

STAND ESTABLISHMENT AND TENDING IN THE INLAND NORTHWEST

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ABSTRACT

The moist, cold, and dry forests of the Inland Northwest occupy approximately 144 million acres. Ponderosa pine, lodgepole pine, western white pine, western larch, and Douglas-fir are usually the preferred commercial species of the area. These early-seral species are relatively resistant to endemic levels of insects and diseases. They tend to grow rapidly and in general produce commercial products at a young age, especially using focused management actions packaged in silvicultural systems that are documented in silvicultural prescriptions. Even-aged systems (clearcut, seed-tree, and shelterwood) are the most appropriate for growing commercial products. In limited circumstances uneven-aged systems may be appropriate on sites where ponderosa pine is the late seral-species. Planting of improved, site adapted trees usually offer the greatest control over the amount, kind, and establishment of plantations. The control of competing vegetation during the site preparation and tending phases of the silvicultural system is usually extremely beneficial in enhancing tree growth and product development. The forest soils of the Inland West are generally deficient in nitrogen and, in some settings, also potassium deficient. The organic and mineral surface layers, often containing ash and loess soils, are vulnerable to compaction, displacement, or damage from fires (prescribed and wild) or mechanical forest operations. Therefore, soil and its conservation should be integral to all activities included in a silvicultural system. For production forestry, herbicides offer an alternative that can maintain the soil resource yet control competing vegetation and most often yield excellent results when properly applied. Cleanings, weedings and thinnings are integral parts of the silvicultural system. These and all parts of silvicultural systems designed to produce commercial products can be readily quantified, displayed, and visualized (spatially explicit) through time using the Forest Vegetation Simulator.

KEYWORDS: Forest products, silvicultural systems, regeneration, stand tending, fertilization, site preparation, forest management.

FORESTS OF THE INLAND NORTHWEST

The Inland Northwest (144.2 million ac) forest region is defined by the Bitterroot, Selkirk, Cabinet, Salmon River, Lemhi, Steens, Purcell, Cascade, and Blue mountain ranges with many having elevations over 5,000 ft. This rough and complex topography results in a variety of forest settings ranging from steep slopes in narrow V-cut canyons to gentle rolling slopes in wide river valleys. During the Pleistocene, alpine glaciers shaped many of the canyons and valleys throughout the area. Now these glaciated landscapes are

covered with a mantle of glacial till often compacted on the valley floors. Much of the fine silt outwashed by the glaciers was redeposited by winds leaving deep layers of loess deposits over many landscapes. Some 15,000 to 12,000 years ago, Glacial Lake Missoula repeatedly filled and emptied, flooding much of northern Idaho and eastern Washington removing topsoil and redistributing the surface sand, silt, and gravels. The eruption of pre-historic Mt. Mazama (Crater Lake, OR) about 7,000 years ago deposited a fine textured layer of ash up to 25 inches thick across the area. The granitic and metasedimentary rocks, ash, and

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loess deposits throughout the area are continually being modified by disturbance events giving rise to a wide variety of soils (Jain and Graham 2005, Quigley et al. 1996).

Moist marine air originating from the Pacific Ocean moderates temperatures within the Inland Northwest, while continental dry and cold air from the east brings cold weather in winter and hot weather in the summer. Dry Arctic air brings damaging frosts in winter and cool periods in summer and the interaction of the marine and continental masses brings convective precipitation and lightning in summer and warm wet periods in the winter. These air masses, along with the heterogeneous and rugged topography, create a highly variable climate, which in turn, supports mosaics of compositionally and structurally diverse forests. Historically (1850 to 1900), 19 percent (27.4 million acres) of the Inland Northwest (144.2 million acres) was covered by dry forests, with 30 percent of them occurring below 4,000 feet and the remainder occurring at higher elevations. Moist forests covered 18 percent (25.9 million acres) of the region. The cold forests historically made up 10 percent of the area with 99 percent of them growing at elevations exceeding 4,000 feet (Hann et al. 1997).

Moist Forests

Moist forests of the Inland Northwest occur in two locations, the eastern Cascade Mountains (east of the Cascade Crest in Washington and Oregon) and the Northern Rocky Mountains (northeastern Washington and Oregon, northern Idaho, and western Montana) (fig. 1). They grow at elevations ranging from 1,500 to 5,300 feet and occasionally occur at elevations up to 6,000 feet (Foiles et al. 1990, Graham 1990, Packee 1990, Schmidt and Shearer 1990, Hann et al. 1997) (fig. 1). These forests are influenced by a maritime climate with wet winters and dry summers. Most precipitation occurs during November through May, with amounts ranging from 20 to 90 inches (Foiles et al. 1990, Graham 1990, Packee 1990, Schmidt and Shearer 1990). Precipitation comes as snow and prolonged gentle rains, accompanied by cloudiness, fog, and high humidity. Rain-on-snow events are common January through March. A distinct warm and sunny drought period occurs in July and August with rainfall in some places averages less than one inch per month. Soils that maintain these forests include, but are not limited to, Spodosols, Inceptisols, and Alfisols. A defining characteristic of the Northern Rocky Mountains is the layer of fine-textured volcanic ash (up to 25 inches thick) that caps the residual soils.

For both locations, the vegetation complexes range from early- to late-seral, and occur within a landscape mosaic possessing all possible combinations of species and seral

stages. Potential vegetation type (PVT) is a classification system based on the physical and biological environment characterized by the abundance and presence of vegetation in the absence of disturbance (Daubenmire and Daubenmire 1968, Hann et al. 1997, Smith and Arno 1999). They are defined by and named for indicator species that grow in similar environmental conditions (Hann et al. 1997). The PVTs in the Northern Rocky Mountains include western redcedar (*Thuja plicata*), western hemlock (*Tsuga heterophylla*) and grand fir (*Abies grandis*) with western white pine (*Pinus monticola*), western larch (*Larix occidentalis*), lodgepole pine (*Pinus contorta*), Douglas-fir (*Pseudotsuga menziesii*) and ponderosa pine (*Pinus ponderosa*) as the early- and mid-seral species (Daubenmire and Daubenmire 1968, Hann et al. 1997). The eastern Cascades PVTs include western redcedar, western hemlock, grand fir, white fir (*Abies concolor*), and noble fir (*Abies procera*). The early- and mid-seral species include lodgepole pine, Douglas-fir, and ponderosa pine while western white pine and western larch are less abundant when compared to forests in the Northern Rocky Mountains (Franklin and Dyrness 1973, Lillybridge et al. 1995).

Lush ground-level vegetation is the norm in the moist forests. The vegetation complexes are similar to those occurring on the west-side of the Cascade Mountains and in some Pacific coastal areas. Tall shrubs include vine maple, (*Acer circinatum*), Rocky Mountain maple (*Acer glabrum*), Sitka alder (*Alnus sinuata*), devil's club (*Oplopanax horridum*), rose (*Rosa* spp.), gooseberry (*Ribes* spp.), huckleberry (*Vaccinium* spp.), and willow (*Salix* spp.). Forbs include baneberry (*Actaea rubra*), pathfinder (*Adenocaulon bicolor*), wild ginger (*Asarum caudatum*), queencup beadlily (*Clintonia uniflora*), bunchberry dogwood (*Cornus canadensis*), and golden thread (*Coptis occidentalis*) (fig. 2).

Throughout the moist forests, native disturbances (snow, ice, insects, disease, and fire) singly, and in combination, created heterogeneity in patch sizes, forest structures, and compositions. Ice and snow created small gaps and openings, thinning forest densities and altering species composition. Native insects (e.g., pine beetle [*Dendroctonus* spp.]) and diseases (e.g., root rots [*Armillaria* spp.]), mistletoe (*Arceuthobium* spp.) infected and killed the very old or stressed individuals which tended to diversify vegetation communities (Hessburg et al. 1994, Atkins et al. 1999). Fires played a role in creating a mosaic of forest compositions and structures. Non-lethal fires (low intensity and severity surface fires that cleaned the forest floor, killed and/or consumed small trees and shrubs, and killed lower branches of overstory trees while leaving them alive) occurred at relatively frequent intervals (15 to 25 yrs) in a

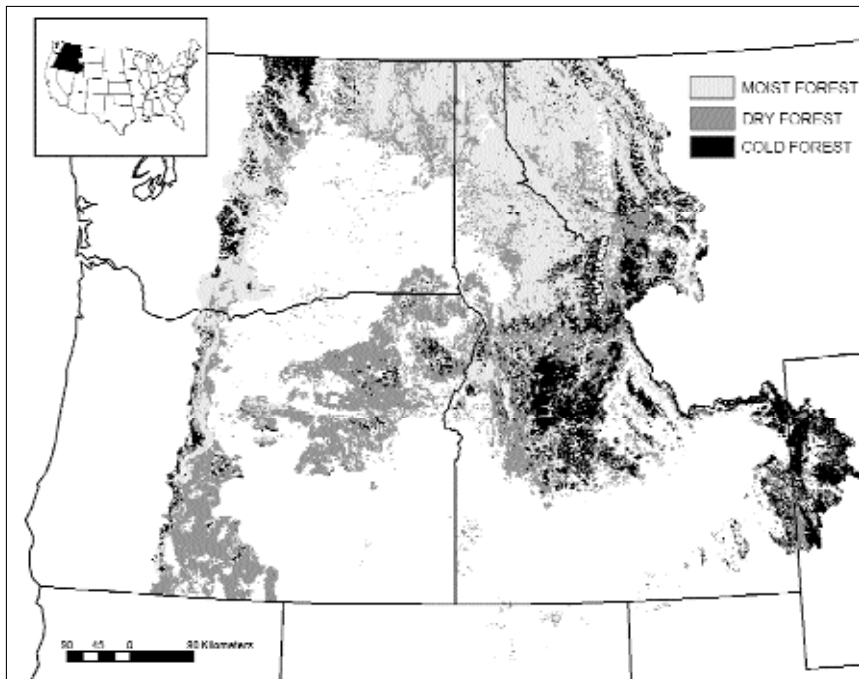


Figure 1—Extent of the forests of the Inland Northwest (144.2 million acres). The cold forests containing subalpine fir and Engelmann spruce potential vegetation types (PVTs) occupy 14.4 million acres (10%) of the area, the dry forests containing ponderosa pine, Douglas-fir, and dry grand fir PVTs occupy 27.4 million acres (19%), and the moist forests containing the moist grand fir/white fir, western redcedar, and western hemlock PVTs occupy 25.9 million acres (18%) (Hann et al. 1997).



Figure 2—A young (100-year-old) stand of western white pine exhibiting a lush layer of ground-level vegetation located north of Wallace, Idaho.

quarter of the area. Lethal fires (intense and severe crown fires that killed and/or consumed the vegetation in all canopy layers) burned about a quarter of the area at intervals of 20 to 150 years but occasionally extended to 300 years. The mixed-fire regime (a combination of lethal and non-lethal fires) occurred across the rest of the moist forests at 20 to 150 year intervals. Fires typically started burning in July and were usually out by early September when the weather changed (Hann et al. 1997). Although fire exclusion played a role in altering the moist forests of the Northern Rocky Mountains, introduction of a European stem rust, white pine blister rust (*Cronartium ribicola*) in 1910, caused the greatest change (Neuenschwander et al. 1999, Fins et al. 2001). The rust infects all five-needle pines, and subsequently decimated the abundant western white pine (fig. 3). Because the rust killed so many trees, the majority of surviving pines were harvested under the assumption they too would succumb to the rust (Ketcham et al. 1968).

