16 Protecting Young Regeneration

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INTRODUCTION

In southwestern Oregon and northern California, abiotic and biotic factors such as heat, frost, weeds, vertebrate animals, insects, disease, and ravel can all limit reforestation success by killing, suppressing, or damaging natural and planted seedlings. Although these problems may not be apparent until after seedlings are planted or until a young stand develops, their genesis often lies with site characteristics, seedling characteristics and nursery practices, the nature of the preceding stand, and methods used in harvesting and site preparation. Protecting seedlings is only one step in the continuum of reforestation activities set out in the regeneration plan (Chapter 1). Some of the pest problems described in this chapter can be treated after planting; treatment of others must be part of harvesting and site preparation. For all, the appropriate time for recognition is prior to harvest. This chapter describes specific damaging agents; how the effects of each are influenced by site characteristics, harvesting and site-preparation practices, and seedling types; and how each can be controlled.

It is always best to prevent damage if possible. Prevention requires an understanding of how site conditions, neighboring stands, harvesting, and site preparation affect damaging agents (Figure 16-1). Coordinating these elements to control pests such as weeds, vertebrate animals, insects, or disease is known as integrated pest management (IPM) (Table 16-1). In IPM, control measures need to be compatible not only with harvesting and site-preparation techniques but with one another.

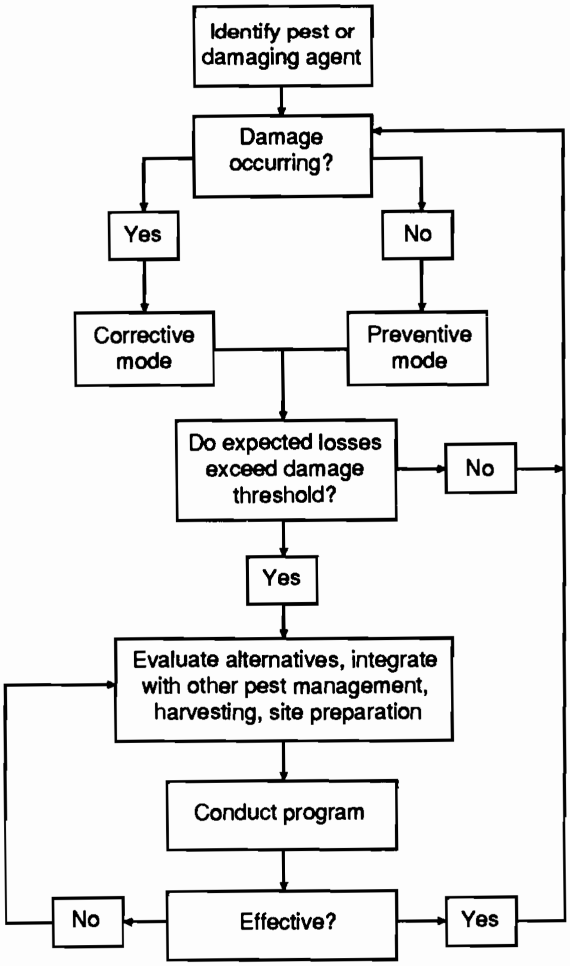

Figure 16-1. A flow chart for managing abiotic and biotic factors affecting reforestation.

Table 16-1. Integration of post-planting seedling protection with propagule types, regeneration method, site preparation, and monitoring. Filling in the cells of this matrix forces consideration of what the potential for damage is; how the propagule chosen will respond to it; how damage might be modified by regeneration method, site preparation, and seedling protection; and what post-treatment monitoring is needed. Each cell should contain the expected degree of damage from each; e.g., high, medium, low; increased, stay-the-same; decrease, and so on.

Site location/timber sale

Regeneration system:

Propagule type:

Site preparation:

Damage potential		Expected response of propagule (species, natural container, bareroot, etc.)	Anticipated effects on damaging agent			
Damaging Agent	Site's potential for damage (pre-harvest survey)		Regeneration system	Site preparation	Post-planting protection	Post-treatment monitoring
Heat						
Frost						
Weeds						
Vertebrates						
Insects						
Disease						
Ravel						

Although prevention is preferable, direct suppression of pests or amelioration of site conditions will sometimes be necessary. Such corrective protection of seedlings provides immediate control when damage is anticipated or detected.

When damage reaches an economic threshold (Stern 1973, Brodie et al. 1987, Row 1987) or begins to threaten long-term forest health, corrective action should be considered. Four types of information are needed (Walstad and Kuch 1987):

- the relationship between the pest population size and the corresponding crop damage,
- efficacy of treatment,
- treatment costs, and
- value of the crop.

If a pest or other damaging agent is not causing economically significant damage, the best alternative is to accept the damage. When insufficient information is available to determine an economic threshold, alternatives can be compared using a variety of methods (Streeby 1978, Brodie et al. 1987, Row 1987).

DAMAGE FROM HIGH SOIL TEMPERATURES

High soil surface temperatures can irreversibly damage stem tissue, particularly of natural germinants, near the soil surface, girdling and killing seedlings (Chapters 6 and 11). Stem damage can be identified from lesions near the soil line and swelling of the stem above. Lesions typically develop first on the south side of a stem. Foliage is not a good indicator of heat damage because it may remain green into the next growing season after the seedling has been girdled (Helgerson 1990b). Larger, bushier seedlings appear to be more resistant to lethal soil surface temperatures than smaller-diameter seedlings or seedlings lacking the ability to shade themselves (Chapter 13).

Damage is most common on flat sites, especially on south-, southeast-, and southwest-facing slopes (Isaac 1938, Silen 1960, Hallin 1968). Heat can kill Douglas-fir germinants on north-facing aspects, but the mortality rate is half or less that on south-facing sites (Silen 1960).

Soil characteristics associated with lethal heating include low heat capacity, low conductivity, surface litter or organic matter, dark or burned surfaces, and dry surfaces. For additional details see Isaac (1938), Cochran (1969), Childs and Flint (1987), Holbo and Childs (1987), and Stathers and Spittlehouse (1990).

Heat damage can be prevented by providing shade from overstory trees or microsite shading near the seedling, by using site-preparation methods that avoid creating hot soil surfaces (Chapter 10), and by planting heat-resistant species or stocktypes (Helgerson et al. 1992) (Chapter 13). A good rule of thumb is that an overstory of 10-12 trees of about 24 inches in diameter per acre will reduce soil surface temperatures to below lethal levels. For exposed sites, numerous microsite shading devices, including shingles, tarpaper, and cardboard, have been tested on a broad range of species and sites (Helgerson 1990b) (Figure 16-2). Manufactured shade devices are widely used because of availability and ease of installation. Shading by stumps, rocks, or woody debris has increased survival of small, nursery-grown Douglas-fir seedlings (Minore 1971), but such materials are not always conveniently available.

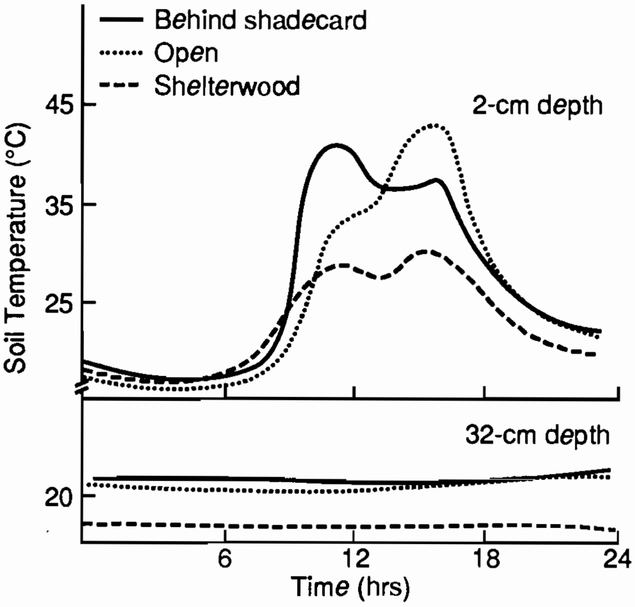

Figure 16-2. Diurnal soil temperature patterns in the open, behind a southwest-placed shadecard, and under a shelterwood at soil depths of 2 cm and 32 cm during a summer day (Childs 1985).

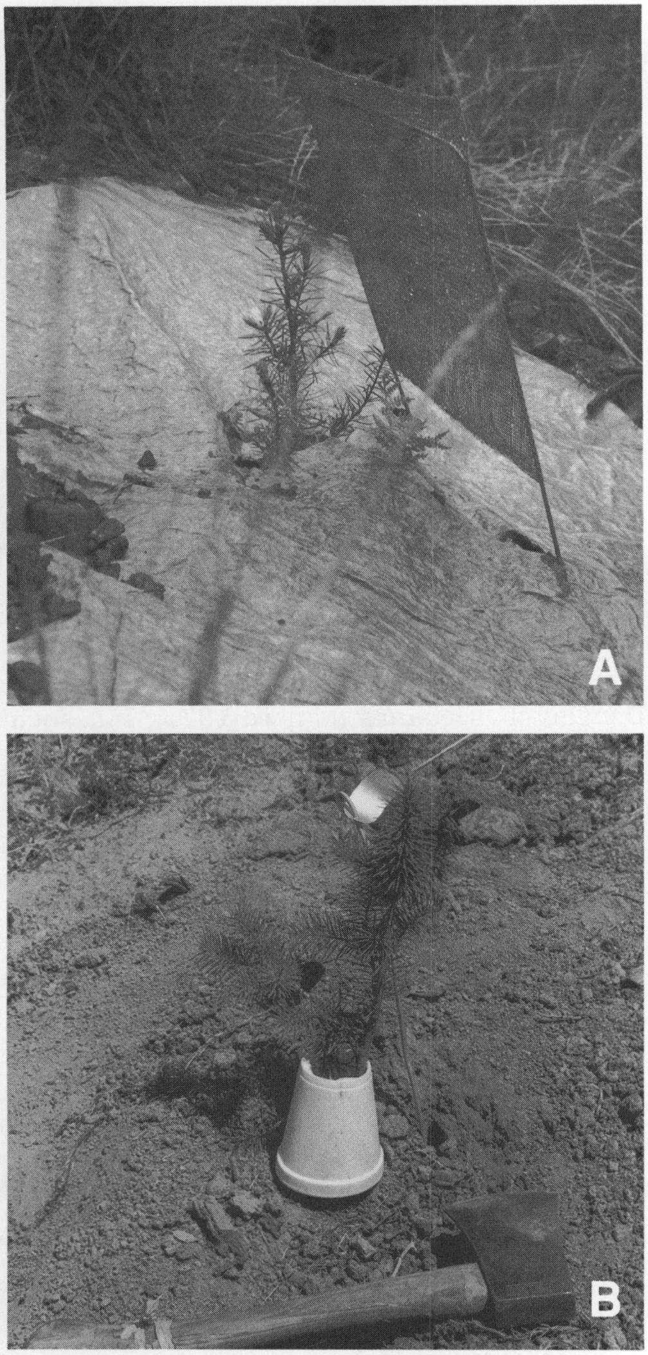

Figure 16-3. Planted Douglas-fir seedling with plastic mesh shade block and Kraft paper mulch (A), and with basal shade from a styrofoam cup (B).

Cardboard shadecards (approximately 8 by 12 inches in size and placed 2-3 inches from the seedling's base) were first used for shading seedlings. These were supplanted in the late 1980s by lower-cost and easier-to-install polypropylene mesh envelopes of similar size, supported by wire wickets (Figure 16-3A). The devices provide more shade when placed to the southwest and inclined over the seedling (Maguire 1955), but they also increase survival when installed vertically due south of seedlings (Helgerson 1990b).

In southwestern Oregon, shading with shadecards increased survival of planted Douglas-fir seedlings on south aspects more than east, west, or north aspects (Hobbs 1982b). Survival increased as the water-holding capacity of the soil decreased (Lewis et al. 1978) and as rock content of the soil increased (Petersen 1982). Some gain in survival may, however, be due to reduced water use (Vanderwaal 1983, Livingston and Black 1987) rather than reduced heat damage. Lowered foliage temperatures from shading do not appear to contribute to survival; Vanderwaal and Holbo (1984) observed needles of Douglas-fir seedlings to be within 2°C of air temperature regardless of shade.

Shading the basal portion of seedlings also increases survival. In California, shading stems of ponderosa pine seedlings with cotton batting or galvanized sheet metal increased survival (Maguire 1955). In southwestern Oregon, polystyrene foam cups (4 inches tall, bottoms removed) inverted around the bases of Douglas-fir seedlings (Figure 16-3B) proved as effective as shadecards (Helgerson 1990a). Cups made of peat moss are also commercially available, have been used operationally, and appear to be effective.

Live plants also provide shade. Initial survival of ponderosa pine and Douglas-fir seedlings can be enhanced, but subsequent survival and growth can be reduced due to problems associated with surrounding vegetation, including poorer planting, rodent damage, and competition (Helgerson 1987). For these reasons, relying on shrubs or herbs for shade is risky (Helgerson 1987).

CORRECTIVE MEASURES FOR FROST DAMAGE

The most common cold-related damage to seedlings appears to be death of tissue from late frosts (Boyce 1961; see also Chapter 6). Actively growing seedling tissues are killed at about -3°C (Stathers and Spittlehouse 1990).

Before budbreak, the most conspicuous injuries from late frost are death of buds and discoloration of foliage. After budbreak, discoloration, wilting, and death of the current growing season's leaves and shoots are the most conspicuous injuries. Conifers repeatedly subjected to late killing frosts become stunted and bushy (Boyce 1961).

