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Regeneration of Douglas-fir in the Klamath Mountains Region, California and Oregon

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One of the most valuable timber species in the United States is the magnificent coast Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco var. *menziessi*) of western Washington, Oregon, and northern California (*fig. 1*). The Pacific Douglas-fir forest cover type (Eyre 1980), with its associated species, is one of the world's most productive (Williamson and Twombly 1983). The preeminence accorded coast Douglas-fir is attributed to its fast growth, long life, and large size at maturity, and to the excellent structural properties of its wood. Considerable attention has been devoted to studying the regeneration of coast Douglas-fir to assure production of future crops.

Historical documentation of the evolution of logging practices and silvicultural methods in the Klamath Mountains Region of Oregon and California is incomplete, although such information would help provide a better understanding of how current regeneration practices developed. However, for three National Forests (the Six Rivers, Klamath, and Trinity) in northwestern California, some of this information is available. Cutting began there in 1947, but logging activities were minor before 1950. Heavy cutting did not start in most working circles until after 1955 (Hopkins 1964). The silvicultural system for Douglas-fir evolved from individual tree selection, to group selection, to clearcutting in blocks.

In the early 1950's, group selection was begun on the Klamath National Forest, and shortly thereafter on the Six Rivers and Trinity National Forests. The objectives of this cutting method were to harvest the most defective overmature trees, create openings large enough to minimize logging damage and competition to the future stand, and yet keep them small enough to promote natural regeneration.

During these first years of harvesting in northwestern California, all yarding was by tractors. On steep slopes this technique caused considerable soil movement, so the advantages and practicability of cable logging were explored. Because (for economic reasons) cable logging requires larger volumes to each landing, clearcutting in blocks was introduced. Between 1955 and 1960, the Six Rivers, Klamath, and Trinity National Forests, in that order, began administering sales that required cable methods on some areas.

After inspecting older cuttings in Douglas-fir and being briefed on the latest research findings, the Forest Supervisors of these three forests, in 1958, agreed that natural seeding was not providing adequate restocking. They decided to plant bare-root seedlings on all clearcut blocks as soon as possible after slash disposal. The amount of Douglas-fir planted on cutover areas had been small before then because natural regeneration had been expected.

First-year survival of Douglas-fir stock was poor in the early plantings, ranging from 0 to 70 percent, but generally less than 40 percent. Since then, planting stock, planting practices, and field survival have improved considerably. However, plantings can still fail because of adverse weather or harsh sites, but more often because of human error.

Regeneration of Douglas-fir is not a problem on all sites, or throughout its range. On the cooler, moister coastal sites, it can be regenerated more easily than on the hotter and drier inland sites. In a similar manner, the species is regenerated more easily near the northern end of its range than

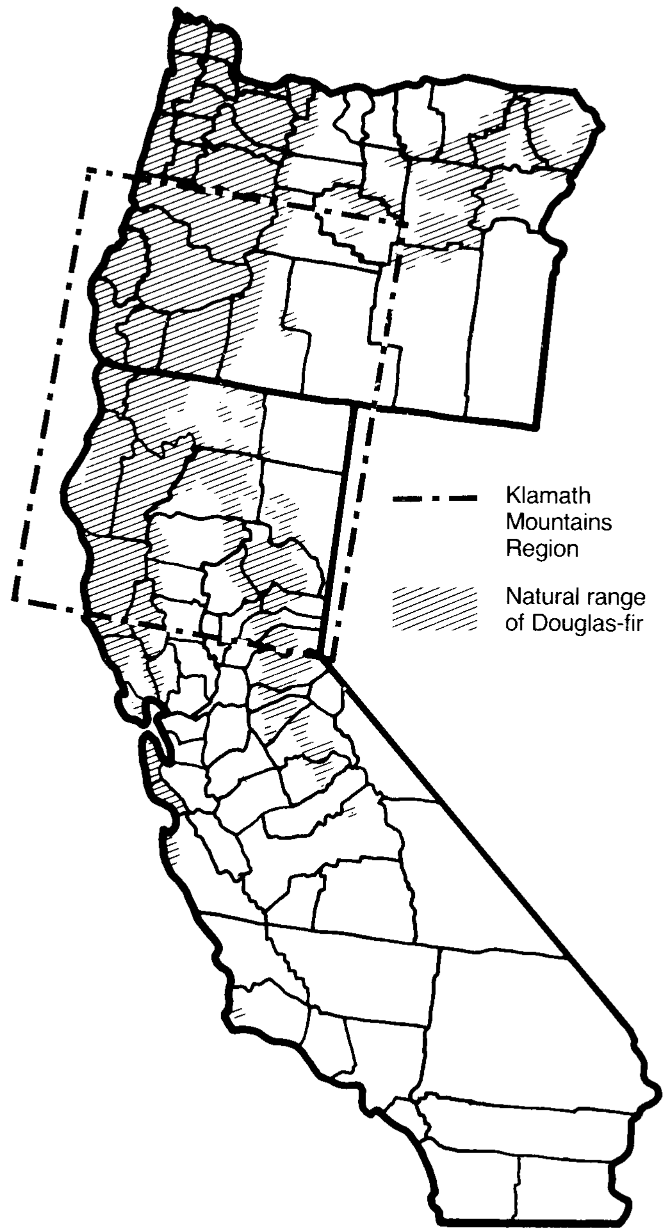

Figure 1--The Klamath Mountains region extends from southwestern Oregon to northern California (Little 1971).

near the southern end. For these reasons, the general physical characteristics of the Klamath Mountains Region must be understood. However, numerous factors other than moisture and temperature are involved in regeneration success.

The regeneration process in Douglas-fir normally follows this sequence: seed production, site preparation, and use of one of the three principal regeneration methods--natural seeding, direct or manual seeding, or planting seedlings. Young stands must be carefully tended because the whole regeneration effort can be thwarted if competing vegetation or foraging animals are allowed to suppress or destroy the young seedlings.