Cold Forests

Within the Inland Northwest, cold forests occur at high elevations occupying about 10 percent of the area. They occur primarily in northern Idaho, central Idaho, and in the Northern Cascades Mountains of Washington (fig. 1). Growing seasons in cold forests are short, ranging from approximately 90 days at the lower elevations to just a few weeks at the higher elevations, and frosts can occur any time of the year. These forests are limited by poorly developed soils, and limited by moisture in some areas. Nearly

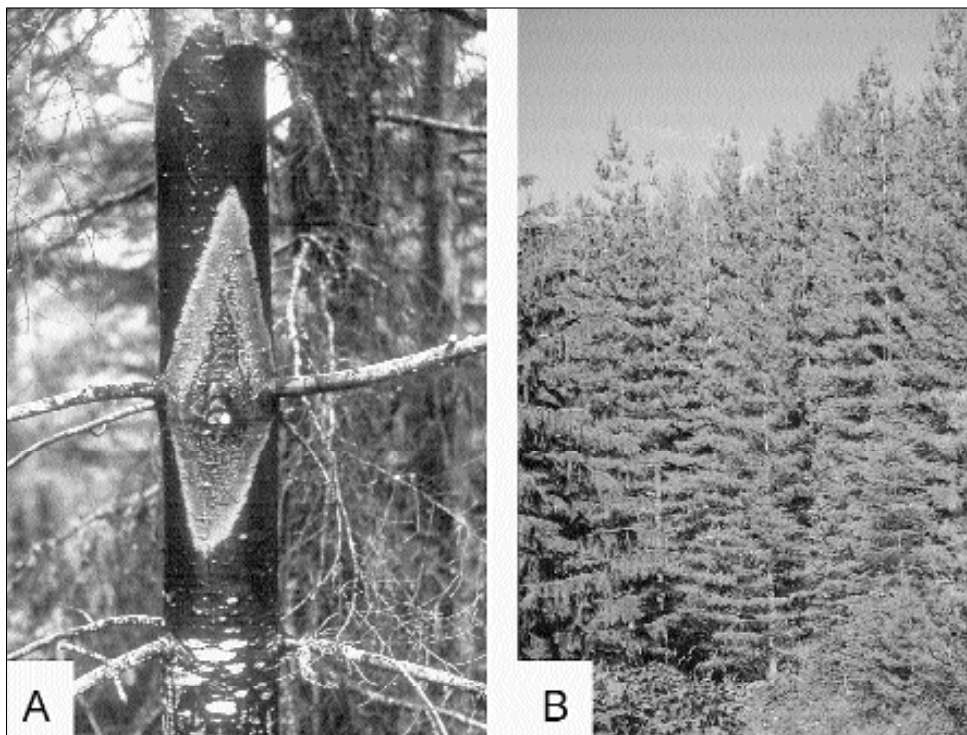


Figure 3—Western white pine blister rust (A), an introduced disease from Europe, in the early 1900s devastated much of the native western white pine. However through breeding programs and natural resistance, western white pine is once again a viable commercial species (B). This stand of first-generation blister rust-resistant pines is $\approx$ 50 years old, $\approx$ 100 to 120 feet tall, and $\approx$ 18 to 22 inches in diameter.

all (99 percent) of the cold forests occur over 4,000 feet, but cold air drainage allows some cold forests to extend below 4,000 feet (Hann et al. 1997).

On settings dominated by subalpine fir (*Abies lasiocarpa*), mean annual temperatures range from 25° to 40° F. Precipitation generally ranges between 24 and 75 inches with the majority falling in the form of snow and sleet. Snow comes early and stays late and can reach depths over 500 inches on settings in the Cascade Mountains with lesser amounts where lodgepole pine persists (central Oregon and central Idaho) (Alexander et al. 1990). The soils supporting the cold forest are relatively young. They were covered by extensive mountain glaciers during the Pleistocene and have been free of ice less than 12,000 years. At the higher elevations, most soil parent material is alluvium or glacial tills, but soil surfaces range from very weakly weathered (cobble with no organic layers) to thick soils composed primarily of organic materials.

Like the moist forests, lush ground-level vegetation is the norm for most settings in the cold forests. Tall shrubs include false huckleberry (*Menziesia ferruginea*) and Sitka alder while the dominant medium and low shrubs are often huckleberries. Pinegrass (*Calamagrostis rubescens*), blue-joint reedgrass (*Calamagrostis canadensis*), and elk sedge (*Carex geyeri*) typify the graminoids occurring in the cold

forests. Some of the most commonly occurring forbs include beargrass (*Xerophyllum tenax*), round-leaved violet (*Viola orbiculata*), and queencup beadlily (Cooper et al. 1991).

The PVTs dominating the cold forests include subalpine fir and subalpine fir/Engelmann spruce (*Picea Engelmannii*). Western larch and lodgepole pine are early-seral species in the subalpine fir/Engelmann spruce PVT, Douglas-fir and western white pine are mid-seral species, and grand fir, Engelmann spruce, and subalpine fir are late-seral species (fig. 4). The mixes of these species occurring in the subalpine fir/Engelmann PVT are highly dependent on elevation (and associated climate), and disturbance frequency and type.

Depending on the physical setting, the cold forests of the Inland Northwest historically (1850-1900) burned at 25 to 100 year intervals. Approximately 10 percent of these forests were burned by non-lethal surface fires, every 30 to 100 years. Lethal crown fires burned 25 to 30 percent of the cold forests every 30 to 100 years with the longer intervals occurring in moist areas. During the short fire season ($\approx$ 60 days), a mixed fire regime burned about 60 percent of the cold forests at 25- to 100-year intervals, with occasional large fires occurring every 100 years (Hann et al. 1997).



Figure 4—A thinned stand of lodgepole pine (an early-seral species) growing on a subalpine-fir potential vegetation type.



Figure 5—A young (70-year-old) ponderosa pine stand being maintained by a low intensity surface fire. Note the presence of some ground-level vegetation.

Dry Forests

Dry forests occur across a wide range of elevations in northeastern Washington, northeastern Oregon, central and southern Idaho, and south-central Oregon (fig. 1) (Hann et al. 1997). Soil parent materials include granites, metasedimentaries, glacial tills, and basalts. Vegetation in these forests is usually limited by water availability and often is subject to drought. Nutrient deficiencies develop in eroded areas that can limit forest development. Douglas-fir, ponderosa pine, and dry grand fir/white fir (PVTs) dominate these settings (Hann et al. 1997). When western larch is present in dry forests it is always an early-successional species (dominant after disturbance). Grand fir/white fir or Douglas-fir are late-successional species that are usually more shade-tolerant than the early-seral species they succeed, while ponderosa pine can play both roles, depending on the PVT (Daubenmire and Daubenmire 1968, Hann et al. 1997). Surface vegetation in the dry forests includes shrubs (kinnikinnick (*Arctostaphylos uva-ursi*), *Ceanothus* spp., snowberry (*Symphoricarpos albus*), ninebark [*Physocarpus malvaceus*]), grasses (pine grass) e.g., bromes (*Bromus* spp.), and sedges (*Carex* spp.) (Foiles et al. 1990, Hermann and Lavender 1990, Oliver and Ryker 1990) (fig. 5).

Fire, insects, diseases, snow, ice, and competition thinned these forests, and surface fires provided opportunities for plant regeneration (Pearson 1950, Foiles et al. 1990, Hermann and Lavender 1990, Oliver and Ryker 1990). In concert, these disturbances historically maintained a variety of structural and successional stages. Fire exclusion, harvesting, and changes in fire regime altered the composition and structure of the dry forests (Hann et al. 1997). The area burned currently by non-lethal surface fires is estimated to be less than 50 percent of the dry forests and the mean interval of these fires is estimated to be to 40 to 80 years. Mixed-fires are estimated to burn 35 percent of the dry forests with a mean interval of 45 to 60 years and lethal fires are estimated to burn 20 percent of the dry forests at mean intervals of 45 to 60 years (Hann et al. 1997).

FOREST SOIL

Soil is the foundation of a forest ecosystem and its character is a major contributor to site productivity (Harvey et al. 1987). In general, nitrogen (N) is the most limiting nutrient in most forests (Moore 1988, Moore et al. 1991). However, there is evidence that potassium (K) also plays a key role, especially in relation to disease and insect infestation (Moore et al. 1994). As stated earlier, much of the Inland Northwest is covered by rich loess and ash soils.

These materials, along with the weathering of the parent materials (granitics, basalts, meta-sediments), all contributed to the productivity of the forest. Therefore, conservation of the soil resource is essential to maintain and sustain forest productivity.

The character of the litter, humus, soil wood, and surface mineral layers of forest soils are critical when developing silvicultural systems (Harvey et al. 1987, Jurgensen et al. 1997). These soil layers are most easily and commonly disturbed by silvicultural activities, yet they are crucial to forest productivity. Depending upon the setting, organic matter (OM) is generally concentrated near the soil surface. Organic matter maintains the nitrogen cycle in soils through its decomposition and by facilitating N fixation (the process of making elemental N into a form that plants can use) and N storage of N (Jurgensen et al. 1979). Physical properties and nutrition are very important soil attributes but the biological component is integral for maintaining forest productivity. In particular, ectomycorrhizae (fungi that have a symbiotic relationship with the plants) and their environment are critical for maintaining soil productivity. Ectomycorrhizae establish on the root systems of trees and facilitate the uptake of both water and nutrients by the tree, which in turn supplies nutrients to the fungi (Harvey et al. 1981, Harvey et al. 1987).

Woody Residues

Although they are not a soil component, the quantity, quality, and disposition of coarse woody debris (CWD) can influence forest soils (Harvey et al. 1987, Jurgensen et al. 1997). The quantity of downed material can vary dramatically, depending on site, forest conditions, and forest treatments (Brown and See 1981). Physically, woody residues protect soil from erosion, displacement and compaction. Residues provide shade and protection from wind and snow and can protect newly established seedlings from livestock (Edgren and Stein 1974, Graham et al. 1992). However, falling or rolling logs can damage regeneration and fuel loadings can threaten forests by increasing the fire hazard (Brown et al. 2003). Decaying logs, especially those with the incipient and advanced forms of decay, are excellent substrates for non-symbiotic nitrogen fixation and if nitrogen-fixing plants such as ceanothus (*Ceanothus* spp.), buffaloberry (*Shepherdia canadensis*), or leguminous forbs are not present, non-symbiotic forms of nitrogen fixation can be significant.