Frost protection is accomplished by selecting an appropriate regeneration method, preparing the site properly, or planting frost-resistant seedlings—all pre-planting considerations. These options are preventive; unfortunately there are few corrective measures available if poor pre-planting decisions have been made. The three best pre-planting/post-planting options are replanting with frost-resistant species (Table 16-2), minimizing competition, and improving drainage of cold air by removing brush (Mahrt 1985). The latter two options may be only marginally beneficial, however, depending on the severity of the problem. Once frost damage has occurred it cannot be corrected.

WEEDS

Hardwoods, shrubs, and herbaceous vegetation can kill conifer seedlings or slow their growth by decreasing available water and light (Chapters 7 and 10) and by providing habitat for vertebrate pests such as pocket gophers, mice, voles, and ungulates. Over much of the region, rapid reforestation in even-aged systems can be difficult unless competition is adequately reduced during the first 5 years to promote conifer dominance on the site.

The amount of weeding needed depends on objectives and on the degree to which the regeneration method has altered the environment to favor weed development (Chapters 7 and 10). Post-planting weed control is most effective when weeds are just developing. The following sections discuss timing of control of hardwoods, shrubs, and herbaceous vegetation and the use of herbicides, mulching, manual and motor-manual cutting, and grazing to control these plant groups.

Timing of Control

Timing of post-planting vegetation control depends on the rate of vegetation development; hardwoods, shrubs, and herbaceous vegetation reoccupy a site at different rates (Chapter 7). Herbaceous vegetation typically reoccupies a site rapidly and may lead to mortality of conifers within 1 year if not treated. Shrubs and hardwoods can sprout rapidly after disturbance, leading to substantial conifer growth losses within 5 years. Shrubs propagated by seed develop more slowly

Table 16-2. Frost and shade tolerance of common tree species of the Cascade and Siskiyou Mountains of Oregon. From Emmingham (1985).

	Shade tolerance		
Frost tolerance	*Intolerant*	*Moderate*	*High*
High	Lodgepole pine Western larch Black cottonwood	White pine Engelmann spruce Shasta red fir	Mountain hemlock Brewer spruce
Moderate	Jeffrey pine Ponderosa pine	Noble fir Sugar pine Incense-cedar	Silver fir Grand fir White fir
Low	Red alder	Douglas-fir Bigleaf maple	Western hemlock Western redcedar
Very low	Pacific madrone Knobcone pine	Redwood Canyon live oak	Port-Orford-cedar Tanoak

Figure 16-4. Ponderosa pine and Douglas-fir 9 years after planting on a droughty, low-elevation site reclaimed from a brushfield. Trees in the upper photo (A) illustrate effects of controlling sclerophyll shrubs after planting. Without control (B), shrubs reclaim the site, killing most Douglas-fir and many ponderosa pine and greatly reducing the growth of survivors. The reference stake is 1 m tall.

than sprouting shrubs; thus their effect on conifer growth will take longer to become apparent. As a rule of thumb, competing vegetation should be treated before it covers 10-30 percent of a site if growth losses are to be avoided (Barrett 1982, McDonald and Oliver 1983, Oliver 1984, McDonald and Fiddler 1990, Tesch and Hobbs 1989, Helgerson et al. 1991). On more xeric sites, growth losses and mortality may occur with less shrub cover (Newton 1981, Radosevich 1984, Cole and Newton 1987, Walstad and Kuch 1987) (Figure 16-4).

Post-planting Weed Control Methods

Herbicides

The herbicide application techniques used in site preparation (Chapter 10) can also be used after seedlings are planted—with one important difference: most herbicides are toxic to conifer seedlings at some time of application or level of exposure, and thus there is a risk of injuring the conifers while treating surrounding weeds. Conifer damage can be minimized by timing sprays to avoid periods when they are sensitive, using soil-active herbicides, and using herbicides low in toxicity to conifers. Radosevich et al. (1980) described the seasonal tolerance of six species of conifers to eight foliage-active herbicides. They noted that severe injury always resulted when photosynthesis was high, predawn xylem sap tension was low, and active shoot growth was in progress. King and Radosevich (1985) compared herbicide sensitivities of Jeffrey pine, sugar pine, red fir, white fir and Douglas-fir. They noted that the best time to apply 2,4-D, glyphosate, and triclopyr was when growth had stopped and seedlings were water-stressed. They also found that each species varied in its degree of herbicide tolerance associated with these criteria. Thus herbicide applications must be targeted at the conifer species being treated.

Further recommendations are provided on manufacturers' labels on herbicide containers, in Conard and Emmingham (1984a and 1984b), and in an interactive computer program, VEGPRO (Wagner et al. 1990), for applying herbicides so as to minimize or avoid injury to conifers. See also Chapter 10 for general guidelines on herbicide use; however, current manufacturers' labels take precedence over any other instruction.

For sprouting hardwoods, effective herbicides include triclopyr and 2,4-D. These can be broadcast from the air or ground or applied as directed sprays to foliage or stems. Application before slashing or burning will minimize subsequent sprouting. Undiluted triclopyr ester can be applied as a spray (Warren 1980) or as a "thin-line" treatment on sprout stems (Warren 1982). Triclopyr, however, severely damages ponderosa pine at all times during the growing season (Paley and Radosevich 1984). Broadcast or directed applications of triclopyr and 2,4-D control sclerophyll shrubs, and glyphosate is effective on deciduous species. Hexazinone has shown promise in California in controlling brush and herbaceous vegetation around ponderosa pine and Douglas-fir. Recommended rates can be found in Johnson (1987).

Greenleaf manzanita and ponderosa pine show differential sensitivity to 2,4-D according to their xylem pressure potential as measured with a pressure chamber. Highest selectivity occurred at the end of September when pine had ceased growing; the daytime xylem pressure potential of the pine was low (indicating high water stress), and that of the manzanita was relatively high (Paley and Radosevich 1984). Thus, monitoring xylem pressure potential can indicate suitable application times.

For herbaceous vegetation, soil-active residual herbicides such as atrazine, hexazinone, and sulfometuron, and foliar-active contact herbicides such as glyphosate, are effective. Soil-active herbicides can be safely broadcast over dormant conifers in the fall. Foliar-active contact herbicides such as glyphosate may be broadcast only when conifers are dormant; at other times of the year they may be used only as directed sprays. Foliar-active herbicides should not be applied over planted seedlings at all in the first growing season. Seedlings freshly planted out of cold storage may, however, show better tolerance of translocated herbicides than seedlings that have started to grow (Dimock et al. 1983). Use of soil-active herbicides should be avoided with container-grown seedlings because the rooting medium allows herbicide to be taken up by roots. When such herbicides are to be used, planting the seedlings deeply enough to cover the rooting medium with soil can protect them.

Manual and motor-manual methods

Studies in southwestern Oregon indicate that on more mesic sites, cutting brush has little effect on short-term survival of conifer seedlings, but it increases their growth in proportion to the frequency of cutting and the amount of brush cut. Douglas-fir seedlings planted in shallow, rocky soils amid sprouting greenleaf manzanita and canyon live oak grew poorly despite one cutting of sprouts in the year of planting. By contrast, dry weights of seedlings planted amid sprouts treated with herbicides had increased about 13 times by the third year after planting (Tesch and Hobbs 1989). Similarly, for Douglas-fir seedlings planted for brushfield rehabilitation on another site, a single slashing of tanoak sprouts during the year of planting offered no increase in survival or growth over that of untreated controls. However, slashing near the time of planting and at the start of the next year appeared to approximately double the size of seedlings after five growing seasons (S.D. Hobbs, personal communication; data on file at Forest Research Laboratory, Oregon State University, Corvallis). The size of Douglas-fir seedlings growing amid sprouting tanoak increased progressively with cutting of radial clearings of 4, 8, and 12 ft (Jaramillo 1988).

Hardwoods and shrubs should be cut before they overtop or dominate conifer seedlings. Otherwise, the sudden exposure of shaded Douglas-fir to full sunlight will slow growth significantly (Newton 1981, White and Newton 1989). Shock from exposure is less with herbicides, but delaying treatment until seedlings are overtopped by shrubs or hardwoods incurs greater growth losses than earlier treatment.

Sprouting hardwoods and germinating brush are most commonly cut with chain saws, and to a lesser extent with circular saws. Sandviks, machetes, brush hooks, and pruning shears have also been used. These tools are regarded as hazardous or low in productivity, or both (Otchere-Boateng and Ackerman 1990). The general hazards of operating power equipment are described in Chapter 10.

Cutting brush while stems are small, which is recommended both to fully protect seedlings and to minimize debris, presents additional hazards. Power saws are safer and more effective when stems are large. Smaller-diameter materials derail chains and grab the saw, and during subsequent cuttings the hardened dead stubs from previous cuttings interfere with the blade. In thick brush, toxic saw exhaust stays in the immediate vicinity of the operator. Recent advances in design of circular brush saws make them easier to manage and less hazardous to the operator while cutting close to the ground (Chapter 10).

Manual or motor-manual brushing is labor-intensive, and the supply of qualified labor may restrict its use. In northern California, mean numbers of acres completed per workday ranged from 0.11 to 0.50, and average costs ranged from $174 to $310 per acre. Special training programs may be necessary to ensure a competent work force (Fiddler and McDonald 1990).

On light-textured soils, ceanothus and manzanita germinants less than 2 years old may be pulled with a "ribes-puller," a claw-hammer-like tool that grabs at the root collar and levers a germinating shrub out of the ground. As with sprouting hardwoods, the larger the area cleared, the greater the benefit to seedlings.

For grubbing and scalping, McLeod tools, hazel hoes, or hoedads are commonly used. In northern California, one-time grubbing of greenleaf manzanita in 2- and 4-ft radii around ponderosa pine seedlings did not improve growth, but grubbing repeated at 2 years in 4- and 6-ft radii did. Grubbing in a 6-ft radius gave results equal to a single application of hexazinone (McDonald and Fiddler 1990).

On suitably flat terrain, tractor-powered cultivators or brush cutters in combination with chain saws or rotary saws can control brush (McDonald and Fiddler 1990). As with sprouting hardwoods, shrubs should be controlled before conifers are overtopped and develop shade foliage. Where red alder trees overtop seedlings, they may be cut with reasonable control of sprouting after they reach about 15 ft in height if they are cut low during the middle of the growing season (Harrington 1984). However, on sites newly regenerated with conifer seedlings, alder should be controlled in the first 2 years after planting, before it causes growth losses.

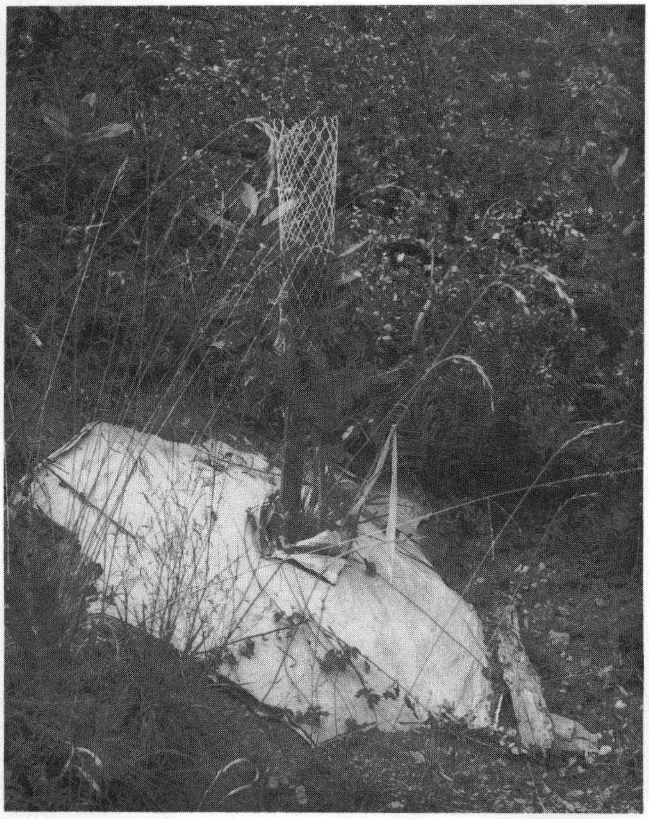

Figure 16-5. Douglas-fir seedling with Vexar™ tube for protection from deer browsing. Deer still browse protruding branches. The lath stake protects the seedling from slipping paper mulch.

Scalping has sometimes been used to control herbs. Newton (1981) summarized data from near Roseburg, Oregon, indicating that scalping of a spot no larger than 3.5 by 3.5 ft offered little benefit to planted conifers. Operational experience indicates that scalping or hand tillage can be effective when all vegetation is cleared in about an 8-ft radius around trees in late spring. This practice, however, is very costly.

Mulching

A mulch consists of any barrier placed on the soil surface to lessen water loss, control weeds, or alter exchange of heat. Mulching seedlings with paper, plastic film, or plastic fabric can increase seedling survival. Mulches can be anchored by digging the corners in, and held flat by placing soil clods, sod, rocks, or sticks on top of the mulching material. Pins may be needed for stronger materials. Kraft-paper mulches tend to come loose when dug-in corners rot. Mulches displaced by gravity, cattle, or deer often kill seedlings by smothering them (Newton 1961). Lath stakes holding Vexar™ mesh tubes protect seedlings from smothering (Figures 16-3A and 16-5). Mulching is easiest on clean sites. Mulches should be applied as soon as possible after planting, preferably as part of the planting contract.