This paper summarizes information about the regeneration of Douglas-fir in the Klamath Mountains Region of northwestern California and southwestern Oregon. Research in the adjacent Coast Ranges of the two States is included as well as relevant studies done elsewhere. This report is designed to serve as a convenient reference, by drawing together the findings of many studies, including some not previously published. And it offers general recommendations for the forest manager and other practitioners.

KLAMATH MOUNTAINS REGION

Geology, Topography, Soils

Excellent descriptions of the geology, topography, and soils of the Klamath Mountains and Coast Ranges are offered by Irwin (1966), Irwin and Hotz (1979), Page (1966), and Snavely and MacLeod (1979).

The Klamath Mountains province of northwestern California and southwestern Oregon, an elongate north-south area of approximately 312,000 ha (12,000 square miles), is bordered on the east by the Cascade province, on the southeast by the Great Valley province, and on the west by the Coast Range province (*fig. 2*). The terrain in this province is highly dissected and mountainous, with ridge crests 1,500 to 2,100 m (5,000-7,000 ft) above sea level and peaks as high as 2,700 m (9,000 ft). Slopes are steep, and relief is commonly 900 to 1,200 m (3,000 to 4,000 ft) in many stream canyons. Evidence of glaciation is widespread in the high mountains. Vestiges of an old erosion surface are recognizable at many places, especially in the western part of the province, where many ridges are approximately the same altitude and the dissected remains of broad valleys are visible, suggesting that relief was generally low before the region was uplifted and dissected by the present drainage system.

The drainage pattern is complex, but the main streams generally flow westward, transverse to the lithic and structural grain of the province. The southeastern part of the province is drained mainly by tributaries of the south-flowing Sacramento River. The remainder of the province is drained mainly by the very extensive Klamath-Trinity River system in California and the Rogue River system in Oregon. Streams in the extreme northern part of the province are tributary to the South Fork of the Umpqua River.

In contrast, altitudes in the Coast Range province are lower, and only a few peaks, along the divide between the northern Coast Ranges and Sacramento Valley, are as high as 1,800 m (6,000 ft) and show evidence of former glaciation. Accordant ridges are common, as in the Klamath Mountains, but generally lower. Drainage patterns of the principal rivers of the northern Coast Range, such as the Eel, Mad, and Van Duzen, tend to parallel the northwesterly structural and lithic grain of the province. Exceptions are Klamath, Rogue, and other streams that rise in the Klamath Mountains and cut across the Coast Ranges on their way to the ocean.

Rocks of the Klamath province consist mainly of marine volcanic and sedimentary rocks that range in age from early Paleozoic to middle Mesozoic and are part of a sinuous belt of old rocks exposed also in the Sierra Nevada of California and in the Blue-Ochoco Mountains of east-central Oregon. For the most part these rocks have been extensively folded and faulted, weakly to strongly metamorphosed, and intruded by many bodies of granitic and other plutonic rocks. Ultramafic rocks, mostly serpentinized peridotite, are plentiful--indeed the province has one of the greatest concentrations of ultramafic rocks in North America.

The Coast Ranges of northern California and southwestern Oregon are mostly composed of graywacke and shale of late Jurassic and Cretaceous age. An outlier of Klamath Mountains rock occurs in the southwestern Oregon Coast Ranges, however, and in California a narrow band of metamorphic rocks, the South Fork Mountain schist, lies along the boundary between the Coast Ranges on the west and the Klamath Mountains and Great Valley provinces on the east.

Most of the graywacke and shale of the Coast Ranges is part of the Franciscan Formation in California (Bailey and others 1964) and its probable correlatives in Oregon, the Otter Point and Dothan Formations (Dott 1971). The Franciscan and related formations also include volcanic rocks, radiolarian chert, serpentinite, and occasional tectonic blocks, or "knockers," of exotic schist. Soil development on these various geologic formations depends to a considerable extent on rock weathering. For example, soils throughout the Klamath Mountains and Coast Ranges of northern California and Oregon that developed from mafic volcanic rocks tend to be redder, stonier, lighter textured, and thinner than soils that developed from adjacent sedimentary rocks. And soils derived from quartz-mica schist in southwestern Oregon are deeper, redder, and support