In addition to CWD, organic input to forest soils comes from many other sources. Grasses, shrubs, root turnover, needle fall, etc. contribute to soil OM. In general, CWD

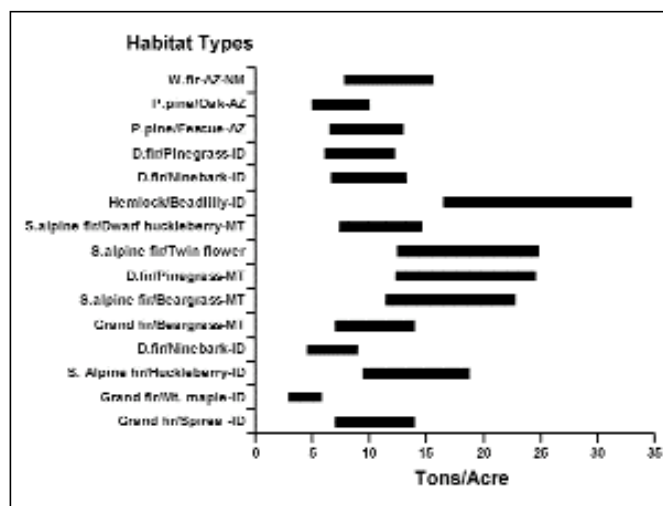


Figure 6—The amount of coarse woody debris suggested by Graham et al. (1994) for maintaining soil productivity in the forests of the Rocky Mountains. A=Arizona, I=Idaho, M=Montana for the habitat types where the recommendations apply.

comes from tree boles and limbs over three inches in diameter (smaller material is usually considered a fire hazard). Accumulation of CWD on the forest floor depends upon the amount of decomposition occurring on a site and the frequency and severity of wildfires that burn a forest (Brown and See 1981, Brown 1983). In general, those forests that were frequently burned by low intensity surface fires tended to accumulate and use less CWD than the cold and moist forests with long fire-return intervals (Graham et al. 1994a, Hann et al. 1997). The amount of CWD suggested for maintaining soil productivity ranges from 3 tons per acre on ponderosa pine settings to over 30 tons per acre on western hemlock settings in moist forests (fig. 6) (Graham et al. 1994a).

Litter

Unconsolidated and undecomposed litter directly provide both N and ectomycorrhizae habitat for soil function. This material is composed of organic materials from trees, shrubs, grasses, forbs, and other plant material. Litter is not usually important for ectomycorrhizal activity, but if moisture is maintained in these layers, ectomycorrhizae can be present (Harvey et al. 1987). However, through its decay, litter becomes a greater soil contributor. Litter can vary widely in amount, composition, and structure depending on forest type and PVT, as well as fire-return interval and decomposition rate. Litter protects the soil from erosion and retains moisture in the lower layers (Pannkuk and Robichaud 2003.) and protects soils from compaction (Lull 1959). Litter can be an impediment to both natural and artificial tree regeneration. If the litter layer is thick, which often



Figure 7—A large accumulation of brown cubical rotten wood occurring in a lodgepole pine stand near Butte, Montana. In these forests, this material can be a major component of the surface soil.

occurs in ponderosa pine forests where decomposition is slow and fire has been excluded, tree seeds falling on this layer germinate, but root elongation may not keep pace with litter drying (Haig et al. 1941, Pearson 1950). On the other hand, if litter remains moist during germination and early seedling growth (a situation that may be found in many moist forests), establishment of tree seedlings on organic layers is quite common (Minore 1972). Because this most often occurs in the moist and cold forests with late seral species, the desired mix of species for commodity production is not often realized.

Humus

Even though the humus (decomposed material in which plant parts are indistinguishable) soil layer may be very thin (i.e. < 0.25 in), it can be a prime site for both N and ectomycorrhizae. For example, in the surface 12 inches of a Douglas-fir/ponderosa pine forest soil, over 20 percent of the total N can occur in the humus and over 30 percent of the ectomycorrhizae (Harvey et al. 1987). In addition, it often has high moisture contents and is rich in calcium, potassium, and magnesium. This layer often represents the transition between organic layers and the mineral soil and, when it is burned over, it is a superb site for seed germination and seedling establishment (Haig et al. 1941).

Soil Wood

A component of forest soils that is often overlooked is soil wood which is highly decomposed wood incorporated into mineral soil horizons and is usually in the form of brown cubicle rot (fig. 7) (Harvey et al. 1987). As it ages and further decomposes, it can take on a much finer texture. As with the other organic components of soil, the quantity and character of soil wood can be quite variable. For example, the amount of soil wood in the surface 12 inches of a forest soil is 20 percent in cold forests, 22 percent in Douglas-fir forests, and over 26 percent in moist forests (Harvey et al. 1987). Soil wood does not usually occur as a layer within soil but rather occurs in deep pockets created by buried logs and decaying stumps (Reinhardt et al. 1991). Soil wood protects soils from compaction, provides OM to the mineral soil, is also an important source of N (≈ 20 percent of the amount in surface 12 inches of soil) and is an excellent substrate for ectomycorrhizae (≈ 50 percent of the amount in surface 12 inches of soil) (Harvey and others 1987). Because of its water-holding availability and nutritional, biological, and physical characteristics, soil wood is often prime habitat for rooting. In the cold forests, these materials, intermingled with exposed parent material, can constitute the majority of the soil (Graham et al. 1994a). Forests dominated by pines and Douglas-fir develop brown cubical rotten wood products that are deposited on the forest floor and are subsequently incorporated into the mineral soil. These products can persist in soils for hundreds of years and during that time provide soil structural and nutritional benefits. In contrast, grand fir/white fir develop white rotten wood products that are dispersed in soil relatively rapidly (decades), thus shortening their contribution to soil productivity (Larsen et al. 1980, Harvey et al. 1987).

Surface Mineral Soil

The surface 6 to 12 inches of mineral soil is derived from the deposits and parent materials of the site, but is also highly influenced by vegetation, surface organic layers and disturbance history inherent to the PVT. The OM incorporated into shallow mineral horizons carries important properties into the mineral soil. Mineral soil with robust OM amounts has better nutrition, water-holding capacity, and structure than soils with small amounts of OM. In addition, OM-rich mineral soils are excellent sites for nitrogen fixation and ectomycorrhizae (Harvey et al. 1987). Surface mineral layers are highly susceptible to compaction and displacement and soils with high volcanic ash content are particularly sensitive to forest operations (Harvey et al. 1989b).

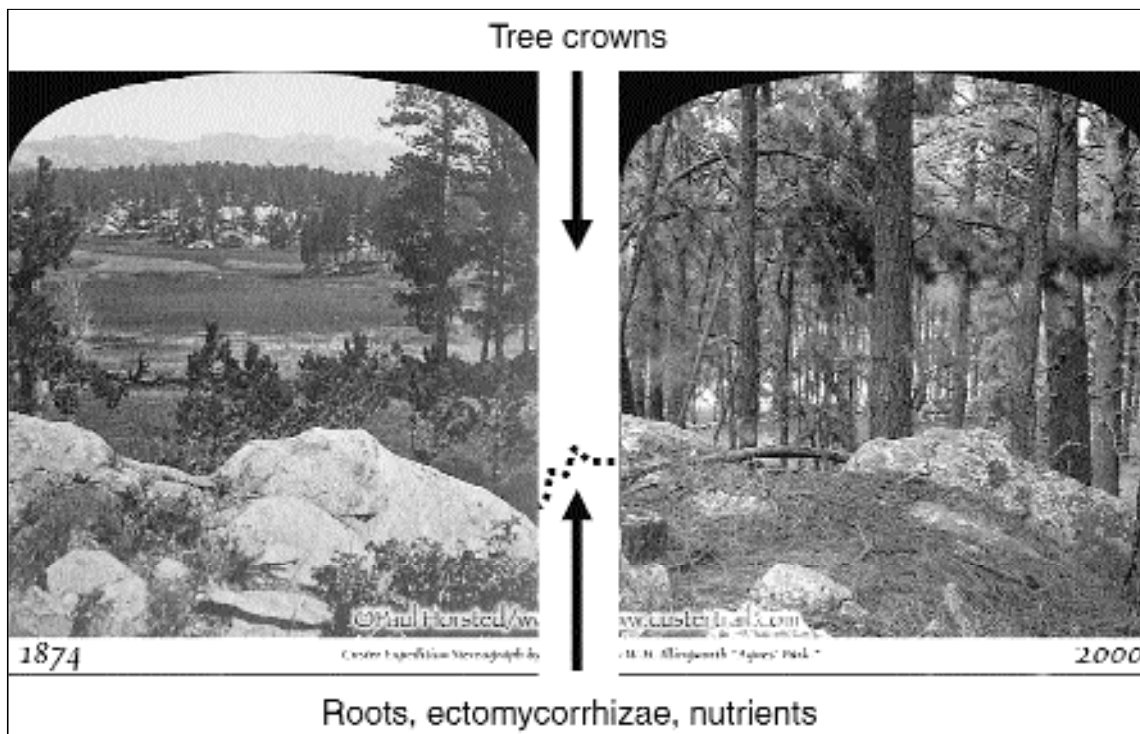


Figure 8—When fires are excluded from ponderosa pine forests, organic layers tend to accumulate and tree roots, ectomycorrhizae, and nutrients tend to concentrate in these layers. Note the contrast between the amount of organic material on the forest floor when General Custer came through the Black Hills in 1874 and the amount that has accumulated around the rocks by 2000. Photos courtesy of Paul Horsted/custertrail.com (Grafe and Horsted 2002).

Altered Forest Soils

Soils in many forests are different from those that occurred historically. Soils have been altered through species changes (within shrub, tree, or forb components), organic material accumulation on the forest floor, and by soil compaction and displacement. These changes have been the result singly, or in combination of fire exclusion, timber harvesting, animal grazing, and climate shifts. There is a gradual shift in the proportion of soil nitrogen reserves and OM in mineral layers of pine forests to surface organic layers in fir forests. Accumulation of both above-and below-ground biomass from roots, needles, and boles in fir forests is accelerating activities of decomposers by increasing and changing the basic substrate they utilize (Harvey 1994). Associated with these changes in litter type and quantity is a likely change in soil surface chemistry, including allelopathic substances with the potential to alter a variety of microbial activities (Rose et al. 1983). Forests dominated by grand fir tend to concentrate both nitrogen and potassium in their foliage; these forests often have live crowns extend down to the soil surface (Mika and Moore 1990, Moore et al. 1991). In general, this combination of a low

canopy structure with nutrients and microbial activities concentrated in or near the soil surface make both of these critical ecological resources susceptible to mechanical and fire destruction (fig. 8).

GROUND-LEVEL VEGETATION

In the forests of the Inland Northwest, ground-level vegetation is highly diverse with the cold and moist forests containing lush and diverse shrub, grass, and forb communities (fig. 2) (Daubenmire and Daubenmire 1968, Pfister et al. 1977, Cooper et al. 1991). Each plant in these communities has a different strategy for reproducing and surviving disturbances (Noste and Bushey 1987). Ground-level vegetation can also play many roles such as maintaining nutrients on a site after a disturbance, providing OM to the forest floor, protecting soils from erosion, and facilitating nutrient cycling (Yarie 1980, Pannkuk and Robichaud 2003). These plants tend to turnover a greater percentage of their biomass each year through litter fall than do trees. Therefore, they tend to cycle nutrients and OM more readily than trees.

Ground-level vegetation often aggressively responds to canopy openings and forest floor disturbances. Species that may not be present before a disturbance can proliferate after a disturbance. For example, canopy removal and prescribed fire can facilitate robust development of *Ceanothus* spp. especially in the cold and moist forests even though none was present pre-disturbance. Seeds of *Ceanothus* spp. lie in wait in the forest floor for scarification through heat to germinate; these species can rapidly occupy a site after disturbance (Noste and Bushey 1987). Other ground-level vegetation, such as alder, willow, and maple, are aggressive resprouters from the root crown, rhizome or above-ground stem. Some species are exceptional at resisting or enduring disturbances. For example, pine grass in the dry and moist forests and bear grass in the cold forest readily survive disturbances.