McDonald and Helgerson (1991) reviewed effects of various types of mulches on seedling survival (Figure 16-6). An ideal mulch material prevents germinating or sprouting weeds from interfering with seedlings, is easily installed and anchored, lasts long enough to allow the seedling to become established, and is cost effective. Mulch material should be opaque to prevent plant growth under it.

Figure 16-6. Grass and forb invasion after timber harvest. Survival of planted Douglas-fir and ponderosa pine that were not mulched was near zero, whereas seedlings mulched after planting and 2 years later are surviving and growing well.

Mulch color does not appear to affect seedling performance, although darker-colored mulches may help warm the soil for root development. They may also raise soil surface temperatures enough to kill weed seeds and sprouts developing under the mulch. The opening around the seedling's stem, however, should be large enough to prevent dark-colored mulches from directly contacting the stem and causing heat damage. Mulch effectiveness increases with size. For herbaceous vegetation, the minimum size for hot, dry sites is 30 by 30 inches; for shrubs, 3 by 3 ft. For tanoak, 6-ft-square and larger mulches of polyester felt have proven effective. Attempts to economize by using smaller sizes have generally been unsuccessful.

A widely used mulch material is two layers of Kraft paper laminated with asphalt. This material lasts typically one and at most two growing seasons. Newspaper mulches last longer and cost 20 to 40 percent less to install than Kraft-paper mulches. They consist of four overlapping sets of 10-14 sheets each placed around the seedling, with a fifth set placed over it with a hole to accommodate the seedling. Newspaper is easily carried in planting bags, whereas other materials can be extremely difficult to transport in the field (M. Main, personal communication).

Low-cost, UV-inhibited polyethylene films can be engineered to last long enough to establish seedlings (3-5 years) and then photodegrade. Paper and plastic film mulches can control herbaceous vegetation (Newton 1961 and 1981). Mulches of more durable materials such as polyester fabrics can control germinating shrubs and sprouting of hardwoods, but they may need to be removed from the seedlings later (McDonald and Helgerson 1991).

Grazing

Cattle and sheep can be used under certain circumstances to control competing vegetation (Doescher et al. 1987). In the Cascade foothills of southwestern Oregon, intensively managed grazing by cattle reduced the leaf area of surrounding herbaceous vegetation and increased growth of Douglas-fir and ponderosa pine 4 years after planting (Doescher et al. 1989). Seedlings in grazed plots were about the same size as seedlings in adjacent plots receiving treatment with atrazine, two brush cuttings, and two mulchings in the same time period (Helgerson et al. 1991b). Grazing of cattle among Douglas-fir and white fir in the Sierra Nevada reduced shrub and herbaceous cover enough to achieve acceptable conifer growth with minimal trampling or browsing damage (Allen and Bartolome 1989). In the Coast Range the grazing of sheep has also been shown to reduce shrub dominance (Sharrow and Leininger 1983).

A key requirement for using grazing animals for weed control is that the weeds be palatable. Many shrub species, such as manzanita, silktassel, tanoak, canyon live oak, and poison-oak, are low in palatability. Their presence could increase due to grazing of more palatable surrounding vegetation. Grazing for weed control is most effective when it is timed to coincide with the period between bud set and bud break, when conifers are least palatable to livestock. Intense foraging before bud break can decrease cover of palatable grasses, forbs, and shrubs, increasing water availability for conifer growth (Doescher and Karl 1990). Removing livestock during active conifer growth prevents damage to seedlings and allows forage species to recover. After conifer bud set, this regrowth may be more palatable than if it were initially ungrazed, and should be grazed again.

Close management is necessary to prevent sheep or cattle from switching to conifers. Cattle and sheep will eat ponderosa pine foliage when other forage is depleted. Moving livestock at the first signs of browsing of conifers will minimize damage. Douglas-fir shorter than 90 cm are susceptible to browsing damage from sheep during the spring (Leininger and Sharrow 1989).

Successful application of grazing for weed control will likely require more advanced planning and coordination than other vegetation management techniques (Allen and Bartolome 1989). Ideal grazing units are large enough to minimize frequent transport of livestock by trucks. Cattle grazing can be controlled by herding, fencing, and watering, and by the placement of salt. Sheep must be flocking varieties and will require tending by a competent sheepherder and a trained dog. Experience indicates that intensive grazing regimes require close cooperation with the livestock operator and may entail supplemental payments. Potential impacts of grazing on water quality and other ecosystem components must be evaluated as with any other vegetation management tool.

VERTEBRATE DAMAGE

Conifer seedlings may be damaged by deer, elk, mountain beavers, mice, voles, pocket gophers, porcupines, and rabbits. These vertebrates cause both direct and indirect damage. Obvious physical damage to seedlings or seeds is easily observed and measured and usually forms the basis for assessing costs. Indirect damage is less obvious. It includes secondary effects such as increased susceptibility to insects and pathogens and increased rotation length because of delayed conifer establishment. Indirect damage may have much greater economic impact than direct damage, but it is more difficult to measure.

The procedure for determining whether to embark on a vertebrate damage control program is the same as for other damaging agents (Figure 16-1). Several clues evaluated together identify each vertebrate pest. These include:

- characteristics of damage to seed or seedling, such as tooth marks, type of cutting, and location of damage on tree,
- tracks or fecal pellets left at damage site,
- presence of burrows and dens, and
- site characteristics and surrounding vegetation.

Identification aids follow in subsequent sections. More comprehensive guides to identification and control of animal damage are found in Lawrence et al. (1961), the Animal Damage Control Handbook (USDA Forest Service 1978), and Campbell and Evans (1984).

Damage to Seeds

Although most forest regeneration is now conducted by planting seedlings, natural regeneration and direct seeding are sometimes used (Chapter 11). In these situations, deer mice, voles, and birds can cause economically significant damage. Rodents damage seeds by gnawing into one end and removing the kernel. Seeds damaged in this way are a clue to rodent predation; however, damaged seeds are difficult to find because they are often removed by rodents and birds.

Repellents, alternate foods, and habitat modification have been used to control damage to seeds. Coating seeds with non-toxic green dye may discourage most birds. Spreading large amounts of birdseed into seeding areas may protect conifer seeds by offering a preferred food. However, such treatment is expensive, and unsterilized seeds may create weed problems.

Damage to Seedlings

Deer and elk

Browsing by deer and elk is identified by the nature of the damage to the seedling, as well as by fecal pellets and tracks. These ungulates most commonly browse laterals and terminals of actively growing Douglas-fir seedlings, and they will browse dormant seedlings when other foods are scarce. New growth is cleanly cut, and older, damaged tissue appears torn or shredded. Deer and elk usually defecate at damage sites, leaving large, oval pellets. Elk pellets and tracks are about three times the size of those of deer.

Deer and elk damage is best predicted before harvest by observing damage on neighboring regeneration sites. Protection measures include placing barriers around seedlings, keeping the brush down, planting large seedlings, using repellents, building fences, and hunting. Vexar™ tubes (Figure 16-5), paper bud caps, and non-rigid plastic mesh are commonly used barriers. On sites where seedling growth is expected to be very rapid, low-cost paper bud caps (DeYoe and Schaap 1983) can be very effective, but not on sites where growth is slower or browsing is more intense. Among mechanical barriers, Vexar™-type tubes appear to cause the least mechanical damage to large transplant Douglas-fir seedlings (Gourley et al. 1990).

The seeding of preferred native forage species on clear-cut sites has reduced the numbers of seedlings browsed by deer (Campbell and Evans 1978). However, such plantings may attract increased numbers of deer and elk, potentially increasing seedling damage. If excess herbaceous cover develops, vole populations may build up to damaging levels. Gourley et al. (1990) observed that controlling surrounding herbaceous vegetation with herbicides in the Oregon Coast Range resulted in greater seedling growth and less damage from deer than physical barriers or repellents. They further observed that seedlings taller than 24 inches were less susceptible to deer browse injury. They hypothesized that larger seedlings, such as 2+1 transplants, resist deer browsing better than the shorter 2+0 seedlings because they retain more leaf area after being browsed.

Repellents derived from putrefied eggs also protect seedlings from browsing by deer and elk. Hydrophilic powder formulations seem to adhere better and last longer in rain than liquid formulations. For maximum effectiveness, repellents should be applied just before bud break. Depending on how quickly seedlings grow, two or three applications may be needed. Tying a strip of plastic flagging to treated seedlings before applying repellent seems to increase effectiveness (Campbell et al. 1987). Some putrefied-egg repellents defoliate seedlings (Gourley et al. 1990). Once deer and elk become habituated to feeding on seedlings at a particular site, repellents may become less effective.

Nurseries, progeny test plantations, and other high-value plantings may be protected from deer and elk damage with fences, either of livestock mesh wire 8 -12 ft tall or of high-tensile electrified wires 5-12 ft tall. Such fences are expensive to install and require extensive maintenance.

Special hunts have been held in areas of high seedling damage in attempts to reduce local deer and elk populations to the point where damage is not excessive. Hunter pressure may curtail elk damage, but it does not seem to effectively reduce deer damage. For additional discussion of identification and control of deer damage, see DeYoe et al. (1986).

Pocket gophers

Pocket gophers are small but formidable herbivores. Their presence is indicated by seedling damage and by mounding. In the absence of snow cover, pocket gophers consume seedling roots from underground burrow systems (Figure 16-7). Damaged seedlings develop brown needles, list to one side, and are easily pulled from the ground. When there is snow on the ground, pocket gophers consume foliage and bark of seedlings and saplings beneath the snow surface. Gopher tooth marks are about 1/16 inch wide per tooth, compared to 1/8 inch for porcupines, the only other gnawing pest causing similar damage. Pocket gophers push soil from their burrows in a fan-shaped mound, plugging the opening with a smaller mound. A test for active burrow systems is to make openings into burrows and then check to see whether gophers plug them (Evans et al. 1990).

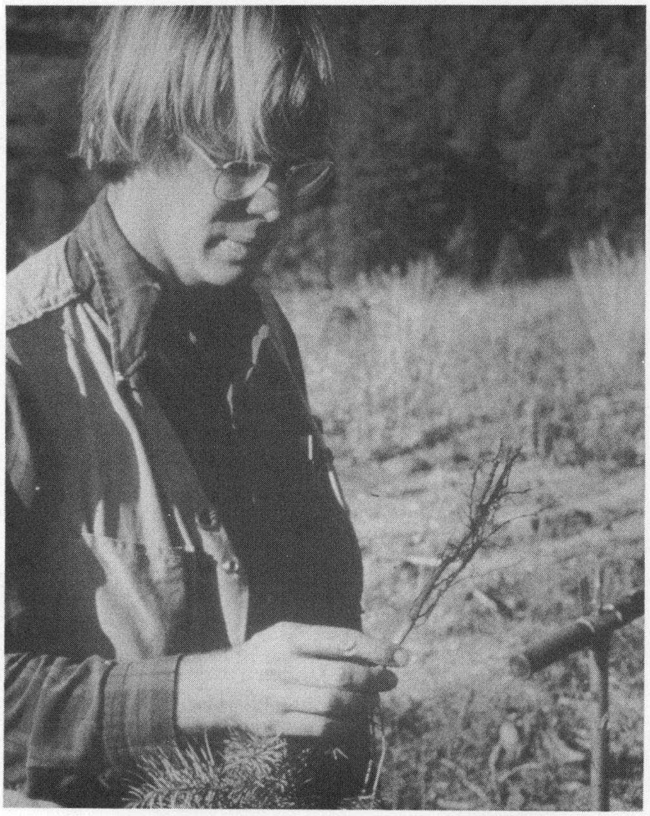

Figure 16-7. Root damage from pocket gophers on otherwise vigorous Douglas-fir seedling. Note herbaceous vegetation in background.

Mound surveys can indicate the need for control of pocket gophers. For each acre of regeneration site, examine a 0.01-acre plot (24-ft-diameter circle) for active pocket-gopher mounds. Plots are usually laid out on straight transect lines spaced at least 150 ft apart. On sites harvested less than 2 years before, control measures should be initiated if 25 percent or more of the plots contain active gopher mounds. On sites harvested 3-5 years before, control measures are justified if 40 percent or more of the plots contain active gopher mounds. Excessive seedling loss to pocket gophers in

Figure 16-8. Porcupine damage on established ponderosa pine 3 years after planting. Note width of tooth marks compared to pencil.

adjoining harvested units regardless of mound density also indicates that control measures will be needed.

Shelterwood or selection regeneration methods that leave canopy to retard development of grass and forbs can keep pocket-gopher populations low (Crouch 1986a). When populations rise, habitat management and baiting are used for control. Because pocket gophers rely on roots and above-ground parts of grasses and forbs for most of their food supply, eliminating this food supply with herbicides will cause populations to decline in 12 to 24 months (Black and Hooven 1977). This strategy followed by baiting can effectively prevent damage (Crouch 1986b). Without baiting, removal of other foods may increase pocket-gopher depredations.

Two types of baits are commonly used: oats treated with strychnine, and paraffin bait bars containing oats treated with diphacinone, an anticoagulant. Baiting is typically conducted by specially trained contract crews during summer and fall, up to the time when snow covers the soil. Baits are placed in burrow systems and the entry point is carefully closed and marked with flagging. The risk of accidental ingestion by other animals is low. Experience indicates that baits should be placed up to within 132 ft of surrounding conifer stands to prevent pocket gophers from reinvading a treated area. Baiting appears to be the only way to keep pocket-gopher populations from causing unacceptable damage during the winter.

