, and S. Samman. 1991. Epidemiologic function of blister rust resistance: a system for integrated management. Pages 235-255 *In:* Hiratsaka, Y. et al. *Rusts of pine.* Information Report NOR-X-317. Forestry Canada, Northwest Region, Northern Forestry Centre.

McMullin, L.H. 1976. *Spruce weevil damage, ecological basis and hazard rating for Vancouver Island.* Canadian Forest Service Pacific Forest Research Centre Inf. BC-X-141.

Meurisse, R.T., W.A. Robbie, J. Niehoff, and G. Ford. 1991. Dominant soil formation processes and properties in western-montane forest types and landscapes—some implications for productivity and management. Pages 7-19 *In:* Harvey, A.E., and L.F. Neuenschwander, comps. *Proceedings—Management and Service.* Intermountain Research Station, Ogden, UT.

Mills, Lynn J. and Kenelm Russell. 1981. *Detection and Correction of Hazard Trees in Washington's Recreation Areas.* Washington State Department of Natural Resources Report No. 42.

Moeur, M. 1992. *Baseline demographics of late successional western hemlock/western redcedar stands in northern Idaho Research Natural Areas.* U.S.D.A. Forest Service Research Paper INT-46 Intermountain Forest and Range Experiment Station, Ogden, UT, 16 pp.

Monnig, G. and J. Byler. 1992. *Forest health and ecological integrity in the Northern Rockies.* U.S.D.A. Forest Service, FPM Rep. 92-7, Northern Region, 7 pp.

Nijholt, W. W. 1978. *Ambrosia beetle: A menace to the forest industry.* Canadian Forest Service BC-P-25. Pacific Forest Resources Centre, Victoria, B.C. 8 pp.

Norris, L.A. 1981. *Behavior of chemicals in the forest environment.* Forest Pesticides Shortcourse, Portland OR. 12 pp.

O'Laughlin, J.O. 1993. *Forest health conditions in Idaho. Idaho* Forest, Wildlife and Range Policy Analysis Group, Report No. 11, Idaho Forest, Wildlife and Range Experiment Station, University of Idaho, Moscow, ID. 244 pp.

Oliver, C.D., D. Ferguson, A.E. Harvey, H. Malany, J.M. Mandzak, and R.W. Mutch. 1994. Managing ecosystems for forest health: an approach and the effects of uses and values. *Journal of Sustainable Forestry,* (in press).

Olsen, J.S. 1963. Energy storage and balance of producers and decomposers in ecological systems. *Ecology* 44:322-331.

Olsen, J.S. 1981. Carbon balance in relation to fire regimes. Pages 377-378 *In:* Mooney, H.A. et al., coord. *Fire regimes and ecosystem properties.* U.S.D.A. Forest Service General Technical Report WO-26. Washington, D.C.

Pank, L.F. 1976. Effect of seed and background colors on seed acceptance by birds. *Jour. Wildlife Management* 40(4):769-774.

Peters, R.L. 1990. Effects of global warming on forests. *Forest Ecology and Management*, 35:13-33.

Pitman, G. B. 1973. Further observations on Douglure in a *Dendroctonus pseudotsugae* management system. *Environmental Entomology* 2:109-112.

Ramsay, C.A. and Thomasson, G.L. (eds.) 1990. *Washington Pesticide Laws and Safety. A Guide to Safe Use and Handling for Applicators and Dealers*. Washington State University Cooperative Extension Misc. 0056, Pullman, WA. 88 pp.

Rand G.M. and Petrocelli, S.R. (eds.) 1985. *Fundamentals of Aquatic Toxicology*. Hemisphere Publishing Company, San Francisco, CA. 666 pp.

Rehfeldt, G.E. 1990. Gene resource management: Using models of genetic variation in silviculture. Pages 31-44 *In: Proceedings, genetics/silviculture workshop*, Aug. 26-31, 1990, Wenatchee, WA., U.S.D.A. Forest Service, Timber Management Staff, Washington, D.C.

Richmond, H. A., and W.W. Nijholt. 1972. *Water misting for log protection from ambrosia beetles in British Columbia*. Canadian Forest Service BC-P-4. Pacific Forest Research Centre, Victoria B.C. 34 pp.

Rochelle, J.A. 1992. Deer and elk. Pages 333-349 *In:* Black, H.C. (ed.) *Silvicultural Approaches to Animal Damage Management in Pacific Northwest Forests*. U.S.D.A. Forest Service, General Technical Report PNW-287.

Ross, H.H., C.A. Ross and June R.P, Ross. 1982. *A textbook of Entomology*, 4th edition. J.W. Wiley and Sons, Inc. New York. 666 pp.

Russell, K. W. 1965. *Conifer freeze damage* 1964-65: Snohomish County, Washington. Department of Natural Resources Management Report 11. Department of Natural Resources, Olympia, WA. 8 p.