When it comes to producing forest crops, ground-level vegetation often competes aggressively with the establishment and growth of conifers (Baumgartner et al. 1986, Boyd 1982). In all forests, the forb, shrub, and grass layers can present formidable competition for nutrients, water, and light with tree seedlings. In addition, it can interfere with conifer development by occupying sites with roots, even though the area appears to be unoccupied and, even though ground-level vegetation may be dead, its root systems can interfere with tree planting. Also, ground-level vegetation can be allelopathic, that is emitting toxins both when the plant is alive and dead, interfering with seed germination and tree development (Ferguson 1991). Indirectly, ground-level vegetation can supply habitat for damaging animals, facilitating trampling, browsing and girdling damage on plantations (Kingery and Graham 1991, Graham et al. 1992, Ferguson 1999).

SILVICULTURAL SYSTEMS

In general, silviculture can be defined as the art and science of controlling the establishment, growth, competition, health, and quality of forests and woodlands to meet the diverse needs and values of landowners and society on a sustainable basis (Helms 1998). The processes silviculturists use to manipulate forest vegetation are included in a silvicultural system and documented in a silvicultural prescription. A silvicultural system outlines a series of treatments over the life of a stand to fulfill a set of values or interests for a particular landowner (Schlich 1906). The prescription is the formulation of a silvicultural strategy using biological, managerial, and economic knowledge to meet stand management objectives (Smith et al. 1997,

Nyland 2002). This plan should ensure that future yields of goods are conserved while harvesting or utilizing currently available goods (Smith et al. 1997). Most often, the early- and mid-seral species are the fastest growing and most tolerant of endemic diseases and insects and are readily managed using well-honed silvicultural systems so, therefore, they are the preferred species for timber and fiber production.

Even-Aged Silvicultural Systems

Even-aged silvicultural systems usually create and maintain stands with trees representing one age class, or a narrow range of age classes. Historically, lethal fires created forests containing even-aged stands. In general, clearcut, shelterwood, and seed-tree systems can emulate these stand-replacing events but these tend to perpetuate early-seral or relatively intolerant (e.g., shade, canopy closure, competition) trees.

With the exception of the clearcut, the other even-aged silvicultural systems (seed-tree and shelterwood systems) include some high forest cover during a portion of the system development. Overstory density and the species prescribed in seed-tree and shelterwood systems depend on the site and desired forest structure and composition. The number of overstory trees prescribed in a shelterwood depends on how much shelter is required to successfully regenerate a desired tree species. As canopy cover increases, the amount of shade-tolerant (e.g., grand fir, hemlock) regeneration will also increase.

Clearcut Method

The clearcut regeneration method is easy to apply and is often well suited for situations where disease and/or insect problems exist. Disposal of hazard fuels and site preparation can readily be accomplished using prescribed fire, mechanical means, or chemical application. In addition, the planting of improved stock from tree improvement programs is facilitated by the clearcut method. Clearcutting is most applicable on sites and PVTs in which biophysical conditions present without canopy cover provide suitable conditions for seedling establishment and development (e.g., western hemlock and subalpine fir PVTs, northerly slopes etc.) (fig. 9). The optimum size and orientation of the clearcut is also predicated on the biophysical setting and the species and kind of regeneration desired (Burns 1983). If natural regeneration is planned, then ample seed and dispersal will need to be available from neighboring seed walls (clearcut edge) or within the tops of the trees left after harvesting.



Figure 9—A clearcut regenerated with western white pine located near Coeur d'Alene, Idaho. Note the well-defined seed wall (clearcut edge).

Seed-Tree Method

The seed-tree method can be applied on all slopes and aspects but needs to be tailored to the forest PVT and biophysical setting. Vigorous, wind-firm trees should be left as seed trees and selected for their phenotypic traits (Hoff et al. 1976). On most settings, four to six trees per acre are adequate for seed production for most preferred species. For example, 7 to 12 trees/acre might be prescribed for a poor seed-producing species (western larch), whereas 3 to 7 seed trees/acre might be utilized with a prolific seed-producing species (western white pine). If possible, site preparation should coincide with a seed crop in the overstory. The seed trees should be removed as soon as possible after regeneration becomes established. Stocking control is usually needed to maintain the desired number and species composition in the regenerated stand (Schmidt 1988). The seed-tree method is ideal where seed dispersal could be problematic from adjacent seed walls if the clearcut method was applied. This often occurs with ponderosa pine because it has heavy seeds that are dispersed shorter distances compared to some of the mid- and late-seral species such as grand fir and Douglas-fir (Haig et al. 1941, Burns 1983) whose seeds disperse longer distances.

Shelterwood Method

The shelterwood regeneration method is applicable on all aspects and slopes, but is especially suited to steep, dry slopes where regeneration would benefit from protection. Dominant overstory densities used in this method range from 15 to 40 trees per acre depending on species. The greater the number of trees left in the overstory, the greater

the proportion and number of shade-tolerant species regenerated (Haig et al. 1941). Because of the wide range in fire resistance of the species occurring on these sites, slash disposal and site preparation may be difficult and expensive depending on species and slope. Vigorous trees should be left in the overstory to withstand the shock of release, stand through weather events (e.g., snow, wind) and act as good seed producers. When an adequate regeneration is achieved, the overstory should be promptly removed (Burns 1983).

Application of Even-Aged Systems

In the cold forests, the clearcut and seed-tree methods are very appropriate for producing even-aged stands of early-seral species (e.g., western larch, Douglas-fir). Lodgepole pine is the most frequently managed species within the cold forests because it readily germinates and develops using clearcuts on the subalpine fir PVTs (Schmidt and Alexander 1985) (fig. 4). Serotiny in lodgepole pine usually ensures the presence of viable seed in the unopened cones present in the slash left after harvesting. However, diligence is needed when disposing of slash and preparing sites to insure the seed stored in the cones is not removed or destroyed. Cone serotiny is variable in lodgepole pine; therefore the presence of unopened cones should be verified prior to relying on this characteristic to supply seed for regeneration (Lotan 1973).

Western larch is often a preferred early-seral species in the cold forests and it also regenerates and develops well using the clearcut system (Schmidt and Shearer 1990). Douglas-fir is more intermediate in response to clearcutting in these



Figure 10—A shelterwood system was used to regenerate western white pine. Rust-free shelter trees were chosen. The seedlings regenerated using this method could exhibit up to 19% resistance to blister rust (Hoff et al. 1976).

settings but it also responds better to the open conditions of a clearcut than spruce and subalpine fir, species that are late-seral associates in these cold forests. In portions of the dry forests, especially those on the more moist PVTs such as the drier grand fir/white fir settings, clearcutting has been successfully used to perpetuate ponderosa pine (Ryker and Losensky 1983).

Clearcutting is very applicable for use in the moist forests (fig. 9). The preferred early-seral species, western white pine, western larch, and Douglas-fir, all regenerate and develop readily using this method. In addition, because of the large amounts of fuel that can be created when harvesting, clearcuts facilitate the use of prescribed fire for preparing sites for both natural and planted regeneration which will decrease the wildfire hazard (Haig et al. 1941, Graham et al. 1983). Regeneration of late-seral western hemlock, grand fir, and western redcedar is often prolific in the moist forests; however, clearcuts tend to favor the early-seral species over the late-seral species, particularly if the preferred species regenerate promptly after harvest (Haig et al. 1941, Graham et al. 1983, Jain et al. 2004). Moreover, some suggest that clearcuts are the preferred method for managing rust-resistant western white pine (Fins et al. 2001).

Seed-tree methods are most applicable in the cold and moist forests but also have been used successfully in the

dry forests on settings in which shelter is not a prerequisite for successful regeneration (Ryker and Losensky 1983). Very often this occurs on PVTs where ponderosa pine readily regenerates such as those occurring in the Black Hills and some sites in Arizona and New Mexico (Pearson 1950, Shepperd and Battaglia 2002). Seed-tree methods can be used in the moist forests to regenerate western white pine, Douglas-fir, and western larch (Haig et al. 1941). In the cold forests, the seed-tree method can be used to regenerate western larch and Douglas-fir and is very applicable in situations where lodgepole pine does not express cone serotiny (Lotan 1973).

Shelterwood regeneration methods are most applicable on settings in which the preferred species, usually an early-seral species, benefits from the presence of shade. This can occur on Douglas-fir and ponderosa pine PVTs in the dry forests where ponderosa pine regeneration benefits from some shade (Pearson 1950, Ryker and Losensky 1983, Shepperd and Battaglia 2002) (fig. 5). In the moist forests, western white pine readily regenerates with the shelterwood method and, in many settings, it prefers partial shade for the first few years of its life (Haig et al. 1941) (fig. 10). Ponderosa pine is often regenerated using one or two stage shelterwoods (Pearson 1950). The preparatory cut favors seed producing pine developing their wind firmness and crown expansion, and the final seed cut provides growing space for the seedlings to be established (Boldt and Van Deusen 1974). By providing these openings, ponderosa pine has the greatest opportunity to become established and out-compete its late- and mid-seral associates such as Douglas-fir, grand fir, and white fir (fig. 5). However, in many settings Douglas-fir would also be the preferred species especially on the drier grand fir or white fir PVTs.

A consistent drawback of using seed-tree and shelterwood regeneration methods is the possibility of perpetuating dwarf mistletoe (*Arceuthobium* spp.). Ponderosa pine, Douglas-fir, western larch, and lodgepole pine, depending on the location and PVT, are all susceptible to infection from mistletoe. Trees without mistletoe can be selected for retention but if the disease is prevalent in the overstory, the clearcut method usually provides more satisfactory control of the disease (van der Kamp and Hawksworth 1985).

Trees in shelterwood and seed-tree systems can be grouped or spaced based on species composition or other designated criteria. The seed-tree and shelterwood component used in these systems can be short- (removed early in the life of the regenerated stand, 30 yr or less) or long-lived (left on the site through the life of the regenerated stand). However, for use in most production situations, prompt

removal of seed and shelter trees, once regeneration is established, is preferred. The longer the overstory remains, the more likely tolerant species will develop and compete with the preferred intolerant species.

Uneven-Aged systems

From a timber management perspective, uneven-aged systems are most likely applicable only on limited sites in which a frequent and continual flow of wood products would be desirable. Uneven-aged systems, both in groups and individual trees, have been used successfully in the ponderosa pine PVTs (Shepperd and Battaglia 2002). However, because these systems perpetuate late-seral species or those favored with closed canopy conditions, uneven-aged systems in most situations would not be preferred for production forestry. However, uneven-aged systems do not have applicability on small scales such as for non-industrial private landowners (Graham and Smith 1983, Graham et al. 1999a)

SITE PREPARATION

The most important component of site preparation is to prepare sites to meet sound and well thought-out objectives. A prescription provides the plan on the kind, composition, and amount of regeneration desired. This plan includes describing seedbed and/or planting site requirements along with the amount, and species (kind) of competing vegetation inherent to the site and its expected response to fire, mechanical, or chemical disturbance. Potential vegetation, habitat types or similar vegetation classifications usually offer excellent descriptions of ground-level vegetation and the seral stage of forest development in which it commonly occurs (Daubenmire and Daubenmire 1968, Pfister et al. 1977, Cooper et al. 1991). In addition, these classifications provide insight into species that may be absent preharvest and their expected response to disturbance.