Oats treated with 0.5 percent strychnine effectively control gophers (Evans et al. 1990), but they quickly become unpalatable due to decomposition of the grain. The bait bars, which are longer lasting, can poison several pocket gophers with a single baiting (Tunberg et al. 1984, Marsh 1987). Recent trials, however, indicate that the kill rate with bait bars may be initially less than that with strychnine-treated oats.

Trapping pocket gophers is not cost-effective. Encasing seedlings in Vexar™ tubes extending below ground level has shown some promise (Anthony et al. 1978). For more details on identification and control of pocket-gopher damage, see deCalesta and Asman (1987).

Porcupines

Porcupine damage is identified by fecal pellets and type of damage. These rodents attack ponderosa pine, ranging in size from newly planted seedlings up to pole-sized trees, stripping bark from the main stem between branches. This girdling kills smaller seedlings (Figure 16-8) and causes forked tops in larger trees. Porcupines can quickly decimate plantations of young pines. Vigorous pine seedlings that are not completely girdled often recover.

Porcupine damage is difficult to predict. In larger trees, damage is difficult to spot until foliage above the eaten area begins to die, usually at the end of the growing season after damage occurs. Needles turn red, then white, and fall off. Although porcupines eat mostly grasses and other herbaceous plants in spring and summer, they can also damage seedlings then. Damage may be more severe in the winter when other foods are unavailable. Porcupines can be located by identifying larger trees used for dens or feeding. These trees often have piles of porcupine fecal pellets at their bases. The fibrous droppings are cylinders 2-3 inches long.

Porcupines are commonly hunted and less commonly live-trapped. Hunting with shotguns or .22-caliber rifles or pistols is typically most successful on moonlit summer nights. Areas to check include denning trees, roads, culverts, and logs over streams. A "corral trap" or "scent station set" constructed of overlapping logs is used with Conibear™ or jump traps (USDA Forest Service 1978). Hooven (1971) provides more-detailed information on identification and management of porcupine damage.

Voles

Because of their small teeth, voles remove bark from seedlings in a fuzzy, patchy pattern. Seedlings die from girdling. Damage is usually within 6 inches of the ground, rarely extending upward more than 12-18 inches. Affected trees are usually less than 0.5 inch in diameter at their bases and are usually growing amid dense herbaceous cover. Voles leave dozens of small, brown fecal pellets about the diameter of pencil lead around the bases of damaged seedlings.

Vole damage can be predicted from habitat. Voles prefer grassy meadows with 6-18 inches of cover for protection from predators. They tunnel just under the soil, and their burrows are connected above ground by trails beaten into the soil. Vole damage can be great in meadows and pastures converted to conifer plantations because of large resident populations.

Habitat manipulation is the best tool for combating vole damage. Sites cleared of grassy cover by broadcast burning, herbicides, or scarification soon lose their vole populations. Without followup treatment, however, grass regrowth on burned or scarified sites may recreate suitable habitat for voles, other rodents, and rabbits. Leaving snags for raptors on treated areas may provide some control, although removal of cover usually reduces vole populations regardless of the raptor population. Rodenticides are registered for vole control, but they have not been particularly successful. Sites are generally so wet that the bait turns to mush and is not attractive. Baited voles eaten by hawks or owls may poison these birds.

Seedlings with stem calipers greater than 0.5 inches are big enough to survive vole damage. When cover cannot be controlled, planting larger-caliper seedlings such as 2+1s or 3+0s can reduce the time seedlings are exposed to vole damage.

Mountain beavers

This rodent is regarded as the number-one vertebrate pest in the Coast Range of Oregon (Campbell and Evans 1984). It can also be found inland, in snow-covered forests at higher elevations. Mountain-beaver activity is identified by characteristics of cut vegetation, burrow systems, and habitat. Seedlings and brush are clipped at a 45-degree angle. Mountain beavers cut smaller conifer seedlings 1-3 inches above the ground and pack them into their burrows. They clip lateral branches from trees up to 15 ft tall, all the way to the top, leaving a bare pole. Mountain beaver also remove bark from saplings and pole-sized trees in strips ¼ - ½ inch wide in a band between 2 and 12 inches up the trunk. They clip branches from vine maple and salmonberry up to several feet above the forest floor near damaged seedlings. Damage typically occurs in late winter to early spring. Because they subsist on a variety of fleshy and woody plants, mountain beavers prefer heavily vegetated sites. On burned or herbicide-treated sites, planted conifer seedlings may constitute the only food available for them. Thus the potential for damage can be high if a large mountain-beaver population exists.

Mountain beavers should be controlled before planting when two or more tunnel systems exist per acre. Burrow openings are about the size of a softball, often with a fan-shaped pile of soil (called a kick-out) 12 inches or wider, extending from the entrance. Burrows are often caved in, and often they open up just under logs lying on the forest floor. Habitat can be reduced with prescribed fire. On burned sites, surviving mountain beavers are readily revealed by their light-colored burrow kick-outs, which contrast with the blackened ground. After burning, trapping with Conibear™ 110 traps set in burrows successfully controls mountain beaver (Hooven 1977, Duddles et al. 1991).

Mountain-beaver damage can be controlled after planting with further trapping, rodenticides, and repellents, and by protecting seedlings with Vexar™ tubes. Placed over seedlings, these can provide good protection but cost up to $250 per acre (Campbell and Evans 1988), and more if they need to be removed to prevent deformity as seedlings grow. Pelleted strychnine baits are registered for Oregon. Treating seedlings with Big Game Repellent Powder™ (BGR-P), a repellent made from putrefied eggs (McLaughlin Gormley King Co., Minneapolis, Minn.), prevents damage for 1 year (Campbell and Evans 1988). Further particulars on mountain-beaver damage and control are provided by Hooven (1977) and Duddles et al. (1991).

Rabbits and hares

Seedling damage, fecal pellets, and habitat characterize these pests. Rabbits and hares are daintier feeders than deer or mountain beavers. They clip seedlings at the same angle as mountain beavers but damage only the last few inches of the terminal or lateral. Rabbits and hares defecate frequently when feeding, leaving piles of fibrous, small, flattened-oval pellets.

The likelihood of damage from rabbits and hares is best predicted from habitat and the occurrence of damage on similar units. Rabbits and hares need cover for protection from predators. Seedlings most apt to be damaged are those on sites with much shrubby cover or those adjacent to brush piles. Elimination of cover by burning, herbicides, or scarification will usually resolve current and future rabbit and hare problems. Pesticides are registered for controlling rabbits, but because they are applied above ground, the potential for accidental poisoning of non-target wildlife is high.

Wood rats

This species can pose serious regeneration problems in brushy areas. Their damage is similar to that of rabbits, and in some areas it can approach the severity of mountain-beaver damage. Wood rats construct nests from branches, blackberry canes, and vines, perching them on sprout clumps or on large stumps. Destroying nests, removing habitat, and protecting seedlings with Vexar™ tubing are effective control measures.

INSECTS

Research from western Oregon indicates that seedlings are susceptible to insect damage during the establishment phase. Preventive measures are based on maintaining seedling health and managing insect habitat in the surrounding area. Corrective measures include using chemicals to kill insects or to modify their behavior and using fire during vulnerable stages in the litter. The following sections describe major functional groups of insects and discuss preventive and corrective measures.

Major Insect Groups

Insects that injure young conifers fall into four categories: sap-suckers, root beetles, terminal feeders, and secondary bark beetles. These groups are based on how insects affect the host plant. Insects belonging to the three last-named groups stay largely hidden within plant tissues.

Sap-suckers

Sap-suckers are represented by aphids and adelgids (sometimes called woolly aphids). Populations of the Cooley spruce gall adelgid, *Adelges cooleyi*, on Douglas-fir (Figure 16-9), and of the giant conifer aphids, *Cinara* spp., on Douglas-fir and pines, can reach levels sufficient to cause serious foliage loss and shoot deformity (Furniss and Carolin 1977, Schowalter 1989). These insects are promoted in young conifer stands by the abundance and proximity of young, succulent foliage and shoots and by accessibility of the canopy to ground- and stump-nesting ants, which cultivate aphids. In fact, ants may be largely responsible for eliminating other exposed plant-feeding insects from small trees (Campbell et al. 1983, Schowalter et al. 1988). Bird predation on exposed insects also may be considerable (Campbell et al. 1983). Infestations are often more severe in young stands from which competing non-host shrubs have been eliminated, probably because the sparseness of the vegetation increases the adelgid's efficiency in finding and foraging on host seedlings (Campbell and Torgersen 1983, Schowalter et al. 1988, Schowalter 1989).

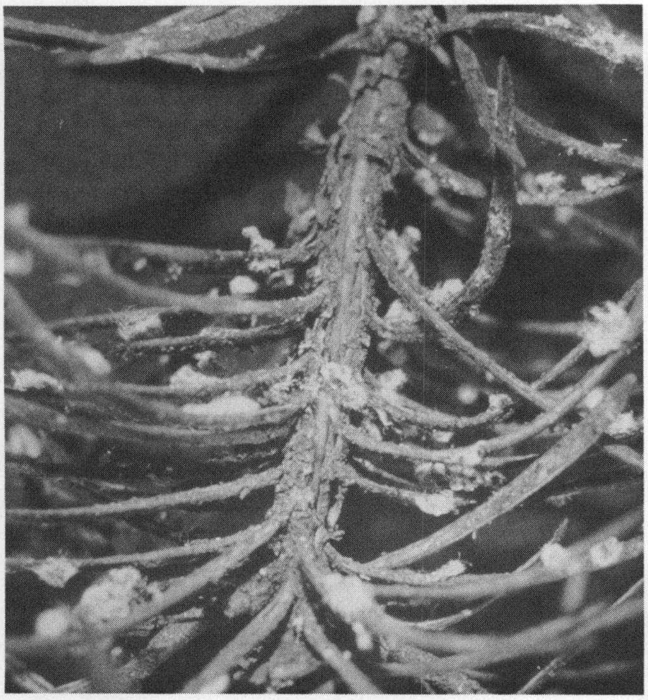

Figure 16-9. Adelges cooleyii *on 2+0 bareroot Douglas-fir. Photo courtesy of Oregon Department of Forestry.*

Root beetles

The root bark beetles, *Hylastes nigrinus* in Douglas-fir and *H. macer* in pine (Figure 16-10A), and the Douglas-fir root-collar weevil, *Steremnius carinatus*, can be serious pests in young Douglas-fir and ponderosa pine plantations. These beetles inoculate stumps and crop trees with the fatal black-stain root disease fungus (Witcosky et al. 1986a), and they also girdle seedlings (Figure 16-10A and B). They breed in dead roots of Douglas-fir throughout western Oregon but are most important in stands less than 30 years old that have either survived disease or been precommercially thinned. Infestations can be especially severe in stands thinned during fall and winter (Witcosky et al. 1986b).

Although fewer than 5 percent of the dispersing beetles appear to carry black-stain spores, nearly 100 percent of seedlings exposed to infected beetles become infected (Witcosky et al. 1986a). Beetles emerging from stumps feed on the roots and root collars of crop trees, and can infect trees up to pole size. Seedlings are often girdled and killed. Because root systems of harvested trees may support these beetles for several years, mortality of new plantings on recently cut sites can persist.

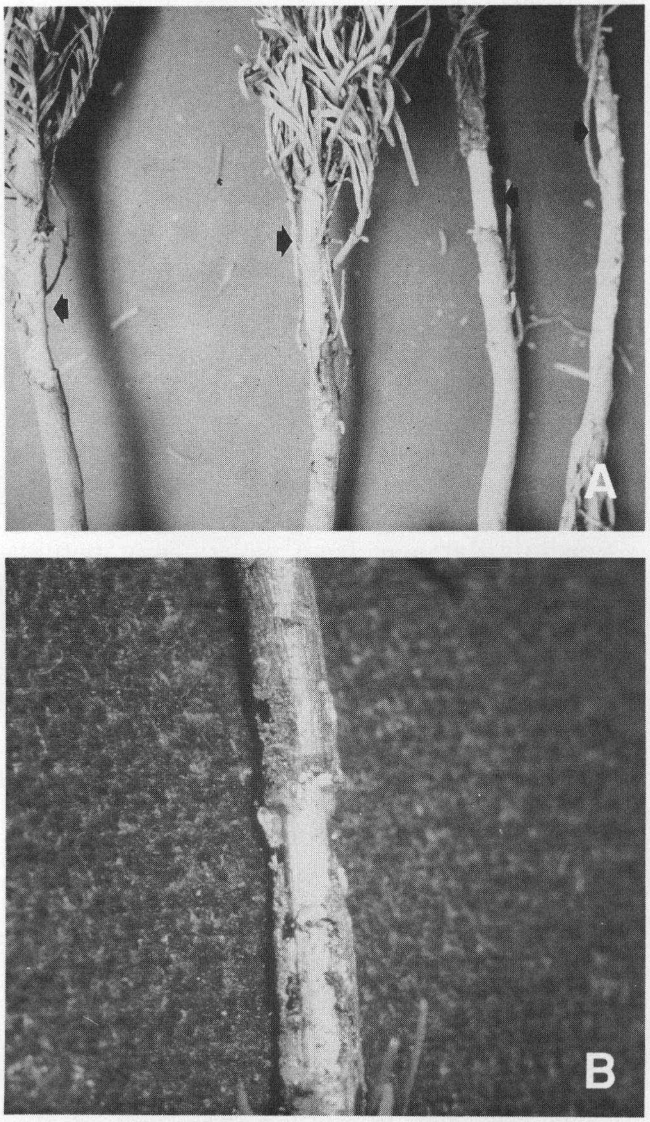

Figure 16-10. (A) Hylastes nigrinus *girdling of roots of Douglas fir seedlings. (B)* Steremnius carinatus *girdling on a 2+0 bareroot Douglas-fir seedling. Photos courtesy of T.D. Schowalter and Oregon Department of Forestry, respectively.*

Steremnius carinatus has attacked planted, container-grown Douglas-fir in Coos County, Oregon. Larger bareroot stock such as 2+0 bareroots and 2+1 transplants are usually only partly girdled and usually survive (D. Overhulser, personal communication, Oregon Department of Forestry, Salem). Condrashoff (1968) provides more information on *Steremnius carinatus*. *Hylastes nigrinus* also damages newly planted Douglas-fir seedlings (bareroot and transplant) when mature beetles feed on roots a few cm below the root collar. The short feeding gallery usually calluses over, but in some cases infection of the wound may contribute to seedling mortality (D. Overhulser, personal communication; Oregon Department of Forestry, Salem).