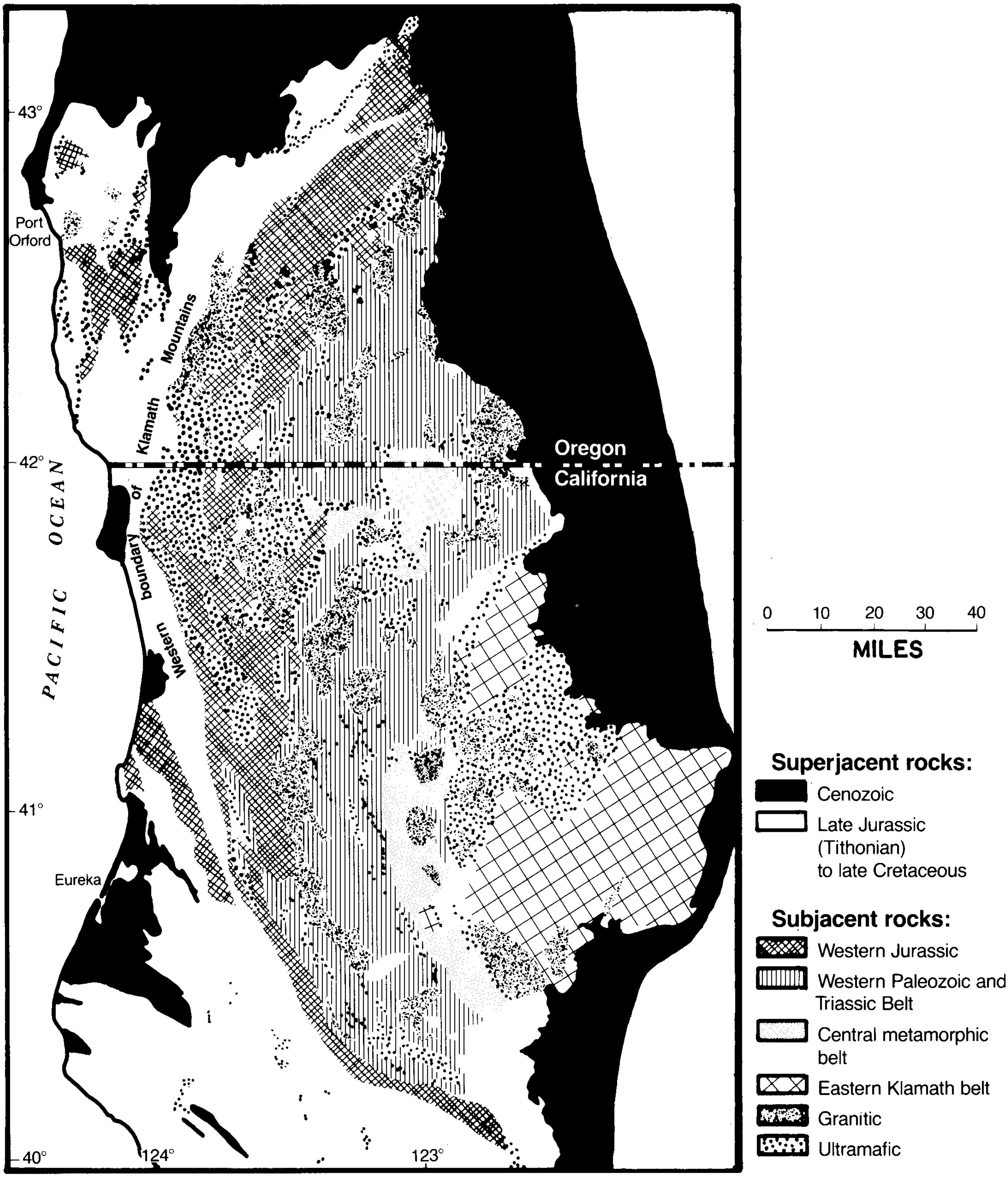

Figure 2--Superjacent and subjacent rocks characterize the geology of the Klamath Mountains Region of southwestern Oregon and northeastern California.

greater timber production than soils derived from adjacent graywacke sandstone (Buzzard and Bowlsby 1970).

In sequence of seven coastal terraces in southwestern Oregon, the sediments on the two highest terraces contain lower Pleistocene molluscan fossils and have weathered to strongly developed Ultisols (Janda 1971). In contrast, lower terraces bear only Spodosols and Inceptisols. On some of the flatter portions of the higher terraces, Spodosols have been superposed on the upper portions of older Ultisols. These observations suggest that the difference in profile characteristics between higher and lower terraces is the result not only of different durations of weathering but also of different weathering environments (Janda 1979).

In the Klamath Mountains province, the parent material consists chiefly of acid igneous and metamorphic rocks. A typical topographic sequence of soils series on schist rock in northwestern California is as follows (Zinke and Colwell 1965): At the lower elevations on the steep slopes in the Trinity River canyon, the sequence begins with the less developed Sheetiron soil series. It then proceeds upslope to the more developed Masterson and Orick soils on the less steep slopes, and finally to the well-developed Sites soils series on the nearly flat ridgetop. This sequence illustrates a pattern in which the most developed soil often is found on plateau-like ridgetops and always on apparently older surfaces in this rough terrain.

The reverse pattern is found along a transect in the California Coast Ranges province (Zinke and Colwell 1965). On a long slope of increasing elevation, a sequence of soil profiles of lessening degree of development with increasing elevation is located on graywacke sandstone. The transect begins with the better developed Josephine soil series at the lower elevations. With increasing elevation it progresses through the lesser developed Hugo soil series to the least developed Hoover series. Similar sequences are found on granitic and andesitic parent materials.

Douglas-fir does not grow well on serpentinite soils developed from ultrabasic parent materials. These soils are characteristically infertile. They are low in nitrogen, phosphorus, and potassium; low in exchangeable calcium; and high in exchangeable magnesium.

Climate

The climate of the Klamath Mountains and Coast Ranges of northern California and southwestern Oregon can be characterized broadly as mild, with wet winters and dry summers (Elford 1970, Sternes 1967). The duration of the wet and dry seasons, as well as the total yearly precipitation, varies with latitude and is influenced particularly by local and regional topography. Most of the Douglas-fir in the region grows within the annual precipitation range of 40 to 100 inches (102 to 254 cm).

The principal atmospheric factors controlling the climate of the region are the Pacific High pressure cell and, to a lesser extent, the Aleutian Low. The Pacific High, so named for its semipermanent location over the northeastern Pacific Ocean, is one of the major eddies in the earth's atmospheric circulation (Shumway 1979). In response to seasonal fluctuations in solar energy, this clockwise-rotating mountain of air migrates northward during late spring and early summer, and then slowly recedes southward during fall and winter. Conditions near the Aleutian Islands favor generation or intensification or both of somewhat smaller eddies that rotate counterclockwise. These low pressure areas, once set in motion, usually drift eastward and are the moisture-bearing storms that move onshore along the Pacific Coast with maximum frequency during winter.

Although somewhat fewer lows are generated during summer, the position of the Pacific High dictates the frequency of storms that penetrate the Klamath Mountains region. During late spring, the northward extension of this vast mountain of air effectively blocks and diverts storms generated in the Aleutians to higher latitudes. After reaching maximum development in July and August, a gradual deterioration and southerly recession of the revolving air mountain allows a steadily increasing number of Aleutian-born storms to batter the Pacific Coast at lower and lower latitudes. The coincidence of maximum eddy development in the Aleutians with maximum southward retreat of the Pacific High causes unusually wet winters along the west coast of North America, between latitudes 40° N and 60° N. Similarly, minimum eddy development with maximum northward protrusion of high pressure causes summers in the Klamath Mountains Region to be remarkably dry.

Between the leeward slopes of the coastal mountains and the foothills of the Cascade-Sierra Nevada ranges is a low, relatively narrow corridor, extending from northern California through Oregon and Washington to the northeast of Vancouver Island. In this area, annual precipitation is less than 1.3 m (50 inches). The area is shielded from heavier precipitation to the west by the coastal mountains and is often short-changed or even bypassed by precipitating systems moving in from the Pacific (Shumway 1979).