Ideally, silvicultural systems should be designed to minimize competing vegetation without using expensive control measures. However, disposal of the slash left after yarding also affects soil compaction and soil organic content (Harvey et al. 1987, Page-Dumroese et al. 1997). Broadcast burning is commonly used to prepare sites throughout the Inland Northwest but slash is also burned after machine piling (fig. 11). Whatever method is used, the objectives of site preparation commonly include reducing fire hazard, providing planting access, and controlling competing vegetation (Baumgartner 1982 Lotan 1986).

In cold, dry, and moist forests, the amount of moisture available to young trees during the summer months is



Figure 11—A helicopter igniting a prescribed fire in a clearcut near Sandpoint Idaho. The fire was ignited in the evening ensuring that moisture contents in the lower duff were above 100% and the fine fuel moisture contents were conducive for producing a low severity fire.

almost always the single most important determinant of whether a planted seedling will survive and the rate at which this seedling will grow (Cleary and Greaves 1976). Of course not all water in a soil profile will be available to regenerated trees. Some will percolate out of the soil profile, some will evaporate, and much will be used by competing vegetation. Effective site preparation can dramatically increase plantation survival and development. Powers and Reynolds (1999), for example, showed that by completely removing competing vegetation, ponderosa pine volume growth was 400 percent greater 10 years later when compared to tree growth on areas with competing vegetation.



Figure 12—A Salmon blade can be used to effectively prepare sites subject to pine grass competition yet still conserve the nutrient-rich surface soil layers.

Mechanical Preparation

Depending on soils and steepness of slope, timely and proper site preparation most often can be accomplished by using machinery. This usually assures excellent site preparation even with sprouting and herbicide resistant species. For example, *Ceanothus* spp. is often effectively controlled mechanically since this method does not heat scarify seeds stored in the forest floor. Depending on equipment and soil conditions, most machines (except cable machines) can safely and effectively operate on slopes with gradients less than 30 to 40 percent (Miller 1986a). Machine methods include rakes pulled or pushed by tractors, special dozer blades, and cable scarifiers to name a few (Lowman 1986). Very often the site preparation is accomplished simultaneously with reducing the wildfire hazard. In general, machines capable of separating slash of different sizes, often called “grapple machines”, displace less soil than rakes attached to the front of tractors; thus the use of grapple machines can help conserve and protect soil layers (Graham et al. 1994a).

Competition from pine grass and other sod-forming grasses present different germination and planting problems than shrub competition. A mechanical option that has shown success for both planting and seed germination is a tractor-mounted rake that exposes mineral soil and prepares planting sites yet does not displace the soil. The machine uses a plow shear blade that rolls the sod, exposes the grass roots, and decreases its survivability, and exposes mineral soil (MTDC 1988) (fig. 12).

In contrast to machinery in the form of tractors, excavators, and other machines, hand tools at the time of planting

are frequently used (Lowman 1986). Scalping or removing competing vegetation using hoes, shovels, hodads, or other hand-tools have been shown to be effective in grass communities. Scalps should be at least two feet in diameter and preferably larger (Miller 1986a). Compared to machinery, hand scalping offers more latitude for locating favorable planting sites. That is, locating sites with deep organic rich soil, away from aggressive competing vegetation, or behind logs that can provide shelter and protection. Site preparation (scalping) should be differentiated from clearing debris prior to opening a planting hole. Clearing is requisite to ensure that organic material (sticks, litter, etc) that may interfere with root to soil contact does not fall into the hole during planting. This can often be accomplished in situations in which soil is covered by litter, which can be cleared, exposing soil often covered with rich humus and fermentation layers. No matter which method of the site preparation used, it is critical that the soil is protected and maintained.

The use of machinery to prepare sites for regeneration is always a compromise between creating soil conditions for regeneration while maintaining and preserving soil productivity (fig. 12). The greatest limitations of mechanical site preparation are slope angle, soil compaction and displacement. As stated earlier, most early-seral species easily germinate and develop on the mineral soil that can readily be exposed by mechanical methods (Haig et al. 1941). A favored micro-site for natural regeneration or for artificial regeneration is one that prepares a weed-free planting/germination spot yet is in proximity to or conserves the nutrient- and water-holding surface organic layers (Graham et al. 1989, Graham et al. 1994a, Graham et al. 1995).

Fire

Fire can reduce fine fuels, prepare germination surfaces, reduce competing vegetation, preserve surface organic layers, and maintain appropriate amounts of coarse woody debris (fig. 11). However, unless fuel and weather conditions are appropriate, fire can create conditions adverse for regeneration and impair soil productivity (Debano 1991, Hungerford et al. 1991). The amount of forest floor consumed by a fire is dependent on its moisture content, particularly in the lower humus and fermentation layers. If the moisture content of these layers exceeds 100 percent when a fire occurs, the majority of litter and fine fuels (≤ 3 inches) do not burn and thus, are generally conserved (Ryan 1982). Under these moisture conditions, nutrients (such as P, N, K) can condense in the humus and fermentation layers and, therefore, are not lost from the site (Harvey et al. 1989). The temperatures at the mineral soil/organic layer interface usually do not exceed 300° C, the temperature at which N is volatilized (Hungerford et al. 1991). At this temperature, water-repellent layers are also less likely to



Figure 13—Shrubs can respond vigorously to prescribed fire.

occur even in coarse-textured soils. Burning when the lower humus layers are moist facilitates consumption of fine fuels, maintenance of CWD levels, and often results in exposure of micro-sites for planting and/or seed germination.

Some ground-level vegetation responds vigorously to heat such as *Ceanothus* spp. with its seed buried in the forest floor. Also, many ground-level species resprout aggressively in response to fire (fig. 13). Therefore, the amount, kind, and severity of fire used to prepare sites needs to be applied with an understanding of the expected response of competing vegetation for a given forest, PVT, and biophysical setting (Baumgartner et al. 1986, 1989).

Chemical Preparation

Chemicals are a very viable technique for site preparation. In particular, herbicides can target specific species or life forms and protect the surface soil layers that can be harmed by both mechanical and fire site preparation techniques. The latitude of site and weather conditions for applying herbicides may be less operationally restrictive than either fire or mechanical methods and, depending on the circumstance, the results may be more cost effective than using either of the other two methods (Baumgartner et al. 1986).

For the optimum growth of plantations, control of competing vegetation is essential. In the dry forests particularly (depending on the PVT), if ground-level vegetation is present before the regeneration harvest is applied, it will likely compete with future seedlings. Therefore, approximately

two years prior to the harvest, an herbicide treatment can be applied to target the shrubby vegetation. Growing in the understory of a high forest canopy, shrubs tend to develop in sun-flecks, be single stemmed, spindly, and weak, thus making them highly susceptible to control by herbicide. When the regeneration harvest is applied, the ground-level vegetation will be absent providing ample planting sites. In contrast, if the chemical treatment is applied after the harvest treatment, ground-level vegetation will most likely be the risk of greater injury to the plantation, delaying the site preparation benefits.

Herbicides used for shrub control in forests include 2,4-D, glyphosate, imazapyr, picloram and triclopyr. To control grasses and forbs, atrazine, 2,4-D, sulfometuron, and hexazinone are suggested (Coop 2004). However, specific time of application and effectiveness of herbicide to affect targeted vegetation varies. Specific details on application and target species are available through the Pacific Northwest 2004 Weed Management Handbook (Coop 2004).

An area mechanically prepared or burned, may provide an ideal setting for the germination, establishment, and development of tree seedlings, but these same conditions are an ideal habitat for weeds (fig. 13). Weeds will quickly develop and compete with the planted seedlings for water, nutrients, occasionally light, and under some circumstances they may be allelopathic, which can further retard seedling development (Ferguson 1991). Pre-emergent herbicides can be applied to the surface of the planting spot such as hexazinone, sulfometuron, metsulfuron, and atrazine products

to control competing vegetation as it develops. It is very important to use the right chemical and the right amount to insure only the weed species and not the planted seedlings are affected. For example, sulfometuron and atrazine are poor choices to use when planting ponderosa pine and western larch, respectively (see Baumgartner et al. 1986 and Coop 2004 for discussions on herbicides and their appropriate efficient, and effective use).

REGENERATION

A requirement for the successful application of a silvicultural system is the timeliness of regeneration, its amount and composition. Environments conducive to seedling establishment can be directly influenced by the amount and composition of over-story retained (seed tree, shelterwood selection) and the intensity and extent of site preparation (mechanical, fire, chemical).

Natural Regeneration

The early-seral and/or preferred species for production forestry, e.g., ponderosa pine, lodgepole pine, western larch, Douglas-fir, and western white pine, readily regenerate naturally (Haig et al. 1941, Pearson 1950). Depending on the forest type and the PVT, natural regeneration may be a viable alternative in many settings using a variety of silvicultural systems. However, less control of the timing, amount, density, and consistency of plantation establishment is possible with natural regeneration compared to artificial regeneration.

The cheapest and most site-adapted regeneration can be achieved through natural regeneration. On ponderosa pine and Douglas-fir PVTs, ponderosa pine and Douglas-fir can be naturally regenerated if appropriate site preparation is accomplished (Shearer and Schmidt 1991, Shepperd and Battaglia. 2002). However, many factors such as seed crop frequency and size, animal predation on the seed, weather damage to seed, and the timing and proper seedbed preparation can make the accomplishment of successful regeneration easier said than done (Haig et al. 1941, Pearson 1950). For example, if the site preparation is not well timed with the production of seed, adequate germination substrate and establishment sites may not be available when seed is produced by the desired species. Weather favoring the regeneration might not occur even if the site preparation and seed crops were well coordinated. Western larch is a case in point. A weather event such as a frost injuring flowers or unexpected cold weather hampering germination can spoil the best-laid plans (Graham et al. 1995a).

Species vary widely in seed production and dissemination (Haig et al. 1941). Western redcedar and western hemlock produce larger and more frequent seed crops than most of their associates. For example, the interval between good seed crops in western larch is highly variable and is often greater than 10 years. The other tree species usually produce good seed crops at less than 5 year intervals. For all tree species, wind plays a major role in seed dissemination. Only lodgepole pine exhibits cone serotiny and the degree of serotiny present is variable within the cold forests (Lotan 1973). Mineral soil and burned-over surfaces tend to supply good soil-to-seed contact, maintain moisture levels conducive to seed germination, plus supply water to the roots as they develop. In the Northern Rocky Mountains, temperature tends to be one of the most critical factors for germination. Minimum soil temperature of 51° F is needed and temperatures between 71° and 81° F are preferred (Haig et al. 1941). Organic seedbeds tend to lose soil moisture faster than roots can develop thereby restricting seedling establishment. Douglas-fir, ponderosa pine, western white pine, and lodgepole pine have intermediate germination rates while western larch and grand fir have low germination rates. In addition, western hemlock and western redcedar usually have high seed germination rates and occasionally reproduce by sprouting. Because these species regenerate easily, they can interfere with the regeneration and development of preferred early-seral species.