Russell, K. W. 1983b. *Deterioration of blowdown timber on the Olympic Peninsula from the Lincoln Day storm*. Department of Natural Resources, DNR Note 36, Olympia, WA. 9 pp.

Russell, Kenelm W. 1992. *Who is Brave Enough to Light the First Match?* Presented at the Annual Northwest Fire Council, Olympia, WA, November 16-19, 1992.

Ruth, D. S. 1980. *A guide to insect pests in Douglas-fir seed orchards*. Canadian Forest Service BC-X-204. Pacific Forest Research Centre, Victoria, B.C. 19 pp.

Sampson, R.M., D.L. Adams, S. Hamilton, S.P. Mealey, R. Steele, and D. Van De Graaff. 1994. Assessing Forest Ecosystem Health in the Inland West. *Journal of Sustainable Forestry*, (in press).

Schutt, P. and E.B. Cowling. 1985. Waldsterben, a general decline of forests in central Europe: symptoms, development, and possible causes. *Plant Disease* 69:548-558.

Shigo, A. L. and H. G. Marx. 1977. *Compartmentalization of decay in trees*. U.S.D.A. Forest Service Agriculture Information Bulletin 405. Washington, D.C. 73 pp.

Shigo, Alex L. 1986. *A New Tree Biology. Facts, Photos and Philosophies on Trees and Their Problems and Proper Care*. Shigo and Trees Associates, Durham, NH.

Silver, G. T. 1958. Studies on the silver-spotted tiger moth, *Halisidota argentata* Pack. (Lepidoptera: Arctiidae) in British Columbia. *Canadian Entomology* 90:65-80.

Sinclair, Wayne A., Howard H. Johnson, and Warren T. Johnson. *Diseases of Trees and Shrubs*. Comstock Publishing Associates. Cornell University Press, Ithaca, NY.

Sine, Charlotte. 1991 (revised annually) *Farm Chemicals Handbook*. Meister Publishing Company. Willoughby, OH.

Sloan, J. 1994. *Historical density and stand structure of an old-growth forest in the Boise Basin of central Idaho*. (Unpublished manuscript.)

Southerland, Jack R., Thomas Miller, and Rudolfo Salinas Quinard. 1981. *Cone and Seed Diseases of North American Conifers*. North American Forestry Commission. Publication No. 1. Victoria, British Columbia, Canada.

Stoszek, K.J. 1988. Forests under stress and insect outbreaks. *Northwest Environmental Journal,* 4:247-261.

Thies, W. G. 1984. Laminated root rot: The quest for control. *Journal of Forestry 83:345-356.*

Tinsley, I.J. (ed.) 1979. *Chemical Concepts in Pollutant Behavior.* John Wiley and Sons. New York. 265 pp.

U.S. E.P.A. 1988. *Pesticide Fact Handbook.* Noyles Data Corp., Park Ridge, NJ. 827 pp.

U.S.D.A. Forest Service 1983. *Swiss needle cast and rhabdocline needle cast.* Forest Disease Management Notes. U.S.D.A. Forest Service, Pacific Northwest Region, Portland, OR. 53 pp.

U.S.D.A. Forest Service. *Forest Disease Management Notes.* U.S.D.A. Forest Service Regional Office, Forest Pest Management. Portland, OR.

van der Kamp, B. 1991. Pathogens as agents of diversity in forested landscapes. *Forestry Chronicle* 67:353-354.

Walstad, John D., Steven R. Radosevich, David V. Sandberg. 1990. *Natural and Prescribed Fire in Pacific Northwest Forests.* Oregon State University Press, Corvallis, OR.

Ware, George W. 1989. *The pesticide book.* Thomson Publications, Fresno, CA. 340 pp.

Waring, R.H. 1987. Characteristics of trees predisposed to die. *Bioscience* 37:559-564.

Warkentin, D.L., D.L. Overhulser, R.I. Gara, and T.M. Hinckley. 1992. Relationships between weather patterns, Sitka spruce stress, and tip weevil (*Pissodes strobi*) infestation levels. *Canadian Journal of Forest Research* 22:667-673.

Weaver, H. 1943. Fire as an ecological and silvicultural factor in the ponderosa pine region of the Pacific slope. *Journal of Forestry* 41:7-15.

Whitlock, C. 1992. Vegetational and climatic history of the Pacific Northwest during the last 20,000 years: Implications for understanding present-day biodiversity. *Northwest Environmental Journal* 8:5-28.

Wickman, B.E. 1992. *Forest health in the Blue Mountains: the influence of insects and disease.* U.S.D.A. Forest Service PNW-GTR-295, Pacific Northwest Research Station, Portland, OR. 15 pp.