Terminal feeders

Terminal feeders typically colonize young conifer plantations between 5 and 10 years of age. Major species include the white pine weevil, *Pissodes strobi*, the ponderosa pine tip moth, *Rhyacionia zozana* (Figure 16-11), the western pine shoot borer, *Eucosma sonomana* (Figure 16-11), and the gouty pitch midge, *Cecidomyia piniinopsis*. Twig weevils (*Cylindrocopterus furnissi*) (Figure 16-12) have also attacked Douglas-fir in interior valleys (D. Overhulser, personal communication; Oregon Department of Forestry, Salem). For more information see Furniss (1942). Grasshoppers or locusts (*Acrididae* spp.) have been a lesser pest.

Larvae of the white pine weevil stunt or kill terminal shoots of young pines and spruce by tunneling under the bark, often girdling the shoot. Tip moth larvae cause similar injury by mining the pith of terminal shoots, stunting growth or killing the shoot. Repeated heavy attacks retard height growth and predispose trees to attack by other insects (Furniss and Carolin 1977, Koerber et al. 1988). Infestations

Figure 16-11. (A) Rhyacionia zozana *damage to ponderosa pine tips in late summer. (B)* Eucosma sonomana *damage to ponderosa pine. Photos courtesy of Oregon Department of Forestry.*

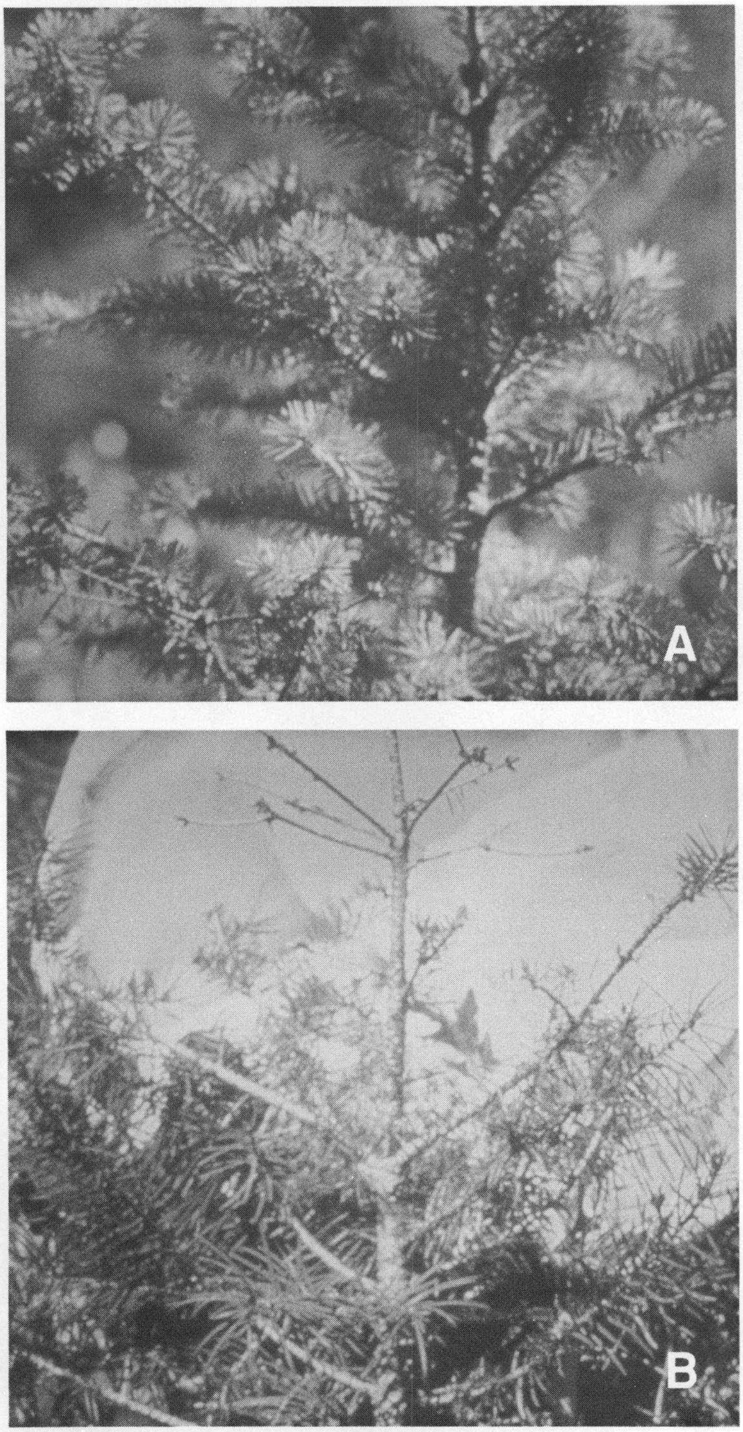

Figure 16-12. (A) Flagging (light color) on tips of lateral branches on Douglas-fir from Cylindrocopterus furnissi. *(B) Defoliation of 2+1 Douglas-fir after attack by* Cylindrocopterus furnissi. *Photos courtesy of Oregon Department of Forestry.*

are most severe in dense stands and on infertile sites (Stoszek 1988). These insects spend a portion of their life cycles in the litter under infested trees, making them vulnerable to predators and to fire (Mitchell and Martin 1980).

The gouty pitch midge also attacks shoots of young, open-growth ponderosa pines in plantations. Larvae feed in resinous pockets under the bark. Light infestations cause no serious injury but may distort annual rings around the feeding site. Severe infestations can retard growth and sometimes kill trees (Furniss and Carolin 1977, Bedard et al. 1988).

On the Klamath National Forest in northern California, grasshoppers killed white fir, red fir, and lodgepole pine planted on clearcuts. Damage was first observed as a scalloped appearance at the end of conifer leaves. As it progressed, needles were eaten to the stem and bark was eaten from seedlings, girdling them (Orcutt 1982). The density of grasshoppers was related to the method of site preparation used. Seedlings on an area receiving only disking had the highest levels of damage. Grasshopper densities were lowest on areas that had been sprayed with glyphosate. Spraying infested areas with malathion in August reduced population densities to 79-80 percent of pre-spray levels for the remainder of the growing season (Orcutt 1982).

Secondary bark beetles

Secondary bark beetles cannot kill healthy trees, but they readily find, colonize, and kill stressed or dying trees, especially those weakened by prior insect or pathogen invasion. The Douglas-fir engraver, *Scolytus unispinosus* (Figure 16-13), often occurs in poorly rooted Douglas-fir seedlings on harsh sites or near logging slash.

Control Options

The relationships between seedling and stand factors and susceptibility to insect attack are poorly defined. Nonetheless, insect populations can be kept at acceptable levels with certain preventive and control measures.

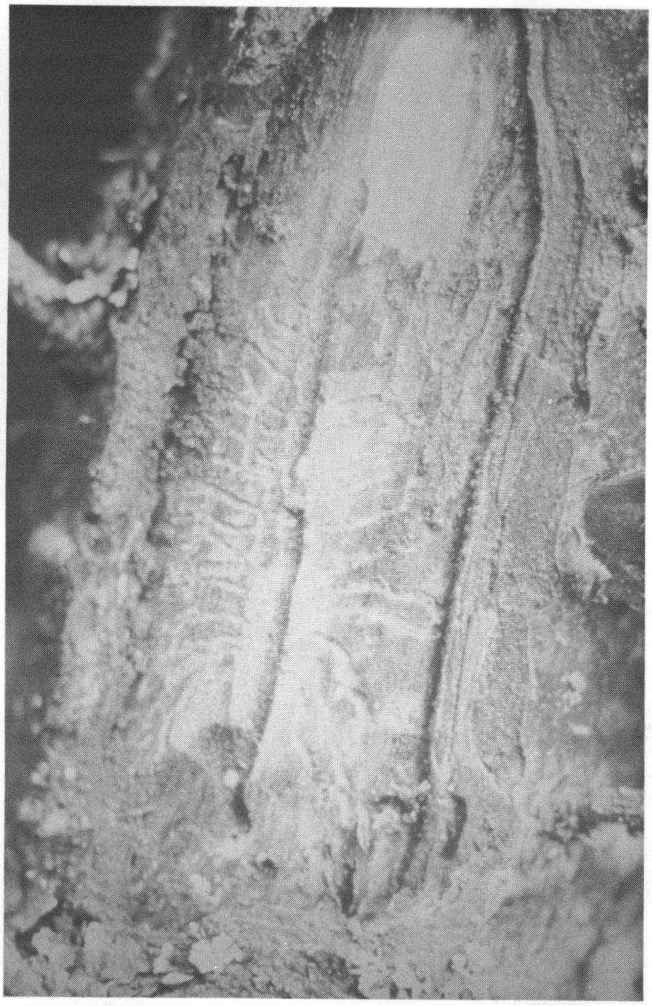

Figure 16-13. Scolytus unispinosis *gallery in small Douglas-fir. Photo courtesy of Oregon Department of Forestry.*

Preventive control

The best way to control seedling losses to insects is to maintain seedling vigor and manage insect habitat in the surrounding stand and landscape. Healthy conifers produce their own chemicals—unpalatable or toxic terpenes and phenols—to resist insect attack. The degree of natural chemical resistance depends on a seedling's genes and site conditions, with some trees showing considerably greater resistance than others (Bedard et al. 1988). However, stressful conditions, such as drought, competition, infertility, poor soil drainage, or frost or other damage, may force seedlings to reallocate limited resources to basic metabolic needs at the expense of chemical defenses (Schowalter 1981, Stoszek 1988). In general, measures that increase the vigor of well-adapted seedlings should also increase their resistance to insect attack.

This issue is complicated, however. Ross (1989) observed that site-preparation treatments that yielded the greatest seedling growth increased the susceptibility of eastern Oregon ponderosa pine seedlings to shoot borer attack. The seedlings were in a particularly susceptible height class. This increased susceptibility may be due to the fact that, under favorable conditions, seedlings allocate non-limiting resources to growth rather than to defenses. He cites Crouch (1979) as observing that atrazine application was associated with increased pine growth and reduced borer attack.

Managing the species and age composition of the surrounding forest helps protect seedlings from insect attack. Trees can be protected from insect populations by physical separation (Schowalter 1986). Non-host trees surrounding susceptible seedlings can produce odors that interfere with the insect's ability to find the host (Visser 1986). Diverse surrounding stands and landscapes also appear to support a greater variety of predators, especially birds and spiders, which control populations of destructive insects (Schowalter 1989).

However, if hardwoods and shrubs are to be managed to prevent insect damage, the benefits should be carefully weighed against losses from weed interference. As established stands age, insect activity may benefit long-term site productivity by enhancing natural thinning, diversification, and nutrient cycling (Mattson and Addy 1975, Wickman 1980, Schowalter 1981).

Corrective control

Corrective control options are limited. Applying insecticides is often impractical, ineffective, or both. Populations of aphids and spider mites often increase after insecticide use because of their rapid reproductive rates and the decimation of their predators. The other major insects are largely protected from all but systemic chemicals. However, the terminal feeders and perhaps the root beetles are vulnerable to disorientation by artificial sources of attractants during the mating and host-selection periods (Niwa et al.

1987, Witcosky et al. 1987, Koerber et al. 1988). Progress has been made on development of synthetic lures. Careful use of prescribed fire might be appropriate for managing the terminal feeders and the root-collar weevil during their susceptible stages in the forest litter (Mitchell and Martin 1980).

DISEASE

Infectious diseases can strike a forest stand at any time from establishment to harvest, but significant losses usually do not occur until stands are 10 years old or more. Tree diseases are far more easily prevented before stands are regenerated than cured or corrected after they are established. For most stand diseases and all seedling diseases, prevention is the only option. Thus, management decisions implemented before regeneration affect the probability of tree loss at all ages from all diseases.

Some diseases are acquired from infected trees or stumps on the site or in adjoining stands. These diseases can usually be detected during pre-harvest stand examinations so that harvesting, site preparation, and seedling selection can be managed to control the disease. Other diseases are introduced into uninfected areas by forest management activities or by natural vectors such as wind, water, or insects. Controlling these diseases requires knowing how they are spread and where infection centers are located.

Stresses caused by genetic maladaptation or the effects of harvesting and site preparation increase the likelihood of disease. Increased incidences of foliar fungi and Armillaria root rot are often observed in off-site plantations. Trees not adapted to the local environment are also more prone to frost and drought injury and consequently become more vulnerable to facultative parasites such as canker fungi. Chronic stress can also be instigated by excessive soil disturbance during harvesting and site preparation. The following sections describe seedling and stand diseases and preventive and corrective control methods for each. Filip and Schmitt (1990) provide an additional guide to identifying and managing stand diseases in true firs.