In moist forests, it is critical to understand the role blister rust plays in stand development especially when using natural regeneration. Shelterwoods can be used to naturally regenerate western white pine and a large proportion of these seedlings would be susceptible to blister rust (Graham et al. 1994b). However, Hoff et al. (1976) reported that over 19 percent of natural regeneration in stands suffering high losses from blister rust could be resistant to the disease (figs. 3, 10). Therefore, when western white pine regeneration is abundant (thousands of trees per acre), a number of the seedlings is likely resistant to white pine blister rust. Nevertheless, distinguishing rust resistant from nonresistant seedlings becomes problematic when the stands are cleaned (precommercial thinning to alter species composition or improve stand condition). The resistance level will not approach that of trees produced in improvement programs but there is an excellent chance that some of these naturally regenerated trees will survive and grow well enough to produce commercial products and provide genetic diversity in western white pine (Graham et al. 1994b Fins et al. 2001) (See section on enhancing the survivability of white pine through pruning).

Table 1—The genetic differentiation among populations of tree species. Adaptation of species is based on the environmental interval by which populations must be separated before there is a reasonable assurance that the populations are genetically different (Rehfeldt 1994)

Species	Environmental Interval		Adaptation
	Elevation Range (ft)	Frost Free Days	
Douglas-fir	650	18	Specialist
Lodgepole pine	720	20	Specialist
Engelmann spruce	1215	33	Intermediate
Ponderosa pine	1380	38	Intermediate
Western larch	1480	40	Intermediate
Western redcedar	1970	54	Generalist
Western white pine	none	~90	Generalist

Artificial Regeneration

Because of the uncertainty of natural regeneration, artificial regeneration often provides more assurance and options for timely stand establishment and species composition, micro-site selection, tree density, and horizontal tree distribution. In addition, artificial regeneration offers opportunities to plant improved stock. Currently (2005), improved planting stock is available for western white pine, lodgepole pine, western larch, Douglas-fir, and ponderosa pine. The improvement developed in breeding programs includes improved tree growth, increased disease resistance, increased cold hardiness, and improved tree form compared to trees naturally regenerated.

However, care needs to be exercised to ensure that trees planted are ecologically adapted to the sites. For example, the environmental interval in elevation in which ponderosa pine populations show habitat specificity is approximately 1380 feet or 38 frost-free days (Table 1). In contrast, no habitat specificity in elevation has been found for western white pine and the habitat specificity interval in frost-free days is 90. The narrowest habitat specificity for any Rocky Mountain conifer occurs with Douglas-fir which has an environmental interval of 650 feet in elevation or 18 frost-free days (Table 1) (Rehfeldt 1994). Therefore, Douglas-fir is considered a specialist and western white pine a generalist in their species' adaptability to sites. Beginning in the early 1900s and in earnest during the 1930s during the Civilian Conservation Corp era, a major ecological mistake was planting off-site (seedlings not adapted to their environment) ponderosa pine seedlings throughout the West. Today, these off-site plantings are often dying from insects and disease and producing malformed trees. Unfortunately, a maladapted forest is being propagated, thus showing why it is critical that seedlings be ecologically matched to the site on which they are planted (Rehfeldt 1994).

Probably no other species is more suited to artificial regeneration than western white pine because of the good nursery and planting practices that have been developed over the last 100 years. With the introduction of blister rust from Europe in the early 1900s millions of white pine were killed. When all control efforts (e.g., killing the alternate host *Ribes* spp., fungicide application) failed, the future of western white pine management in the western United States appeared bleak (Ketcham et al. 1968). By 1950, the Office of Blister Rust Control, Northern Region of the USDA Forest Service, USDA Forest Service Northern Rocky Mountain Forest and Range Experiment Station, and the USDA Forest Service, Pacific Southwest Forest and Range Experiment Station began a program to develop rust-resistant western white pine. By 1985, seed orchards were producing a second-generation of western white pine that were 65+ percent resistant to the disease (a portion of the trees do get infected but survive) (Bingham 1983). The goal of the white pine tree improvement program was to increase its' resistance to blister rust and to accomplish this by using multiple genes, thus minimizing potential disease mutations (Fins et al. 2001). With this multi-gene approach the rust may infect and even kill some trees, but many trees, even if they become infected, continue to survive and grow to a saw timber rotation of 60 to 80 years (Graham et al. 1994b) (figs 2, 3, 9, 10).

In general, there are two types of seedlings that are planted, bare-root and container grown, and both have their place in production forestry. Bare-root seedlings are usually lifted from the nursery beds in the early spring for planting in the spring. Depending upon the silvicultural method and site preparation, a different size and age of seedlings can be specified. In addition, a key characteristic of a proper root-to-shoot ratio can be specified. Generally, seedlings less than

three years old can readily be planted. Large-sized seedlings often offer a higher success of establishment compared to smaller seedlings because of their ability to endure competing vegetation, damage from animals, or harshness of site. Seedlings with large diameters may be specified for areas prone to vegetation, woody debris or snow potentially pushing over small seedlings (Schubert and Adams 1971, Baumgartner and Boyd 1976, Cleary et al. 1978).

Great strides have occurred in recent years in producing container-grown seedlings that meet a wide range of specifications. This can be accomplished by controlled growing conditions and by different sized and treated containers. In addition to a variety of seedling specifications, seedlings can be produced to plant during different planting cycles determined by the site and management objectives. As with most bare-root seedlings, container seedlings are most often planted in the spring but they can also be grown for planting in the fall (Landis et al. 1990, Landis et al. 1992).

Under special circumstances, seedlings can be planted in the summer if they are properly conditioned. Such situations exist when high elevation areas are not available to plant during the spring or fall because of snow. In the greenhouse, seedlings can be artificially moved through a growth cycle from bud burst through shoot elongation and bud set in a matter of weeks. By doing so, dormant seedlings can be planted during the summer (Landis et al. 1990, Landis et al. 1992).

Even though seedling production from seed collection through planting has been investigated and refined for 100 years, the successful completion of the entire regeneration process is often problematic. Seedlings well prepared in the nursery/greenhouse need to be handled with utmost care while in storage and on the planting site to ensure a dormant seedling is planted (Schubert and Adams 1971, Baumgartner and Boyd 1976, Cleary et al. 1978).

We suggest that choosing desirable micro-site positions that offer protection, have organic matter rich soil, and are free of competing vegetation is preferable to planting on a rigid grid. In most production operations and to minimize future tending operations, 200 to 250 trees per acre would suffice. A preferred micro-site for planting trees includes: places with adequate soil moisture, soil temperatures exceeding 40° F, uniform root-to-soil contact, and no soil impediments that would distort roots (e.g., produce J-rooted seedlings). In high organic soils, container-grown stock appears to do better than bare-root stock because root-to-soil contact can be more readily achieved (Schubert and Adams 1971, Baumgartner and Boyd 1976, Cleary et al. 1978).

Animal Damage

A variety of animals (insects, rodents, omnivores, ungulates, and livestock) may damage tree seedlings by eating, browsing, trampling, and breaking limbs. Animals including, but not limited to, porcupines (*Erethizon dorsatum*), pocket gophers (*Thomomys* spp.), cattle, sheep, hares (*Lepus* spp. and *Sylvilagus* spp.), black bear (*Ursus americanus*), deer (*Odocoileus* spp.), and elk (*Cervus* spp.) can damage seedlings of most western tree species. The potential for damage should be thoroughly evaluated prior to implementing the silvicultural system (Kingery and Graham 1991, Knapp and Brodie 1992).

A variety of preventive and remedial techniques have been tested with mixed results. These have included providing an alternative food source or planting unpalatable tree species (Black and Lawrence 1992), modifying habitat to disfavor specific browsing animals, physically or chemically protecting tree seedlings, frightening browsers away, and trapping or killing browsing threats. Unfortunately, one method does not solve all browsing problems. Many recommend large planting stock because it typically is less vulnerable to animal damage (Loucks et al. 1990, Cafferata 1992, Graham et al. 1992, Marsh and Steele 1992). Nolte (2003a) suggested using a five-step process to reduce the effects of animal damage: 1) assess the severity and potential damage if no action is taken, 2) evaluate the feasibility of alleviating the problem, 3) develop a strategy prior to browse damage prevention measures, 4) implement a program, and 5) monitor the consequences. The preferred approach will depend on the results from site-specific monitoring and the most effective treatment may require integrating several methods within the silvicultural system.

Physical protection of seedlings with polypropylene mesh tubes is an option and appears to be successful in some cases (Black and Lawrence 1992). Fencing areas to keep livestock out can be effective, but expense limits its use (Nolte 2003b). Other forms of physical deterrents might be possible. Graham et al. (1992) noted that seedling damage from livestock fell below 10 percent when coarse woody debris (> 3.0 inches in diameter) was greater than 30 tons per acre. In some cases, minimizing disturbance avoids creating habitat that may increase pocket gopher populations (Marsh and Steele 1992). For example, the grasses that exist on a site can be killed using hexazinone (most commonly Velpar®), and this, in turn, will dissuade gopher use. Pocket gopher predation on planted seedlings is highest the first summer that the trees are planted and the first two winters (Ferguson 1999). Studies have shown that controlling pocket gopher populations with strychnine baiting poses relatively little risk to non-target species (Arjo

2003) but the effects of removal may be short-lived since replacement animals usually occupy the vacant habitat, thus necessitating the repeated application of treatments for maximum efficacy.

FOREST TENDING

The silvicultural system does not end with the regeneration treatment (i.e., clearcut, seed-tree, etc.). After a stand is regenerated or entered, stand tending is generally warranted to ensure the desired stand structures and compositions are developed and maintained (Fisher 1988). Tending activities (i.e., thinning, cleaning, weeding, liberation (overstory removal), sanitation, and fertilization) can occur at a variety of time intervals and intensities depending on forest type, PVT, species present, and past stand development. Release of species after periods of crowding or suppression is directly related to the length and vigor of the crown (McCaughey and Ferguson 1988, Ferguson 1994). Generally, shade intolerant species respond well to release after suppression and intolerant species respond poorly. Lodgepole pine, which often regenerates prolifically, is prone to stagnation early in its development, making later release cuttings less effective (Johnstone and Cole 1988). Therefore, stand tending is an integral part of both even-aged and uneven-aged silvicultural systems. Treatments can occur within all canopy levels and many intermediate treatments can produce forest products (Graham et al. 1999b).

In contrast to not acquiring enough regeneration, the issue in many forests is excessive regeneration that makes weeding and cleaning plantations (natural stands) essential for satisfactory development. For example, in the ponderosa pine forests of the Black Hills in South Dakota, ponderosa pine regeneration is often so prolific it creates a fire hazard and compromises future stand development options (Shepperd and Battaglia 2002). Similarly, in the cold forests, over-abundant lodgepole pine regeneration is often the norm, again making tending operations imperative if the stands are going to develop productively (Johnstone and Cole 1988) (fig. 4). Within the moist forests, natural regeneration is often plentiful making cleaning and weeding operations a necessity (Haig et al. 1941, Deitschman and Pfister 1973, Graham 1988) (fig. 9).