In a manner somewhat analogous to regulation of seasonal distribution of precipitation by the Pacific High, the temperature over the Klamath Mountains Region is dominantly influenced by the Rocky Mountains, and to an even greater extent by the Cascade-Sierra Nevada ranges (Shumway 1979). These mountain systems form two separate, substantial barriers to invasion of air masses from the east--air masses that are much colder in winter and considerably warmer in summer.

Normally, these mountain ranges hold back extreme types of weather, which develop in the continental interior, thus allowing the Pacific Coast to remain under the moderating influence of the Pacific Ocean. Water temperature offshore remains relatively constant throughout the year--around 50°F (10° C)--so that any air mass entering unobstructed from the west is warmed in winter and cooled in summer (Shumway 1979). The maritime influence extends inland across the coastal mountains in parts of Oregon and Washington, but in northern California it is limited to a narrow corridor west of the Coast Range. Considerably more severe continental climates prevail a relatively short distance inland.

Vegetation

Two vegetation zones are prominent in the Klamath Mountains Region; the Mixed Conifer Zone and the Mixed Evergreen Zone (Franklin 1979). Characteristic species in the Mixed Conifer Zone include Douglas-fir, incense-cedar, sugar pine, white fir, and ponderosa pine.[1] Of these species, Douglas-fir and incense-cedar are the most important in terms of timber volume.

Succession is a slower process in the Mixed Conifer Zone than in the Western Hemlock Zone, which is regarded as representing modal or average conditions of temperature and moisture for the Douglas-fir Region as a whole (Franklin 1979). Regeneration of trees in the Mixed Conifer Zone generally is slowed by the more severe environment. In addition, brushfields dominated by chaparral-like evergreen shrubs frequently develop. Typical species are varnishleaf ceanothus, mountain whitethorn ceanothus, narrow-leaved buckbrush, golden chinkapin, canyon live oak, and hairy manzanita. Brushfields slow the rate of establishment and growth of conifers.

The Mixed Evergreen Zone is located in the western Siskiyou and Klamath Mountains (Franklin 1979). Average sites typically are occupied by an overstory of mixed conifers, with sclerophyllous broadleaved trees in the understory. The most important forest trees, which are probably major climax species, are Douglas-fir and tanoak. A variety of other trees also may be present, the most characteristic being hardwoods such as Pacific madrone and golden chinkapin. Conifers that may be present include sugar pine, ponderosa pine, incense-cedar, Jeffrey pine on serpentine, Port-Orford-cedar on moist sites, and knobcone pine on recent burns, Understory communities (low shrub and herb layers) typically are not well developed. Poison oak, Oregon grape, California honeysuckle, oceanspray, California hazel, and rose are characteristic shrubs in the Illinois River region and indicate a more xeric environment than typical of the Western Hemlock Zone. Succession is often slow in the Mixed Evergreen Zone, at least as to development of new conifer forests after disturbance. Sites can be lost easily to evergreen hardwood stands or to dense evergreen chaparral.

In northwestern California, the Douglas-fir forest type develops best on northerly aspects, deeper soils, and the less steep slopes. Generally, Douglas-fir is much less successful on southerly aspects (Hopkins 1964). On poorer sites--particularly ridgetops--and on occasional flats, sugar pine, ponderosa pine, and incense-cedar may predominate; and on the southern and eastern fringes of the region, ponderosa pine and sugar pine begin to replace Douglas-fir (Hopkins 1964). Hardwood understories are heavier nearer the coast (Hopkins 1964). The optimum climate for hardwood species that compete with Douglas-fir in California is found in the extreme northwest corner of the State--an area approximately coincident with Del Norte County, where hardwoods form dense growth, even under heavy overhead canopies.

The present floristic pattern in the California portion of the Klamath Mountains Region reflects a comingling of the Pacific Northwest and California-centered species (Sawyer and Thornburgh 1977). Existing vegetation patterns are controlled primarily by differences in parent material, and secondarily by elevation and by soil moisture as it relates to topography (Waring 1969, Wittaker 1960). Klamath montane forests grow mostly above low-elevation coniferous forests. And dominant species such as Douglas-fir, ponderosa pine, and sugar pine are typical of low as well as montane elevations.

Two subregions--western and eastern--have been identified within the Klamath Mountains Region (Sawyer and Thornburgh 1977). In the western subregion, low-elevation Douglas-fir/ hardwood forests give way in the higher elevations to Douglas-fir/ white-fir, then to white-fir/ California red fir, and finally to California red fir/ mountain hemlock. These forests grow in relatively cooler and moister climatic areas than those in the eastern subregion. They are subject to greater maritime influence because of their location (e.g., the Siskiyou Mountains), or because of an overall westerly aspect (e.g., the Marble Mountains, western Salmon Mountains, and western Trinity Alps). In the eastern subregion, the climate is drier and more continental. The forest zonation pattern is comprised of dominantly ponderosa pine forests at low elevations, giving way at higher elevations to pine/ white fir, then to white fir/ California red fir, and finally to California red fir/ mountain hemlock.

Within each of the elevational zones in the Klamath Region, forests along streams have an abundance of herbs and shrubs. In contrast, floristic diversity is lacking on dry slopes, and understory vegetation is virtually absent. With change in elevation, each species assumes a different ecological role by virtue of its response to altered environmental conditions. The resulting pattern is one of changing forest composition as elevation increases. In the western subregion of the White Fir Zone (the lowest of four elevational zones), white fir is the most competitive species in all habitats. Therefore, this species, along with Douglas-fir, dominates mature forests. In the drier eastern subregion, Douglas-fir plays a less competitive role, and other species such as ponderosa pine are less environmentally restricted. The resulting mature forests are of more mixed character than those on comparable habitats in the western sub-region.