Seedling Diseases

Nursery-grown seedlings

Infected or damaged seedlings usually exhibit symptoms in the nursery. Phytophthora root rot is the most common nursery disease that can limit field performance. Infected trees are yellowish, with poor growth, sparse needles, and poorly developed roots. This disease occurs in low-lying areas of the nursery. Examination of the beds before lifting will quickly reveal any significant *Phytophthora* problem (Cooley et al. 1985).

Winter injury is difficult to detect. Cambial tissue should be inspected for discoloration a few weeks after winter injury is suspected to have occurred. If winter injury or other injury, such as that derived from poor lifting and handling, is suspected, a sample of trees should be tested for root growth potential (RGP) before outplanting (Ritchie 1984).

Disease problems can develop in long-term storage when temperatures are above freezing and a source of spores is present. Most mold on stored trees is harmless. Profuse mold indicates a poor storage environment and the possibility of associated physiological damage to the trees, but unless buds or the inner bark of stem or roots are killed, the mold causes no lasting direct damage. Scraping bark and buds with a fingernail will quickly differentiate firm, white-colored, healthy tissue from soft, discolored, diseased tissue.

Careful temperature control in storage is the first defense against storage molds. Freezing is optimal, but temperatures below 35°F will prevent damage in most cases. Seedling foliage should be clean and roots should be free of caked mud, because it often carries spores of mold fungi (Hocking and Nyland 1971, van den Driessche 1977).

Careful examination provides the best insurance against accepting and planting diseased or damaged seedlings. Unhealthy seedlings usually die quickly after planting. Post-planting remedies for diseased seedlings do not exist; the only option is to replant.

Natural germinants

Forest soils are inherently healthy. High levels of organic matter support bacteria and saprophytic fungal populations that are antagonistic to seedling diseases. *Fusarium* spp., important causes of damping-off and other seedling root diseases in conifer nurseries, cannot survive in forest soils (Schisler and Linderman 1984). *Pythium* spp., the other important cause of damping-off, are present, but in low numbers except where drainage is poor. In most forest soils, disease appears to be less important than damage from shrews, mice, or weather conditions, especially drought, in determining the survival of natural germinants (Gashwiler 1971).

Diseases of Existing Stands

The primary diseases affecting natural regeneration and planted stands are root rots, mistletoes, and stem decay existing in the previous stand or in adjoining stands. Root rots and mistletoes cause more damage to mature forests than all other agents. These diseases can be identified during pre-harvest stand surveys.

Root rots

The root-rot fungi are adapted to long periods (up to 50 years) of saprophytic survival in stumps or roots of killed trees. Trees are killed as these fungi break down cellulose and lignin in roots. They may die quickly due to windthrow from weakened roots, or slowly from decreased translocation of water and photosynthate. Damage is usually not evident until plantations are 10 or more years old, when options for cost-effective control are greatly diminished. The time to act against root disease is during harvest, site preparation, and regeneration (Hadfield et al. 1986).

Root-rot fungi are easily detected in mature stands by routine stand exams before harvest. Most stands will be healthy. Infected stands should be

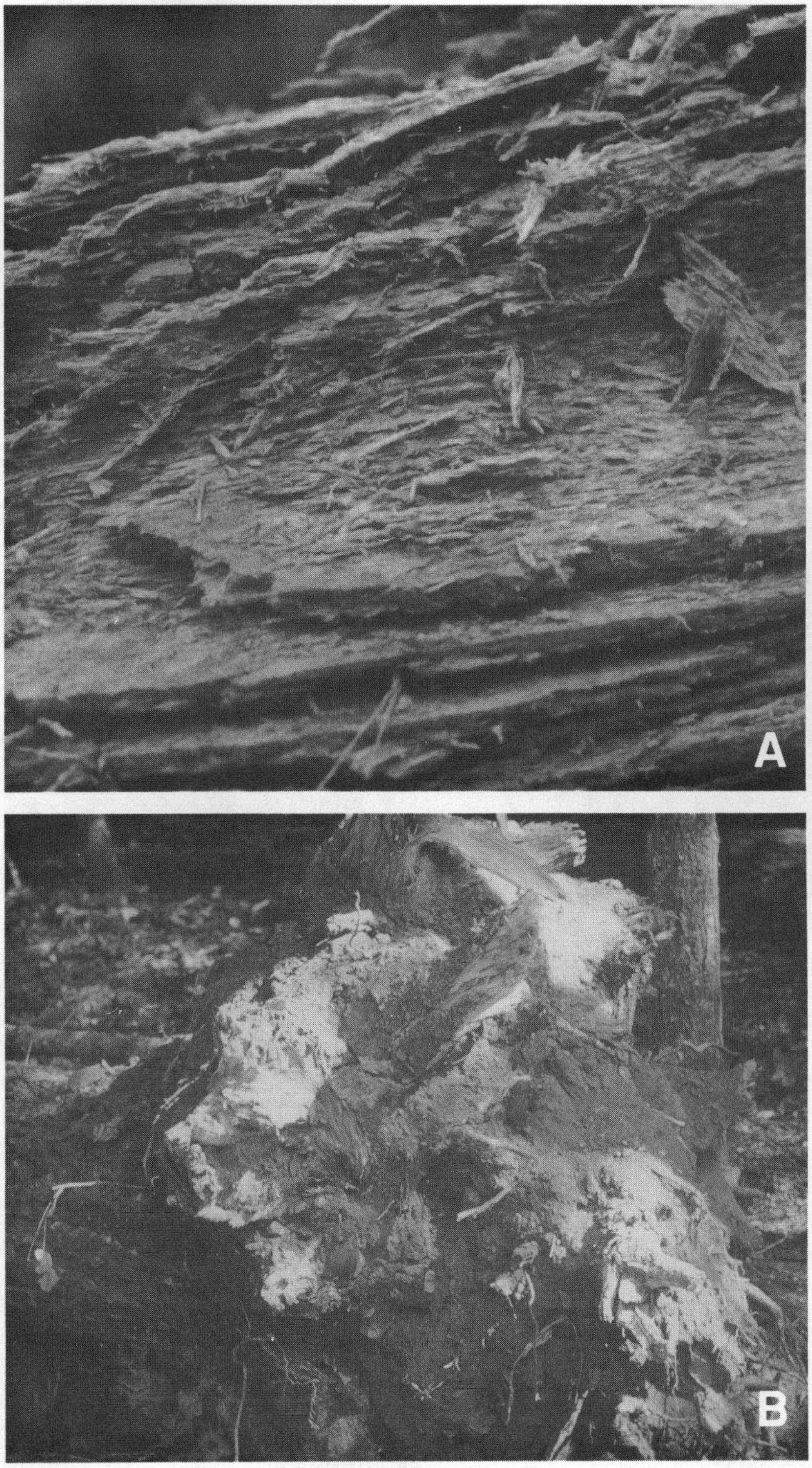

Figure 16-14. (A) Delamination of white fir and (B) windthrown white fir caused by Phellinus weirii. *Photos courtesy of USDA Forest Service, Region 6, Pest Management.*

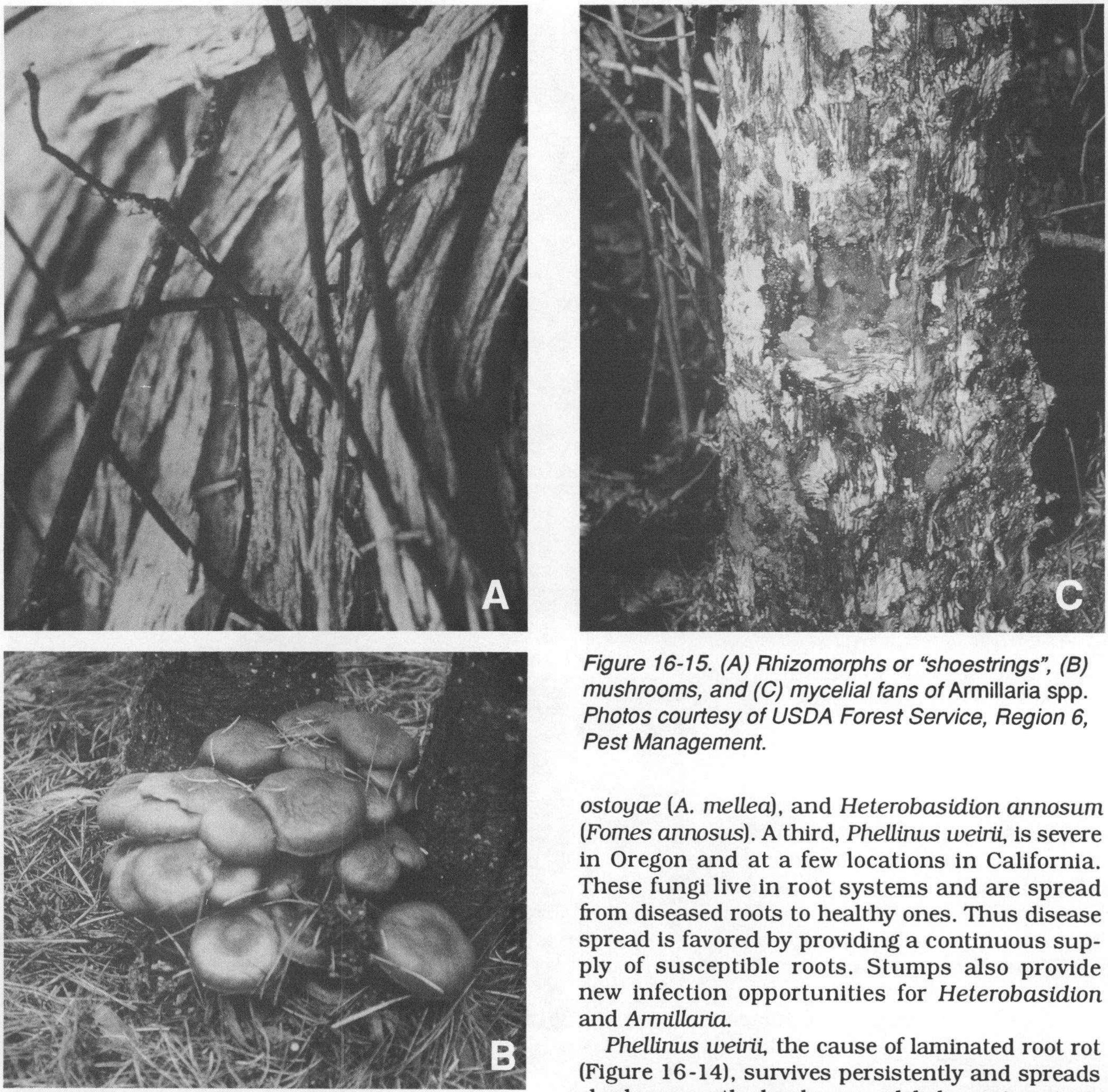

Figure 16-15. (A) Rhizomorphs or "shoestrings", (B) mushrooms, and (C) mycelial fans of Armillaria spp. *Photos courtesy of USDA Forest Service, Region 6, Pest Management.*

examined more intensively by specially trained or experienced persons to determine which fungi are causing damage, which tree species are affected, and how serious the problem is. Root rots can also be detected after harvesting by examining stumps for decay.

Two root-rot fungi widespread in southwestern Oregon and northern California are *Armillaria ostoyae* (*A. mellea*), and *Heterobasidion annosum* (*Fomes annosus*). A third, *Phellinus weirii*, is severe in Oregon and at a few locations in California. These fungi live in root systems and are spread from diseased roots to healthy ones. Thus disease spread is favored by providing a continuous supply of susceptible roots. Stumps also provide new infection opportunities for *Heterobasidion* and *Armillaria*.

Phellinus weirii, the cause of laminated root rot (Figure 16-14), survives persistently and spreads slowly across the landscape solely by root contact, infecting and killing susceptible trees. *Armillaria*, the cause of shoestring root rot, also spreads via root contact, with its rhizomorphs ("shoestrings") increasing its ability to spread (Figure 16-15). *Armillaria* often colonizes fresh stumps before attacking surrounding trees. It causes the most damage when trees are of poor vigor. In many cases it also acts as an aggressive pathogen, moving through otherwise healthy stands much as *Phellinus* does (Wargo and Shaw 1985).

Heterobasidion annosum causes annosus root and butt rot (Figure 16-16). It is spread not only by root contact but very efficiently by airborne spores which infect fresh stump tops and scars on living trees. *H. annosum* causes a butt rot in hemlock and a serious root and butt rot in true firs, and it rapidly kills ponderosa pine without causing significant decay (Hadfield et al. 1986). Most of our knowledge of annosus root rot comes from the Sierra Nevada, where it attacks true firs and pine; coastal Washington and British Columbia, where it attacks hemlock; and the northeastern and southeastern United States, where it attacks pine. We have little informa-tion directly relevant to southwestern Oregon and northern California on which to base predictions of loss or control strategies. However, damage will likely be greatest where stumps are created amid crop trees, as in precommercial thinning or uneven-aged regeneration methods.

There are no methods for controlling these root rots in established stands. Three strategies of preventive action can, however, reduce root-rot damage in future stands (Shaw and Roth 1978, Thies 1984). First, physically removing infected stumps from the ground removes most of the source of infection for the next stand. This can be done by bulldozers or excavators. Alternatively, planting trees tolerant of or immune to infection, or favoring such species in natural-regeneration schemes, halts the spread of the fungus and over time forces it to exhaust itself in the old, infected roots and stumps. The choice of species depends on which pathogen is present and on site constraints. Pines, cedars, and hardwoods are generally more tolerant of root rot than Douglas-fir or true firs (Shaw and Roth 1978, Thies 1984). A third stategy can be used to protect pine and fir from annosus root rot: fresh stumps can be treated with chemicals or biological agents to prevent colonization by spores of *Heterobasidion*.