Weedings

Weedings occur during the sapling stage of stand development to remove competitive vegetation, such as specific trees or shrubs, and other vegetation that may compete with crop trees (Smith et al. 1997, Helms 1988). Weedings tend

to be applied before or simultaneously with cleanings (treatments aimed at redistributing stand growth to selected stems). Most often weedings are essential in mixed-species stands and those prone to robust development of mid- and late-seral trees or when grass or shrub development interferes with stand development (Deitschman and Pfister 1973, Miller 1986b). In dry forests, this often occurs where grand fir and/or white fir, Douglas-fir, ninebark, or *Ceanothus* spp. tend to aggressively compete with ponderosa pine. Similarly, in the moist forests, grand fir, western hemlock, and alder are frequently removed to favor western white pine and western larch. Weedings can be accomplished most often mechanically or chemically and, in rare situations, fire can be used to weed a plantation of unwanted competing vegetation (Saveland and Neuenschwander 1988).

Chemical

Frequently, within a year or two after plantation establishment, even on settings where the competing vegetation was removed during site preparation, weeds tend to return and interfere with seedling development (Petersen 1986). Weeding young stands with herbicides is a viable alternative on many settings. However, specific time of application and effectiveness of the herbicide to affect targeted vegetation varies (specific details on application and target species are available through the Pacific Northwest 2004 Weed Management Handbook (Coop 2004). The actual timing of when weeds interfere with tree growth depends on forest type, PVT (weed species present and their ability to colonize or survive), type and success of the site preparation applied (Noste and Bushey 1987, Baumgartner et al. 1986). Herbicides that can be applied over the top of established seedlings and have been successful in controlling weeds include several hexazanone products (e.g., Velpar®, Pronone®). These herbicides are effective in removing weeds without damaging most conifers except western larch. Sulfometuron (Oust®) also removes weeds readily but is not preferred for use with ponderosa pine because of potential tree damage. Granular herbicides can be applied with a “weedometer” that distributes herbicides within a 3 to 5 foot radius of seedlings. Glyphosate (Roundup®, Accord®) can be directionally applied to weeds between trees and shields (e.g., PVC-plastic) can be used to apply herbicides within close proximity of seedlings.

Within 4 to 6 years on some PVTs, tall shrubs (e.g., maple, alder, willow) not controlled by a pre-harvest herbicide, readily sprout and often aggressively compete with planted trees (Lotan 1986). Imazapyr (a compound in Arsenal®, Chopper® and Onestep®) can be aerially (helicopter) or hand (backpack sprayer) applied to control this high shrub competition. Glyphosate, applied as a directed

spray, can be used to control tall shrub competition as well as hexazanone, applied in the form of Pronone®. In north-eastern Oregon, Oester et al. (1995), found that hexazanone, applied as a spot or broadcast spray, increased both survival and growth of planted ponderosa pine. It has been found to be more effective (more toxic) at controlling weeds when it is applied in conjunction with N fertilizers compared to applying the herbicide alone. When applied in this fashion, Pronone® has been found to be toxic to conifers even though the dose was believed to be safe. Presumably, the addition of N makes both the conifers and weeds grow later in the growing season thus making them both vulnerable to the herbicide. The most effective combination of N fertilizer and Pronone® will probably use smaller herbicide dosages, such as only ½ to ¾ of the amount that would be used when applied by itself. The combination of fertilization and weed control should enable stands to develop more quickly than would occur after the application of a single treatment.

Most conifers have a high tolerance for hexazanone and imazapyr, while most grasses and woody (dicot) species are very susceptible. Western larch, however, is very susceptible to damage from both of these herbicides. In most settings, a directed application of glyphosate using a backpack sprayer will control unwanted vegetation in western larch stands. The exact weeding approach and chemicals used will depend on the forest, PVT, biophysical setting, and nature of the competing vegetation (e.g., life form, species, size, distribution) (Coop 2004).

Precommercial Thinning (Cleaning)

Precommercial thinnings are applied during the sapling stage of stand development where specific trees are kept and others are removed so that growth of selected stems is favored (Smith et al. 1997).

In general, all of the early-seral species (ponderosa pine, lodgepole pine, western white pine western larch, and Douglas-fir) respond positively to precommercial thinning (Schmidt 1988). Of course, the magnitude of the response is predicated on the PVT and the biophysical setting. However, with judicious control of planting densities, the need for thinning to redistribute growth to selected trees should be minimized. In stands with prolific natural regeneration (such as may occur with western larch, western white pine, lodgepole pine, and on some sites, Douglas-fir and ponderosa pine), precommercial thinning is necessary to distribute the site's growth potential to a manageable number of trees that will result in future tree sizes consistent with predicted markets for wood products (Schmidt 1988).

Moist Forests

Within the moist forest, the most important period in the life of either a plantation or a natural stand is between 10 and 30 years. Prior to this time, stand densities have minimal impact on tree development. During this 10- to 30-year period, species composition and future stand dynamics are largely determined. Past this age, stand improvement can be accomplished only at high expense and at a heavy sacrifice to growing stock (Davis 1942). Western white pine over 30 years old will respond to release, but the required wide tree spacings will reduce stand yields (Deitschman 1966). Four hundred trees per acre at age 30 appear to be a good goal. These densities provide for good diameter growth, good volume production, and future thinning opportunities. The timing of cleaning a western white pine stand is a compromise impacted by waiting as long as possible to allow blister rust to be fully expressed, maintaining canopy closure to discourage *Ribes* spp. and competing conifer regeneration, and to treat stands early as possible so as to not create an unmanageable fire hazard (abundance of fine fuels) (Graham 1988).

Western larch also readily responds to precommercial thinnings at 10- to 15 –years of age (Schmidt and Seidel 1988). Though expensive, thinning of extremely dense stands, containing 1,000 to 25,000 stems per acre, will respond well to thinning. During these treatments, mistletoe can also be removed from the stand. Western larch benefits greatly from early thinning because it relieves overstocking and allows larch to capitalize on its rapid juvenile growth. Schmidt and Seidel (1988) suggest that stocking levels for western larch range between 45 and 75 percent of normal stocking or in the range of 400 trees per acre or less. Thinning dense stands transfers growth to fewer numbers of rapidly growing trees, thus maintaining good vigor and crown development, increasing resistance to wind, snow, and insects, and permitting more uniform diameter growth. Judicious thinning regimes can result in shorter rotations and increased merchantable yields. Target Douglas-fir densities also fall in the range of 400 trees per acre in precommercial thinnings in the moist forests (Lotan et al. 1988). It appears that the greatest benefit from thinning in mixed stands of western white pine and associates is to improve stand and tree quality. Cleanings do not increase overall volume production, but do increase future value of stands by concentrating growth on fewer, selected better quality trees.

Western White Pine Pruning—Most lethal blister rust infections occur in the lower crown when trees are quite young (≈15 years). Pruning the lower branches of white



Figure 14—A precommercial thinning (cleaning) in a sapling-sized ponderosa pine stand. Note the large amounts of fuel produced, which is a common occurrence, and needs to be decreased to protect the stand from severe wild-fire.

pinus to a height of 8 to 10 feet, but not reducing the live-crown ratio to less than 50 percent, appears to offer the tree some protection from blister rust infection while not substantially reducing tree growth rates. In addition, removal of any branches with cankers greater than 6 inches from the bole greatly increases the chances of the tree surviving to produce a commercial product. Schwandt et al. (1994) showed that by cleaning western white pine stands (10 to 18 years old) to a spacing of approximately 10 feet by 10 feet and pruning the lower branches, the value (1992 prices) per acre (22 years later) of the white pine doubled in the treated stands (\$2000 per acre) compared to that of untreated stands (\$1000 per acre).

Cold Forests

Natural stands of lodgepole pine, which commonly regenerate following wildfire, are frequently dense (Johnstone 1985, Johnstone and Cole 1988). Likewise, stands that regenerate following harvest and site preparation (scarification and/or prescribed fire) often establish in dense clumps. Even when lodgepole pine is planted or cleaned at an early age, ingress of seedlings may result in denser stand conditions than desired. Lodgepole pine does not self-thin well on any PVT; thus without treatment dense stands tend to

remain dense. In these situations, tree growth is suppressed and stands are subject to heavy mortality from snow and wind. Consequently, stand yields will be well below the capacity of the site.

Determining thinning densities for all species and, in particular lodgepole pine, the optimum management density is a tradeoff between tree size and stand volume objectives. Young lodgepole pine responds more readily to density reductions compared to old trees (Murphy et al. 1999). Merchantable cubic volume production per unit area is maximized at relatively high (≈ 1000 trees per acre) initial stand densities. A single precommercial thin (≈ 400 trees per acre) at age 20 on many sites would produce commercial yields by age 40 compared to never producing a commercial product by age 120 years without the treatment (Cole and Edminster 1985). However, for most management considerations, cutting cycles of 30 years seem feasible and offer commercial yields at several points during the rotation (≈ 120 years).

Dry Forests

Within the dry forests, the upper level management zone for Douglas-fir approaches ≈ 2000 trees per acre of 3

inch diameter trees. However, a more realistic precommercial thinning density would approximate 450 trees per acre and, of course, these estimates would be predicated on the future management options and product needs. A target of 140 to 220 ft² of basal area and 60 to 100 trees per acre would be the range of tree densities that would be preferred for most Douglas-fir settings (Lotan et al. 1988).

The upper management zone (tree density) for ponderosa pine is, for the most part, roughly based on threshold levels of risk for bark beetle attacks. The lower level of stocking for ponderosa pine is largely determined on the stand density in which regeneration is likely to occur (fig. 14). The highest stand densities for precommercial thinning would be in the range of 700 trees per acre and the minimum values would be in the range of 200 trees per acre. Target stand densities should not exceed 150 ft² of basal area and minimums in the range of 50 ft² would suffice in most situations (Edminster 1988). As with other species, these values would be based on the PVT, biophysical setting, management objectives, and the markets available for products. Significant declines in volume production will be realized with low residual stand densities. If rapid development of merchantable-sized material is a goal, than the lower residual stand densities are desirable. On lower productivity sites, more than one precommercial thinning may be required to maintain the desired stand structures. Low initial stand densities, either through planting or cleaning, may greatly influence thinning opportunities.

Thinnings

Beyond the sapling stage, thinnings redistribute growth potential to fewer trees leaving stands with the desired structure and composition. Even though thinning from below is the most common method, there are other methods that have applicability depending on the forest, PVT, and management objectives and desires of the landowner. Low (thinning from below), crown (thinning from above), selection (diameter-limit thinning), free thinning, and mechanical thinning all have application in the moist, cold, and dry forests of the Inland Northwest (Nyland 2002, Smith et al. 1997).

Low thinning is when trees are removed from the lower canopy, leaving large trees to occupy the site. This method mimics mortality caused by inter-tree competition or surface fires and concentrates site growth potential on dominant trees. Low thinnings primarily remove intermediate and suppressed trees, but heavy thinnings can also remove many in the codominant crown class. Low thinnings not only remove understory canopies but can also alter species

compositions. Usually, different tree species have characteristic development rates that result in individual species dominating specific canopy layers. For example, in dry forests, ponderosa pine primarily occupies the dominant canopy layers, whereas shade-tolerant grand fir, white fir, or Douglas-fir occupy the intermediate and suppressed layers. A low thinning in these stands therefore favors the development of the dominant and codominant ponderosa pine. Depending on the desired stand structure, low thinnings can remove few to many trees. Also, thinnings need not create regular spacings but rather can vary both the number and degree of clumping of residual trees.