Trees that are regionally common have broad habitat requirements, high competitive abilities, or high colonizing abilities (Sawyer and Thornburgh 1977). Thus, in the western subregion of the White Fir Zone, Douglas-fir can main-

[1]Scientific names of plants and animals are listed in the *appendix*.

tain significant stand importance in competition with white fir because of its wide-ecological tolerance, longevity, and high colonizing ability. With increasing elevation, however, Douglas-fir becomes progressively less competitive. In the higher-elevation zones, the species is confined mainly to xeric habitats.

SEED PRODUCTION

Because Douglas-fir does not reproduce by sprouting, the quantity, quality, and frequency of seed crops are of prime importance for both natural and artificial regeneration. Douglas-fir trees seldom produce seed before they are 10 years old and 15 feet (4.5 m) tall (Isaac 1943). Open-grown trees begin producing seed in appreciable amounts at age 20 to 30 years, but do not produce maximum crops until they are 200 to 300 years old (Fowells 1965). On the average, heavy seed crops are produced every 5 to 7 years in the Pacific Northwest (Isaac 1949). Between heavy seed crops, at least one crop usually fails, and two or more crops are light or medium (Fowells 1965).

Seed Quality

Seed crops in old-growth stands of Douglas-fir in northwestern California may be scanty for several years, and are generally of poor quality (Roy 1960a). Only 18 percent of the total seeds collected over an 8-year period were sound. Seed quality may be much better in young stands. Seed viability was 53 percent in the unthinned portion of a 49-year-old stand in western Washington (Reukema 1961).

The poor quality of the seed from old-growth trees was attributed only partly to insect damage, and mainly to the lack of embryo and endosperm in many seeds with fully formed seed coats (Roy 1960a). The problem appears to originate from either a lack of pollination or fertilization. Parthenocarpy--the development of unpollinated cones with full-sized but empty seed coats--is common in many species, including Douglas-fir (Allen 1942). A small percentage of Douglas-fir seed from parthenocarpic cones may be viable and able to germinate and produce seedlings (Allen 1942, Orr-Ewing 1957).

Cone Crop

The number of reproductive bud primordia initiated would appear to be a promising indicator of a good cone crop, but not all of them develop. Some primordia abort early and disappear; others develop bud scales, then cease further development and become latent (Owens 1969). Thus, the number of cones produced is not determined directly by the number of primordia initiated, but by the proportion of primordia that develop as reproductive buds. Abundance of maturing cones on shoots formed the previous year greatly reduces the possibility of these primordia becoming reproductive buds.

Rain during the pollination period appears to have no major adverse effect on seed set (Silen and Krueger 1962). Cones receptive to pollen during predominately rainy periods showed little reduction in filled seeds when compared with cones receptive during clear weather.

Shade, on the other hand, does affect the formation of flower buds. A month of shade during shoot elongation definitely reduced female buds and increased male buds for a year, but a year later, both male and female bud numbers were reduced (U.S. Dep. Agric., Forest Serv. 1971). This finding suggests that the start of flowering, or at least some necessary precondition for flowering, occurs 26 to 30 months before seedfall.

The influence of shade in reducing the number of flower buds formed probably also accounts for the distribution of cones within the crowns of individual trees. Among 20 open-grown Douglas-fir trees between 10 and 39 years of age, cone numbers were greatest near the tips of branches in the upper two-thirds of the crown on the south-facing side of the tree (Winjum and Johnson 1964). Cones also were longest, and cut-counts (the number of seeds exposed by cutting cones longitudinally) were greatest, in cones from these parts of the crown.

Stimulating Production

Attempts to stimulate seed production by Douglas-fir have not been entirely successful. Techniques most frequently tried include fertilization, thinning, and girdling. On Brush Mountain of the Six Rivers National Forest, northwestern California, seed production did not increase significantly after mature Doubls-fir were fertilized with nitrogen and phosphorus. Urea (43 percent active) provided nitrogen at 200, 400, and 600 pounds per acre (224, 448, and 672 kg per ha), and super triple phosphate (52 percent active) provided P_20_5 at 2000 pounds per acre (224 kg per ha). Studies in a mature stand of Douglas-fir on Vancouver Island likewise showed no noticeable response in seed production during a 3-year period after fertilization (Crossin and others 1966).

Fertilization of younger stands to stimulate seed production has had variable success. In a 35-year-old stand of Douglas-fir in Washington, ammonium nitrate was applied at rates of 200, 400, and 600 pounds per acre (224, 448, and 672 kg per ha). None of the plots (including unfertilized) had any appreciable cone crops in the first, second, or fourth years after fertilization. The fertilized plots did, however, produce more cones the third year, although the magnitude of the increase was not reported (Reukema 1968).

More encouraging results were reported for plots treated with 200 pounds per acre (224 kg per ha) each of nitrogen and phosphorus, in the Pacific Northwest. The treated plots produced more than eight times as much seed as did unfertilized plots (Youngberg 1968). A similar eightfold increase in seed production in a thrifty 20-year-old stand of Douglas-fir in southwestern Washington was produced after 200 pounds per acre (224 kg per ha) each of nitrogen and phosphorus were applied (Steinbrenner and others 1960).

The form in which nitrogen is supplied may determine whether cone production is stimulated. Increasing rates of nitrogen, applied as nitrate to 13-year-old Douglas-fir trees at time of vegetative bud-break, increased cone production the following year from two to seven times, whereas ammonium nitrogen produced no response (Ebell and McMullan 1970). Shoot growth, however, was similar for the two forms of nitrogen. Nitrate fertilizer increased the number of reproductive bud primordia.

Thinning, under certain conditions, also stimulates seed production. Three thinning treatments are being tested in a 49-year-old stand of Douglas-fir in western Washington. Although seed production among the thinning regimes did not differ significantly, each thinned plot produced about twice as much seed in a good year as unthinned plots (Reukema 1961). Thinning did not alter the proportion of sound seed produced, nor did it stimulate seed production in poor seed years.