Managing root rots is particularly difficult in uneven-aged silviculture because periodic harvests leave a susceptible overstory intact for a long time. Root-rot losses are especially high in stands with a large component of true fir. Severely

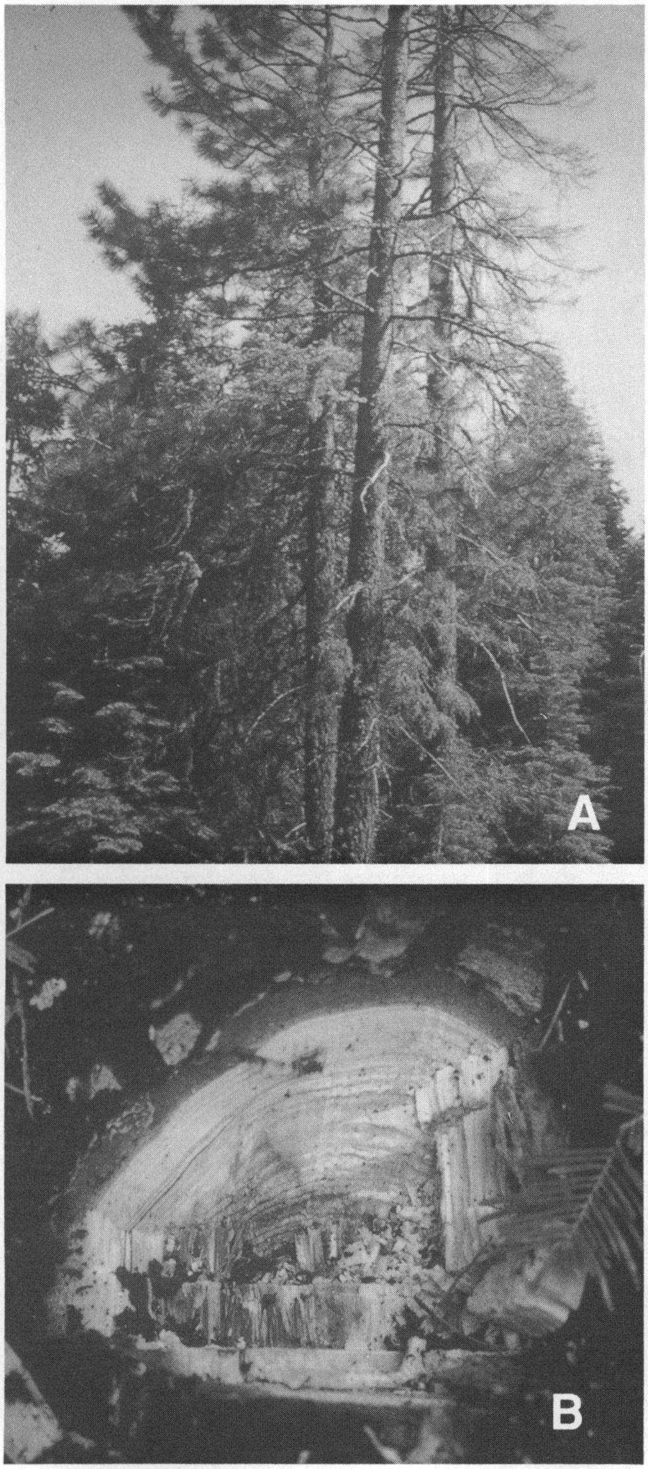

Figure 16-16. (A) White fir tree and (B) stump infected by Heterobasidion annosum. *Photos courtesy of USDA Forest Service, Region 6, Pest Management.*

infected stands may require clear-cutting followed by stump removal, or replanting with resistant or tolerant species (Filip and Schmitt 1990), or both.

Mistletoes

Dwarf mistletoes of several species attack the principal conifers of the region and are probably the most damaging pest group. As with the root rots, damage is most severe in established stands, and control is most effective during reforestation (Scharpf and Parmeter 1978). These parasites are actually flowering plants of the genus *Arceuthobium*. They spread from tree to tree by sticky seeds that are shot out of ripe fruits. Seeds stick to foliage, slide to the base of a needle when wet by rain, and germinate. The emerging radicle forces its way into the inner bark, where the mistletoe plant develops.

Mistletoe damages conifers by diverting growth to the area of infections, swelling branches near the mistletoe broom (Figure 16-17). Damage is most severe in silvicultural systems in which susceptible regeneration grows up beneath an infected overstory, exposing smaller trees to mistletoe seeds released from above (Hawksworth and Scharpf 1984).

The incidence and severity of mistletoe should be noted for each tree species during the pre-harvest stand exam, while the reforestation prescription is being developed. If mistletoe is present in or near the harvest unit, preventive actions can be planned. Post-planting corrective actions are very limited.

Where clear-cutting is feasible, mistletoe control is simple. The plants cannot survive on dead material; a newly planted crop will be disease-free if all infected residuals are destroyed. Thoughtful layout of clearcut boundaries can greatly reduce the rate of recolonization from infected trees outside the unit. When it is unfeasible to remove all infected trees prior to reforestation, resistant species should be planted. Douglas-fir mistletoe will not damage the true firs or any of the pines, for example, nor will the ponderosa pine or true fir mistletoes cross over to Douglas-fir. Species manipulation is often the only practical option for mistletoe control in mixed conifer forests.

If susceptible species must be regenerated beneath an infected overstory, the overstory must be promptly removed when seedlings are established because chances for infection increase as seedlings grow. Unfortunately, new infections remain hidden for 3 or more years, but if the overstory is removed within 5 years of seedling establishment, infection in the understory will be minimal. Infected seedlings should be removed during precommercial thinning.

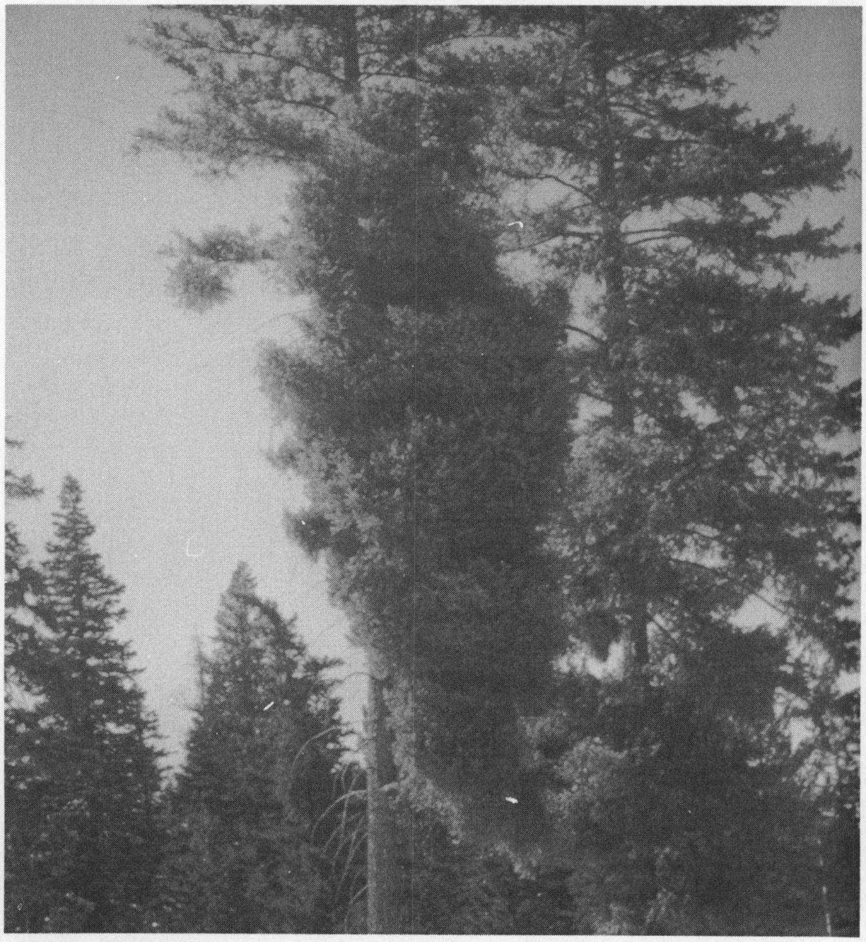

Figure 16-17. Large mistletoe broom (Arceuthobium) *in Douglas-fir. Photo courtesy of USDA Forest Service, Region 6, Pest Management.*

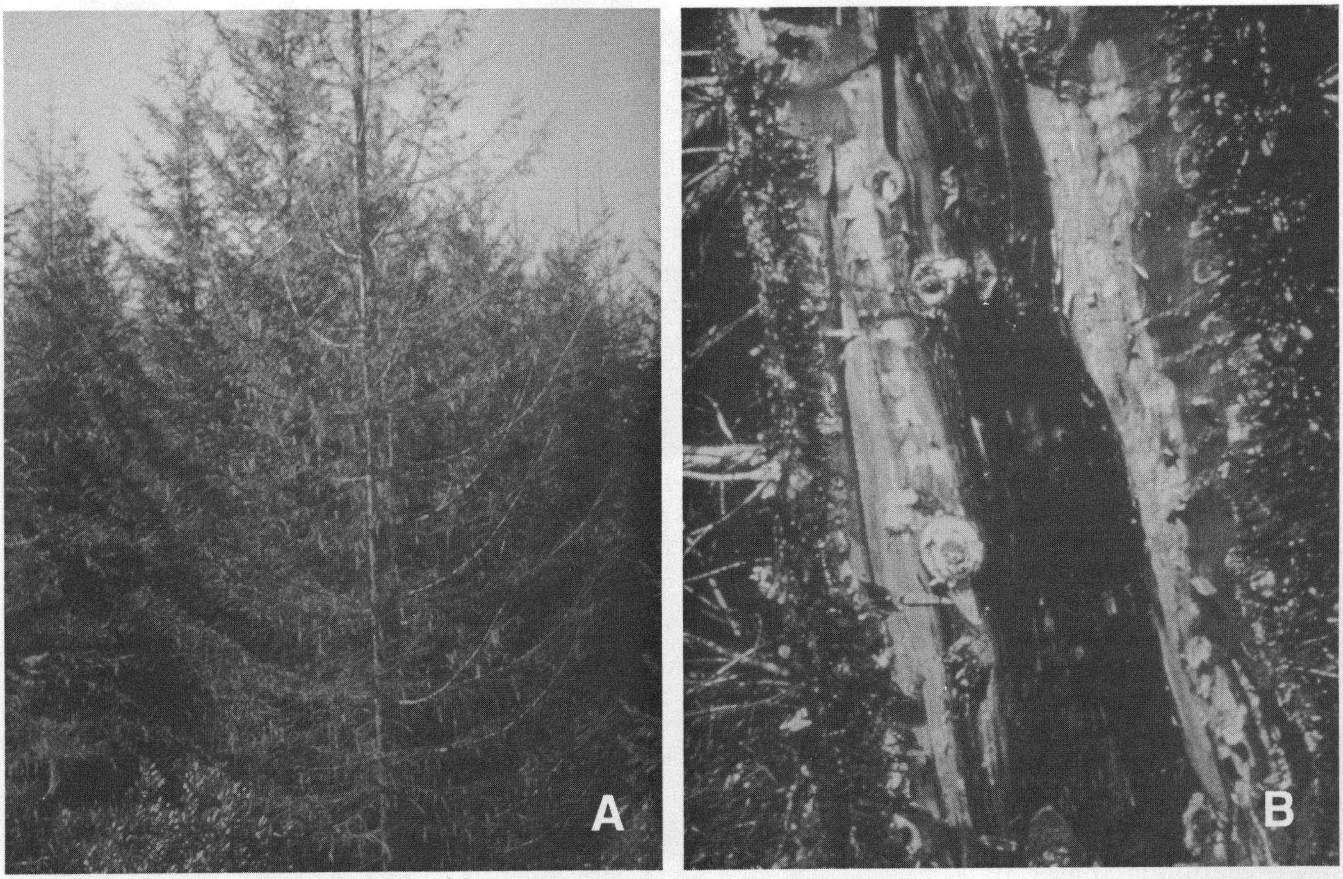

Figure 16-18. (A) Young Douglas-fir tree and (B) root infected with Leptographium (Verticicladiella) wageneri. *Photos courtesy of USDA Forest Service, Region 6, Pest Management.*

Stem decay

Stem decay of true firs is largely caused by the Indian paint fungus, *Echinodontium tinctorum.* Spores of this fungus commonly infect suppressed trees growing in the understory. The fungus lies dormant in the pith of the tree for decades before the onset of active decay.

Heart rots are generally considered to be a problem of mature or overmature timber, not reforestation. When managing true firs, however, the amount of cull at future harvest may well depend on the regeneration method used. Reliance on advance regeneration of true fir on sites where the trees are severely suppressed and significantly older than they look may lead to severe decay losses in the future stand (Filip et al. 1983). If advance regeneration of true firs meets reforestation goals, the incidence of Indian paint fungus in mature trees and the age and vigor of understory trees should be noted in the pre-harvest stand exam. Saplings show no external indication of infection, and no practical test exists to reveal latent infections. Using only young, vigorous advance regeneration, planting seedlings, or converting to another species will reduce the risks.

Diseases Introduced Into a Stand

Pathogens that spread by fungus spores carried on the wind, on insects, or in water or mud on vehicles may enter a stand at any time. Losses from these fungi can be minimized with good harvesting and regeneration practices.