Crown thinning, or thinning from above, reduces crowding within the main canopy. Dominant and codominant trees are removed to favor residual trees in these same classes. This method is used to remove selected trees in the dominant and codominant crown classes that are competing with more desirable trees (Nyland 2002). Selection thinning removes dominant trees to favor smaller trees. This method is often applied by removing trees greater than a certain diameter. Diameter-limit cuts that continually remove the largest trees may well be dysgenetic and can be a disguise for high grading (removing trees of high economic value without concern for future stand development). By maximizing removal of the current value from a stand, future options may be limited and the only recourse for the future may be to regenerate. Stand structures and species compositions created by using selection thinning are limited and, in general, favor shade-tolerant species or trees occupying the intermediate and suppressed crown classes. Often the stands created by selection thinnings are prone to epidemics of insects and diseases. Compared to the other thinning methods, selection thinning is less useful in these forests because of the limited stand structures and compositions it creates.

Free thinning, sometimes called crop-tree thinning, primarily releases selected trees. This method favors specific trees, whereas the remainder of the stand goes untreated. Depending on what is presented in various portions of a stand (tree spacing, species, vertical structure, etc.), the thinning criteria can be highly flexible and produces stands with large amounts of diversity. It can be used in any of the crown classes for releasing specific trees. This method has the most flexibility for creating various stand structures and compositions.

Mechanical thinning removes trees based on specified spatial arrangements (Nyland 2002). This method is often applied in plantations where every other row or every other tree in a row is removed. Such a rigid thinning prescription



Figure 15—Helicopters can be used to apply nitrogen fertilizer (urea pellets).

is easy to apply, but the stands created often lack diversity in either structure or composition. This method also resembles strip thinning, where a strip of trees is removed. Mechanical thinning may be well suited for timber production on uniform sites but has limited value for producing conditions that meet other resource values.

Use of herbicides following any form of thinning has rarely, if ever, occurred in an Inland Northwest forest. Nevertheless, there are some situations where past heavy thinning and/or patchy stocking have created stands with substantial biomass in competing vegetation. In these situations some form of herbicide application might be appropriate to maintain the desired forest structure. The repertoire of herbicides that might be considered at this point would be very similar to those applicable for use in stand weeding.

Fertilization

As stated earlier, nitrogen (N) is the most limiting nutrient in the Inland Northwest and the greatest growth response comes from the addition of N (fig. 15). The combination of stand density control, along with the application of N, appears to be the best approach for managing young stands and accelerating their growth and crown development (Graham and Tonn 1979, Weetman et al. 1985, Moore 1988, Moore et al. 1991)

Within the dry forests, ponderosa pine shows a strong linear response up to approximately 400 pounds of N per acre. Plantations with weed control can show twice the fertilization response as unweeded plantations (Powers et al. 1988). Powers (1988) found that volume growth was nearly four times greater with weeding than no treatment but the combination of fertilization and weeding produced volume growth nine times greater than untreated stands. Similarly, Douglas-fir can be rather responsive to fertilization and response varies by stand density, soil parent material and pre treatment N. Two-hundred pounds per acre appears to be a good treatment and the response appears to last about 6 years but most likely depends on stand density (Moore 1988).

Within the cold forests, lodgepole pine grows on some rather infertile sites making it respond dramatically to improved nutrition, especially following precommercial thinning (Weetman 1988). Some evidence suggests that thinning, along with fertilization, increases lodgepole pine's resistance to attack by mountain pine beetle. Also fertilizing in the spring prior to bud burst seems to provide the best response. Hamilton and Christie (1971) showed that mean annual increments of 172 to 214 ft³ per acre were achievable by fertilizing prior to crown closure.

There is a shift of nutrients from soil to tree, once the canopy is closed. As the tree's demands on soil rapidly decline following canopy closure, the nutrient cycles within the tree and through the tree-litter system are then fully charged (Weetman 1988). The cycle within the tree is based on the recovery and reuse of nutrients prior to the death of old tissues, including those of the leaf before abscission, and can be up to 85 percent efficient. However, the slow release of N from litter can lead to late-rotation ($\approx$ 60-80 years) N deficiency. In Oregon, fertilization of a 40-year-old closed-canopy lodgepole stand with 600 pounds of N per acre produced an 8-year volume response of 79 percent over a control stand and 370 pounds of N per acre produced a 3-year volume response of 87 percent over a control (Cochran 1979).

Within the moist forests, grand fir is very responsive to fertilization. The other species appear to be well adapted to the nutrition regime of the moist forests. This lack of fertilization response could possibly be related to the prevalence of the nutrient-rich volcanic soils. It also appears that western white pine has wide amplitude of N demand (Graham and Tonn 1979).

Most conifers favorably respond to the application of N at the time of planting, especially in concert with competitive vegetation control and proper site preparation. One option is to apply nutrients in the nursery which will provide robust root growth and enhance establishment when the seedlings are planted. Another opportune time to apply fertilizer is when a planting is about 5 years of age. Both of these fertilizer applications tend to further plantation establishment and increase juvenile tree growth.

STAND MANAGEMENT PLANNING

In the Inland Northwest, stand density studies, in particular thinning and precommercial thinning (cleaning and weeding), have been conducted for nearly 100 years. The concept of yield tables and normal stocking was produced from this research (Haig 1932). In some settings, the information in these yield tables are as valid today as the day they were produced (1930s). The concept of site index and the site index curves produced during that time are also still very applicable (in 2005).

However, today there are more precise and robust tools available for stand management planning. In particular, the Forest Vegetation Simulator (FVS), with variants available for areas across the United States, can be calibrated to a given site and species mix (Dixon 2002). FVS contains three major components: regeneration establishment, small tree development, and large tree development (Wyckoff et al. 1982, Ferguson et al. 1986). These components can be related to the physical setting based on location, slope, aspect, elevation, PVT (e.g., habitat type, plant association), site index, and stand density index. The small-tree component can be calibrated to a specific site by inputting the periodic height increment of seedlings and saplings and the large-tree component can be calibrated by inputting the periodic diameter increment of large trees (Dixon 2002).

All three components work in concert to project stands into the future by incorporating various management activities including harvesting, site preparation, planting, thinning, pruning, and fertilization to name a few. The influence these and other stand treatments have on stand development can be projected into the future and displayed using a variety of stand metrics. Some of these include: stand diameter,

height and species distributions, total and merchantable volume distributions by species and diameter, volume accretion and mortality by diameter and species, total and merchantable removals by diameter and species, amount and characteristics of regeneration by species and individual tree characteristics. Several extensions are available to display attributes such as those related to wildfire and fuel treatments, root diseases, blister rust, bark beetles (e.g., Douglas-fir beetle (*Dendroctonus pseudotsugae*), mountain pine beetle (*Dendroctonus ponderosae*)), and defoliators such as the spruce budworm (*Choristoneura occidentalis*) and tussock moth (*Orgyia pseudotsugata*). The FVS output can be customized for desired time intervals, readily linked to economic analysis, and pictorially displayed using the Stand Visualization System. And, most importantly, FVS can be linked to geographic information systems making the management tool both spatially explicit and providing information at resolutions customized for each owner and application (Dixon 2002).

SUMMARY

Silvicultural systems describe the planned treatments through the life of a stand and are documented in a silvicultural prescription (Smith et al. 1997, Nyland 2002). By doing so, all of the treatments and their expected outcomes from stand establishment through tending activities are integrated and designed specifically for the biophysical environment presented and designed to meet the management objectives for that stand fulfilling the goals of the land-owner. Developing silvicultural systems for specific sites enables silviculturists to recognize the different vegetation complexes and successional pathways inherent to the moist, cold, and dry forests. In other words, one prescription does not fit all stands, especially for the different forests and environments intrinsic to the Inland Northwest.

In general, the early-seral species western white pine, western larch, ponderosa pine, Douglas-fir, and lodgepole pine, are the most resistant to native insects and diseases, the fastest growing, and the most aggressive establishers on the given potential vegetation type (PVT) on which they occur. For production forestry, the most appropriate regeneration method to apply in the cold forests is a properly applied clearcut. Likewise, within the moist forests, clear-cutting provides good results but seed-tree and shelterwood regeneration methods are also applicable depending on the desired species mix and the biophysical setting (potential vegetation type, slope, aspect, current vegetation). Within the dry forests and especially on the grand fir and/or white fir potential vegetation types, clearcutting and seed-tree regeneration methods are very appropriate for the production of ponderosa pine and Douglas-fir. However, on the

drier PVTs (e.g., dry Douglas-fir and ponderosa pine), a shelterwood system offers protection for the seedlings during the establishment period and may provide better results than the total or majority canopy removal of clearcutting and seed-tree methods. Two-stage shelterwoods (preparatory cut followed by a seed-cut) are suitable on ponderosa pine PVTs. Also, under most circumstances, selection systems are most appropriate for use on ponderosa pine PVTs for the production of wood crops.

The foundation of all forestry is the soil resource. The soil and its management in all phases of the silvicultural system need to be recognized. In many portions of the Inland Northwest, the residual soils are covered with volcanic ash and/or loess deposits enriching them and, more often than not, contain the majority of the site's productive potential. Frequently the biological and nutrient capital of a forest soil tends to be near the surface of the mineral soil or integrated into surface organic layers. The humus, fermentation, and buried rotten wood layers in forest soils especially need to be recognized for their contribution to the nutrition of a site. In some settings, a major contributor to the organic matter on a site is coarse woody debris and it should be recognized and managed appropriately.

Because of the importance of soil and especially the nutrient rich (e.g., N) surface layers, we hope that the role these layers play in maintaining forest productivity will be more widely appreciated and suggest that these soil layers should only be scarified and/or scalped for a purpose. The contributions of ground-level vegetation to maintaining forest productivity in many settings should also be recognized. In particular, many shrubs and forbs fix N and ground-level vegetation can conserve both nutrients and soil in the face of catastrophic disturbances such as wildfire. Prescribed fire is an excellent tool for preparing sites for both natural and artificial regeneration, managing competing vegetation, and reducing the wildfire hazard. However, prescribed fire needs to be integrated into the silvicultural system and used judiciously to produce desired conditions.

Each conifer species is ecologically adapted to a site and it is paramount that seedlings be adapted to the site on which they are planted. The ramifications of planting maladapted seedlings may not become apparent until the stand is developing disease and/or insect epidemics or the trees are malformed. Because the forest sites are so variable on a fine scale, all planting and tending activities should take advantage of the small differences inherent to a site and multi-species, multi-spacing plantings, cleanings, weedings, and thinnings should be considered and used where appropriate.

The benefits of using appropriate herbicides are often substantial when managing forests in the Inland Northwest. However, herbicides can be costly and environmentally difficult to use. Research continues on herbicide alternatives. For example, some research addresses herbicides that have not yet been tried in the Inland Northwest, some focuses on herbicide doses, some on formulation, and some on fertilizer-herbicide combinations. No doubt, herbicide use will continue to be a viable alternative for managing many Inland Northwest forests for wood production.

To facilitate stand and forest management planning, a calibrated, spatially explicit version of the Forest Vegetation Simulator (FVS) is an effective tool. FVS can be created and adapted to particular settings and provide realistic views of stand and forest management alternatives and their impacts on forest development over time. Various extensions of FVS are available for evaluating and displaying insect, disease, and wildfire impacts to a stand. Most importantly, FVS is a very appropriate way of integrating all aspects of stand establishment and tending into a silvicultural system and its use fosters documentation of silvicultural prescriptions.

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