Stem girdling and other forms of stem injury also have been reported to stimulate cone production. In British Columbia several double-stemmed Douglas-fir trees were used to study cone production response to partial girdling. On each of three such trees, one stem was girdled and the other not. Two of these trees were girdled in August 1957, and the third was girdled in May 1958. In fall 1959, cone production from the three girdled stems averaged 7.4 times more than that of their ungirdled partners, but declined to 1.6 and 2.3 times that of the control stems in the next 2 years (Ebell 1971). In the same study, single-stemmed trees were girdled at weekly intervals. The onset of flowering was found to be the best time to apply this technique. Responses obtained by girdling between time of flowering and vegetative bud-break were variable, and cone production was adversely affected when trees were girdled later than 1 week after vegetative bud-break.

Cone production reduced carbohydrate concentration in shoots of all ages, as well as the growth and number of new shoots, and the number of developed buds per shoot (Ebell 1971). These findings help to explain the absence of consecutive abundant cone crops and suggest that cone-inducing treatments should not be applied in good flowering years, because they would be out of phase with the tree's ability to respond to such stimuli.

Losses to Insects

At times, insects cause serious damage to Douglas-fir cones and seeds. Although more than 60 species of insects have been found in Douglas-fir cones (Keen 1958), only 4 regularly cause significant damage in California (Koerber 1960): cone moths *Barbara colfaxiana* (Kearf.) and *Dioryctria abietella* (Dennis and Schiffermüller), seed chalcid *Megastigmus spermotrophus* (Wachtl), and cone midge *Contarinia oregonensis* (Foote). These species as well as another cone midge, C. *washingtonensis* (Johnson), are also the principal insects that damage Douglas-fir cones and seeds in Oregon (Lavender 1978).

The proportion of the seed crop destroyed by insects varies greatly from year to year. When the seed crop is large, losses to insects may be only 3 to 5 percent, while insects may destroy nearly all of a small crop. At three locations in Humboldt County, California, the proportion of Douglas-fir seed destroyed by insects ranged from 46 to 95 percent in 1959 and from 26 to 63 percent in 1961 (Koerber 1962,1963).

SITE PREPARATION

Successful regeneration of a logged area, regardless of method, usually requires site preparation. Although occasional examples can be found of well-stocked young-growth stands of Douglas-fir that developed after logging without special site preparation or, for that matter, without a conscious effort at regeneration, these are fortuitous exceptions to the general rule. In the Klamath Mountains Region, prompt regeneration of Douglas-fir in areas logged or burned requires direct seeding or planting.

Site preparation generally has three main objectives: removing or consolidating debris left after logging, thereby reducing impediments to planting or seeding and future management operations; killing or substantially weakening shrubs, hardwoods, grasses, and other vegetation that might compete seriously with conifer seedlings; and preparing a mineral soil seedbed. Fulfilling the first objective also reduces the fire hazard--an important consideration for future protection of the new stand. Additional objectives (Stewart 1978) are reducing compaction or improving drainage of surface and upper soil horizons, creating a more favorable microsite on harsh sites, and controlling diseases.

Intensive site preparation is essential to ensure successful establishment of a new crop of trees (Buck 1959). At least 70 percent of the area on a cutblock should be bare mineral soil. Establishment and early growth of Douglas-fir is proportional to the original amount of bare area, regardless of whether regeneration is by natural seeding, artificial seeding, or planting.

The four most common site preparation methods are mechanical preparation, prescribed burning, chemical treatment, or combinations of these (Cleary and others 1978, Stewart 1978). In deciding which method is best in a given situation, several factors must be considered, including slope steepness, soil characteristics, the amount and distribution of slash, the density and probable response of the competing vegetation, and the relative costs of the methods. In some instances, adverse effects on soil and water may preclude use of a particular method in a given locality, or impose restrictions on how the method may be used.

Mechanical Techniques

Mechanical site preparation includes a wide range of techniques, from hand scalping of individual seeding or planting spots, to scarification as a byproduct of logging, to thorough removal of brush and debris by large tractors with various types of blades or other attachments. Generally, the degree of site preparation achieved solely through logging disturbance is highly variable, probably because it is only a byproduct of logging and usually is not included as an objective in the logging plan (Stewart 1978). Also, many shrubs resprout from crowns and roots after logging injury, and thus reliance on logging disturbance alone is rarely successful as a means of suppressing competing vegetation.

Not only is logging disturbance often inadequate site preparation, but it may have varying degrees of adverse effects on the site. In the Oregon Cascades, the effect of four logging methods--tractor, high-lead, skyline, balloon--upon soil surface conditions was studied (Dyrness 1965, 1967, 1972). Of particular interest are the percentages of the surface which were classified as either "compacted" or "deeply disturbed". In order of decreasing percentages of areas in these two condition classes combined, the logging methods ranked as follows: tractor (35.7 pct), high-lead (18.8 pct), skyline (8.1 pct), and balloon (4.3 pct). Surface-soil bulk densities for compacted areas were significantly higher than for undisturbed areas, indicating decreased soil porosities for the former. Soil compaction hampers seedling root development, both because of the physical impediment and because of reduced aeration in the rooting zone.

Tractor logging on fine-textured soils when soil moisture is high can cause puddling, displacement, and compaction on skidroads. In southwestern Washington, soil compaction on skidroads, which covered about 26 percent of the area logged by tractors, reduced stocking by nearly 50 percent and the number of established seedlings by two-thirds when compared with off-road conditions (Steinbrenner and Gessell 1956). Seedlings on skidroads were less vigorous and grew less in height during the first 2 years than did seedlings planted elsewhere. Under such circumstances, special site preparation techniques may be warranted to correct soil compaction.

In contrast to the often ineffective site preparation that results from logging disturbance, highly effective site preparation can be achieved by machine clearing after logging is completed. This method, although expensive, can provide maximum exposure of mineral soil, if that is the desired objective. One way to reduce costs is to keep tractors moving forward, working around obstructions rather than attempting complete eradication (Gratkowski and others 1973). Crawler tractors of various sizes equipped with bulldozer blades, rake blades, or toothed brush blades generally are used. Toothed blades can be pushed through the soil to uproot brush species while minimizing movement of topsoil into windrows (Stewart 1978). Formation of windrows leads to loss of topsoil, which may significantly reduce the growth of Douglas-fir seedlings. In one plantation, seedlings on subsoil grew only two-thirds as much as those on topsoil, and in another plantation they grew less than half as much (Youngberg 1979).