Black-stain root disease

This disease is caused by the fungus *Leptographium (Verticicladiella) wageneri*, carried by root-feeding weevils (*Steremnius carinatus* and *Pissodes fasciatus*) and bark beetles (*Hylastes nigrinus*). These insects, like many of their forest relatives, are attracted initially to stressed trees. The fungus is transmitted during feeding or gallery construction and kills the tree by blocking water transport in the roots (Figures 16-18). As the tree dies, it becomes attractive to more beetles seeking places to breed, and the progeny, in turn, are infected by the fungus as they emerge (Hansen et al. 1986). The fungus also spreads locally via root grafts and grows for short distances through the soil.

Black-stain root disease is now widespread in the Pacific Northwest, but it is most damaging in southwestern Oregon and northern California. Disease incidence is strongly correlated with roads, skid roads, landings, and tractor logging and precommercial thinning operations. Seedlings can be killed by black-stain, but 10- to 20-year-old plantations show the most damage. The disease is often present but seldom damaging in mature forests. The principal risk to the new stand will come from active infection centers in adjacent plantations. Preharvest risk assessment should extend to these areas, and precautions should be taken if black-stain is found within 1 mile of a proposed harvest area.

As with other diseases, the best chance to prevent black-stain comes during harvest and reforestation. If a site is at high or moderate risk of black-stain infection, minimizing site disturbance during logging is especially important. Cable logging with minimum ground impact should be used wherever possible. If tractor logging is necessary, use appropriate equipment and well-planned skid trails to minimize soil disruption and keep drainage ways intact as much as possible. Black-stain hazards can also be reduced by thinning only during the hot summer months. Hansen et al. (1986) offer guidelines for reducing risks.

There are two host-specific varieties of black-stain in the region, one attacking Douglas-fir and the other attacking ponderosa and lodgepole pine. Establishing a mix of conifer species, especially along roads, skid roads, and landings, will slow the spread of the disease and ensure a stand if the Douglas-fir or pine is killed. Precommercial thinning attracts fungus-carrying beetles and weevils; thus, spacing trees wide enough to avoid thinning can prevent infection.

Port-Orford-cedar root rot

Port-Orford-cedar, one of the world's most valuable conifers, grows commercially only near the coast in southwestern Oregon and northern California. Its economic future is threatened by an introduced fungus, *Phytophthora lateralis*. The disease produced by this fungus has ramifications that extend beyond the loss of the cedar. If the disease cannot be controlled by current practices—

Figure 16-19. Port-Orford-cedar adjacent to road is infected with Phytophthora lateralis. *Photo courtesy of USDA Forest Service, Region 6, Pest Management.*

and it is uncertain at this point whether it can—harvest of other trees growing with cedar may be curtailed to limit the spread of the disease.

Phytophthora lateralis is a water mold with swimming spores. *Phytophthora* is normally associated with low-lying areas with poorly drained soils, not mountainous terrain where commercial Port-Orford-cedar is found. The fungus is carried upslope, however, in mud on road-building and logging equipment, and then it moves downhill in surface water. The propensity of cedar to regenerate on disturbed roadsides and in wet drainages increases the chances for contact between spores and roots (Figure 16-19). Within a few years of infection, the inner bark of the roots is destroyed and trees are killed.

Protection of old-growth and regenerated Port-Orford-cedar requires special precautions to avoid introducing *Phytophthora* during harvest and regeneration (Zobel et al. 1985). Specific practices vary with the situation; they range from dry-season logging and road building to road closures and steam cleaning of equipment. Careful planning is required in all areas near a harvest unit that are capable of supporting Port-Orford-cedar, even if these areas are not located in the unit. Presence of the fungus and vulnerability of cedar must be assessed downslope of the unit and along all haul routes. Areas designated for future management of Port-Orford-cedar must be carefully selected to be beyond the ready reach of spores carried in mud or water. Guidelines on preventing the spread of *Phytophthora* are available from the Siskiyou National Forest, Grants Pass, Oregon.

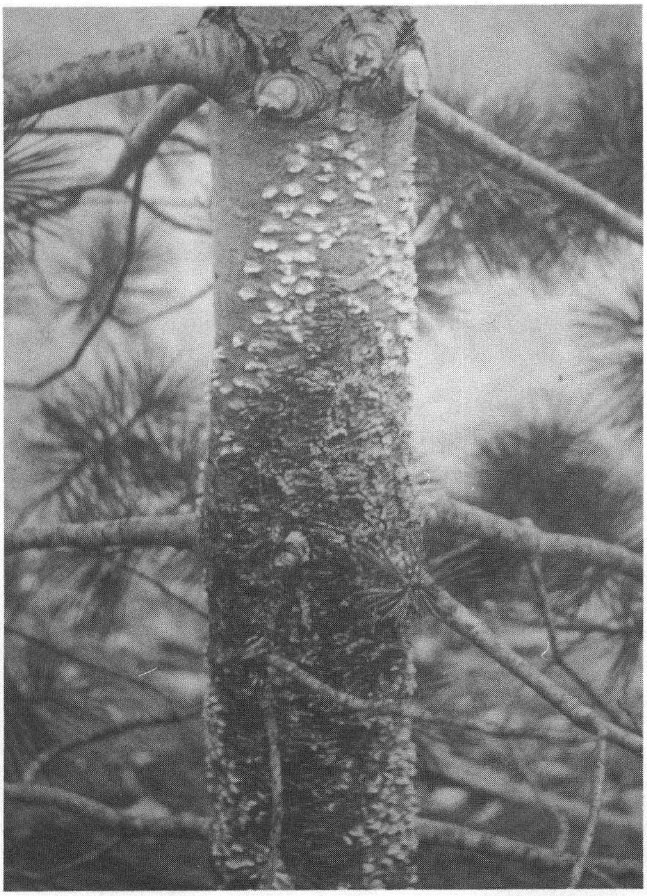

Figure 16-20. Young sugar pine showing fruiting bodies of Cronartium ribicola. *Photo courtesy of USDA Forest Service, Region 6, Pest Management.*

White pine blister rust

The rust fungus *Cronartium ribicola* attacks both white pine and sugar pine in the Northwest, spreading from the alternate hosts, species of *Ribes*, via windblown spores. The probability of infection is determined by the degree of genetic resistance in the pine, a complex and poorly understood mechanism, as well as the proximity of *Ribes* and the microenvironment. The spore sacs, or "blisters," of the fungus burst through the bark on branches or boles of infected trees to release the bright orange spores (Figure 16-20). A canker develops that eventually girdles the tree.

Future infection rates can be reduced, even with the limited knowledge available, by careful planning. Blister-rust hazard should be assessed before harvest, and regeneration plans developed accordingly. The incidence of rust on susceptible pines in adjacent units provides the most direct evidence of hazard. The abundance of nearby *Ribes* spp. should also be considered. Rust-resistant white pine and sugar pine should be used in areas of high infection hazard; seedlings are available from USDA Forest Service nurseries. Genetically unimproved white pine or sugar pine can be planted in areas of moderate to low risk if other precautions, such as *Ribes* removal or pruning, are taken (Goddard et al. 1985). After infection occurs, blister-rust damage can be limited in young, established stands by pruning (Hayes and Stein 1957) and precommercial thinning.

RAVEL

Effects on Reforestation

Ravel is the downslope movement of loose surface gravel, or scree, and woody debris. H.A. Froehlich and D.W.R. Miles (personal communication; data on file at Forest Research Laboratory, Oregon State University, Corvallis) provide a comprehensive review of the characteristics of ravel and its effects on reforestation. They describe scree-mantled soils as consisting primarily of angular soil particles >2 mm in diameter, with at least 50 percent of these particles >12.7 mm. Finer-textured soil may or may not underlie the coarser surface material. Such sites present problems for forest regeneration not only because of their surface instability but also because of their low water-holding capacity. Although more than 1 million acres of forest land in southwestern Oregon may hold ravel-prone soils (H.A. Froehlich and D.W.R. Miles, personal communication), mortality of planted seedlings on two ravel-prone study sites was less than 10 percent (D.H. McNabb, personal communication; data on file at Forest Research Laboratory, Oregon State University, Corvallis). On one of these sites with a 70-percent slope, cable logging increased ravel movement above pre-harvest levels by disrupting woody materials that were holding soil in place, but ravel movement quickly stabilized after logging.

Ravel movement can be accelerated by logging and prescribed fire. Rates of ravel movement after burning were several hundred times greater on slopes steeper than 60 percent than on less steep slopes (McNabb and Swanson 1990).

Protecting Seedlings from Ravel

Ravel can be prevented by using low-impact harvesting and site preparation to minimize disturbance of the site. Management practices should be directed at retaining fine soil particles in order to maintain the stability of the surface layer (H.A. Froehlich and D.W.R. Miles, personal communication). Because ravel-prone sites are steep, only cable or helicopter logging systems should be used. Lysne et al. (1982) describe how cable systems can disturb the ground. If burning is to be used for site preparation, the lowest intensity of fire that will open planting access or control weeds should be prescribed.

If ravel cannot be avoided, corrective measures can be taken to get seedlings established. Seedlings should be planted deep enough to place roots into any finer soils below the gravel layer (Hobbs 1982a; H.A. Froehlich and D.W.R. Miles, personal communication). Such deep planting, however, may create over-steepened slopes directly above the seedling, increasing chances of burial. Seedlings can be protected from burial by planting below stumps or by placing artificial barriers above seedlings (H.A. Froehlich and D.W.R. Miles, personal communication), including 1-by-4-inch wooden stakes, lath stakes holding Vexar™ tubes, and V-shaped structures made of wooden shingles attached to wooden stakes. On one ravel-prone site, however, such devices were found to be expensive and to produce only small increases in survival (McNabb and Crawford 1984); unprotected seedlings survived well. Larger-diameter seedlings are more resistant to damage or burial than smaller seedlings, but they may be more difficult to plant if the mineral soil beneath the ravel has a high rock content.

SUMMARY

Young seedlings in southwestern Oregon and northern California are faced with a host of biotic and abiotic impediments to their survival and growth. Competing vegetation, the depredations of wildlife, insects, and diseases, damage from excessive heat and cold, and difficulties posed by ravel-covered sites must all be competently managed if young regeneration is to thrive. This chapter discusses each of these limiting factors and proposes measures for prevention or control that have been identified in reforestation research in the region.

High soil surface temperatures threaten survival of seedlings, especially on south-facing sites. Naturally seeded regeneration appears to be more susceptible than nursery-grown seedlings. The effects of high temperatures can be mitigated by shade, either from live plants such as an overstory or surrounding vegetation, or from sources such as debris, shadecards, or polystyrene foam cups. Shade from live plants can threaten seedling survival and growth by increasing competition for resources. Larger or bushier Douglas-fir seed-lings can also show acceptable resistance to heat damage.

The most common cold-related damage to seedlings appears to be death of tissue from late frosts. Protection from frost is best accomplished through preventive measures—selecting an appropriate regeneration method, preparing the site properly, and regenerating with frost-resistant conifer species such as lodgepole pine and ponderosa pine. Regeneration methods that leave a shelterwood overstory can moderate extreme cold temperatures, but they can pose competition problems. Post-planting measures are limited: minimizing competition, removing brush to improve cold-air drainage, and replanting with frost-resistant species are probably the only options.

Competition from hardwoods, shrubs, and herbaceous vegetation can severely inhibit seedling survival and growth. Weed competition, in fact, is the most widespread hindrance to successful reforestation in the region. A basic understanding of the dynamics of competition and succession in plant communities is necessary to anticipate weed problems, choose regeneration methods and site-preparation techniques that minimize them (and avoid those that aggravate them), and select the most efficient post-planting control measures. Control is most effective when weeds are small.

Surrounding plants not only compete with conifers but harbor vertebrate and insect pests. Some vertebrate damage—e.g., from voles, rabbits, and wood rats—can be prevented by choosing site-preparation techniques that minimize cover. Pocket gophers and mountain beavers can be controlled through habitat manipulation before planting coupled with baiting or trapping afterward. Damage from deer and elk can be controlled by planting large seedlings, controlling weeds, or by using repellents or barriers. Porcupines can be controlled by hunting.

Four major groups of insects threaten survival and growth of young conifers: sap-suckers, root beetles, terminal feeders, and secondary bark beetles. Root beetles can also transmit the fatal black-stain root disease to Douglas-fir. Preventing damage by maintaining seedling health and managing insect habitat in the surrounding area is the best policy. Insecticides may not be available, or may be impractical to apply over large areas, or may increase populations of other insect pests. Some insects are vulnerable to disorientation by artificial attractants during mating periods.

Diseases can be present at any time during the life of a stand. Significant losses begin to be apparent at about 10 years of age. Phytophthora root rot is the most common nursery disease. Root rots, mistletoes, and stem decays are the primary diseases that exist in natural and planted stands. Black-stain root disease, Port-Orford-cedar root rot, and white pine blister rust are the most important diseases that can be introduced into a stand. Tree diseases are far more easily prevented than cured. Planting resistant seedlings, blocking disease vectors, and managing sources of inoculum in existing stands are the best measures of control.

Ravel, the movement of scree and woody debris on steep slopes, can bury or damage planted seedlings. Ravel can be prevented by using low-impact harvesting and site-preparation methods to maintain soil stability. Establishment can be improved by planting seedlings deeply enough to place roots in the mineral soil below the surface layer. Larger-diameter seedlings are more resistant to damage or burial, but they may be more difficult to plant on ravel-prone slopes if the soil beneath is rocky.

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