Advantages of mechanical site preparation techniques are these:

- Effective on sites not suited to prescribed burning or on sites with dense stands of brush species that are resistant to herbicides (Stewart 1978).
- May reduce planting costs due to the removal of live or standing dead brush.

Disadvantages are these:

- High operational costs.
- Not practical on slopes steeper than 30 percent, because of possible hazard to equipment operator, and--on certain soil types-may induce accelerated erosion.
- Most effective during summer, when soil compaction may be a problem.
- Loosens topsoil thereby increasing erosion hazard and germination of dormant brush seeds buried in the soil (Gratkowski and others 1973).

Prescribed Burning

Burning alone also can prepare sites satisfactorily under certain conditions but usually entails some element of risk, because the kind of weather and fuel moisture conditions that produce clean burns also make control of fires difficult. For maximum effectiveness, all hardwoods remaining on a cutblock should be felled before burning (Buck 1959). Recent advances in ignition technology, notably the use of a helicopter to achieve ignition with great speed and accuracy throughout a cutblock, have permitted much better control of burning patterns and fire behavior, and greater safety for the slash-burning crew.

Although in many instances burning has been the only feasible way to reduce the large accumulation of logging debris left on a cut-block, studies have shown that burning also produces some undesirable effects. Most of these detrimental effects are associated with "severe" burning--intense, prolonged fire that consumes all duff and changes the color of the upper layers of mineral soil, usually to red (Morris 1958). Fortunately, studies have shown that in normal slash disposal operations, less than 5 or 6 percent of the total area of a cutblock is subjected to severe burning conditions (Morris 1958, Tarrant 1956).

The detrimental effects of severe burning include these: a reduction in the soil macroscopic pore space and percolation rate, with a resultant increase in runoff and erosion (Tarrant 1956); creation of a crusty, compacted surface; an increase in soil surface temperatures (Neal and others 1965); and a long-term decrease in total nitrogen (Neal and others 1965, Knight 1966), the higher the temperature of the burn, the greater the nitrogen loss (Knight 1966). On steep slopes where the retention of vegetation and duff contributes to soil stability, burning can destroy these protective elements, resulting in increased soil movement (Mersereau and Dyrness 1972). Conversely, burning stimulates the germination of seeds of certain brush species, notably those in the genus *Ceanothus* (Gratkowski 1961c), which often results in serious competition to young conifer seedlings a few years later.

The detrimental effects of burning on conifer regeneration appear to be more serious on some soil types than on others. The regeneration success on burned and unburned cutblocks situated on erodible granitic soils of the Klamath National Forest in northwestern California was evaluated (Heavilin 1977). The cutblocks had been hand-planted 6 years earlier with 2-0 Douglas-fir seedlings. Conifers were seven times more numerous on the unburned than on the burned cutblocks, and the average height of the tallest conifer on each sample plot was nearly twice as great on the unburned as on the burned cutblocks. The results suggest that modification of slash-burning policies on this soil type may improve regeneration success.

To evaluate the influence of slash burning on regeneration success in the Pacific Northwest, a series of paired plots on cutblocks representing a variety of slopes, aspects, soil types, and slash and brush conditions was established on the Cascade Range of Washington and Oregon, and in the Oregon Coast Range (Morris 1958). Plot sizes ranged from 0.25 to 0.50 acres (0.10 to 0.20 ha). One member of each pair was burned by regular slash-disposal crews while the other was left unburned. For at least 5 years after burning, brush crowns covered more area on the unburned than on the burned plots. In the first season after burning, crowns of live brush covered about 3 percent of the area on the burned plots, and 12 percent on the unburned plots. Species differences also were apparent. The main brush species on unburned plots were vine maple and Pacific rhododendron. On burned plots, snowbrush was most abundant.

Subsequent observations on 13 pairs of these plots on the west slopes of the Cascades near Oakridge, Oregon, showed that only for 5 years after burning was there significantly more brush on unburned than on burned plots (Steen 1966). By 7 years, the differences in brush cover were no longer significant. Similarly, conifer reproduction was significantly more abundant on the unburned than on the burned plots for only the first 6 years after slash burning. Thereafter, differences were no longer significant. Conifers present before logging were not included in these comparisons. Height growth of Douglas-fir seedlings has not been consistently superior on either burned or unburned cutblocks. Seedlings on unburned cutblocks on granitic soils in northwestern California grew substantially taller than those on burned cutblocks (Heavilin 1977). On the other hand, the opposite was true on the Gifford Pinchot National Forest in southeastern Washington: height growth of 1-year-old seedlings on severely burned soil was significantly greater than that on unburned soil, and 2-year-old seedlings grew best on lightly burned seedbeds (Tarrant and Wright 1955). On yet another area--the H. J. Andrews Experimental Forest in the Oregon Cascades--no significant height differences among seedlings growing on unburned, lightly burned, or severely burned seedbeds were found. Differences in soil type, vegetative competition, seedling condition and characteristics, and a host of other factors probably account for these apparent anomalies.

The advantages of prescribed burning for site preparation are these:

- Can be used on steep terrain.
- Results in large, easily planted areas.
- Does not cause soil compaction.
- Costs less than mechanical eradication.

Disadvantages include these:

- Fire control can be difficult and expensive.
- Large complement of well-trained personnel is required, limiting the amount of acreage that can be burned.
- Smoke pollution can be a problem.
- Burning is not suitable for highly erodible soils.
- Many shrubs resprout if fires do not kill the roots and root crowns, and fire may induce germination of seeds of some brush species.
- Burning results in loss of soil nutrients--especially nitrogen (Gratkowski and others 1973).

Chemical Treatment

Chemical site preparation exposes no mineral soil but can be effective in retarding competing vegetation. In fact, chemical site preparation alone has only two purposes: to reduce or eliminate competition, and to alter animal habitat (Stewart 1978). Thus, herbicides alone are effective for site preparation only when residual vegetation is highly susceptible, when slash density is low, when litter is light enough to permit seeding, or when brush is sparse enough to allow planting at reasonable cost. Under many conditions, herbicides are used most effectively in conjunction with either mechanical treatment or prescribed burning. The situations where such combinations are most appropriate are described in the next section.

The advantages of using chemicals for site preparation are these:

- It is often the least expensive method of site preparation.
- It requires a minimum of manpower and supervision to treat large areas quickly.

- It produces the least disturbance and does not compact, loosen, or move topsoil, or expose the surface to erosion.
- It can be used on all types of terrain.
- The disadvantages of chemical treatment are these:
- Planting can be more expensive amid chemically killed brush.
- Mineral soil necessary for natural or artificial seeding is not exposed.
- Dominant competitors must be susceptible to herbicides.
- Herbicides may be unacceptable near certain areas.
- Sprayed standing brush protects small animals that may damage seedlings from predators.
- Rapid resurgence of vegetation may require early and frequent respraying to assure dominance of the planted trees (Gratkowski and others 1973).

Combination Treatment

Under some circumstances, a combination of mechanical, burning, and chemical treatments is the most effective site preparation. Often herbicides may kill a competing brush species but leave such dense standing dead brush that planting would be difficult if not impossible. The physical impediment must be removed before the area can be regenerated successfully, and mechanical removal is one possible technique. This combination method has an advantage over mechanical clearing alone, in that the herbicide treatment can reduce resprouting (Stewart 1978). The cost of spraying may be more than offset by reduced costs of subsequent mechanical site preparation (Gratkowski and others 1973). Reversing the treatment sequence also provides an effective combination. Sprays applied after scarification can control sprouts and seedlings of brush species, or control invading grasses (Stewart 1978).

The combination of herbicides and prescribed burning also has proved to be an excellent site preparation technique under appropriate conditions. The method has two variations, one termed "brown and burn" and the other "spray and burn" (Stewart 1978). The brown and burn method uses contact herbicides to desiccate leaves and twigs before burning. Because contact herbicides are not translocated into roots, they will not prevent resprouting after burning. Most contact herbicides, are highly toxic and must be handled with caution. Therefore, this method is not always advisable.

The spray and burn technique uses translocated herbicides to defoliate and control residual vegetation before burning. Burning is delayed several months to a year or more after spraying to achieve maximum root kill and stem desiccation (Stewart 1978). In northern California, best results are obtained if two growing seasons are allowed to elapse between spraying with phenoxy herbicides and burning (Bentley and others 1971, Green 1970). Even if some resprouting occurs after the spray and burn treatment and necessitates respraying, the resprouts and brush seedlings. that occupy the burned area usually are more susceptible to herbicides than full-crowned mature plants (Stewart 1978).

REGENERATION

Natural Regeneration

Factors that affect the success of natural regeneration include a suitable seedbed, the frequency of good seed crops, the quality of seed, and cultural and other practices that can stimulate seed production. Also needed is adequate dispersal distance of seed from parent trees.

Currently, little reliance is placed on natural seeding as a means of regenerating Douglas-fir because of the irregularity of good seed crops, difficulty of timing the timber harvest to coincide with a good seed crop, problem of controlling seed-eating predators, and vagaries of the weather during the critical germination period. Seedlings that develop from naturally disseminated seeds do, however, often increase the conifer stocking on many cutblocks regenerated by one of the other methods.

Seed Dispersal

The amount of seed reaching the ground decreases rapidly as distance from the seed source increases. In studies of seed dispersal in four old-growth Douglas-fir stands in northwestern California, the amount of seed falling 5 to 6 chains (100 to 120 m) from edges. of clearcut blocks averaged only one-tenth the amount under uncut timber. Thus, for natural regeneration, cutblock widths should be limited to 8 chains (160 m) (Roy 1960b).

In the wetter climate of western Washington, distance from the uncut timber edge beyond 500 feet (152 m) of a 130-acre (52.6 ha) clearcut block clearly affected stocking. The block was in old-growth Douglas-fir with an understory of younger western hemlock. Five years after logging, 59 percent of the block was stocked with conifers (only 26 percent with Douglas-fir). On nearby small group cuttings that ranged in size from 1.2 to 4.0 acres (0.49 to 1.62 ha), 85 percent of the milacres were stocked with conifers (40 percent with Douglas-fir) (Worthington 1953).

Shade, as well as distance from seed source, can influence the success of natural regeneration. This was apparent in a study of 15 clearcut blocks in the Oregon Cascades, 13 of which were less than 9 acres (3.6 ha) and 2 larger (Franklin 1963). The smaller units were of four types: (1) north-south strip clearcuts. (2) east-west strip clearcuts, (3) rectangular clearcuts, and (4) circular clearcuts. The two larger units were a seed-tree cutting of about 20 acres (8 ha) and a staggered-setting clearcut of about 48 acres (19 ha).

All 13 of the small clearcuttings were regenerated adequately within 4 years after logging, and on 8 of them the number of seedlings increased significantly as the number of hours of shade increased. This relationship was more pronounced on the strip clearcuts oriented east-west than on those oriented north-south.

On the 20-acre (8 ha) seed-tree cutting, 36 seed trees were left on about two-thirds of the area. As on the smaller units, this treatment resulted in adequate regeneration within 4 years after logging. The seed trees had been selected for vigor, and were spaced 120 feet (37 m) apart. The shade cast by these trees helped promote prompt seedling establishment.

The effect of cutblock size on stocking was minor on 13 staggered settings (12 larger than 40 acres) in the Oregon Cascades and Coast Range. In fact, it was less important than were the effects of aspect, ground cover conditions, or burning treatment. Cutblocks having the best stocking had northerly aspects, light slash, light herbaceous cover, and had not been burned (Lavender and others 1956).

Seed Predators

Mice, shrews, voles, chipmunks, and squirrels often reduce or prevent natural regeneration. Foremost among these seed predators is the white-footed deer mouse, which destroys more coniferous tree seed than any other small mammal in western Oregon (Hooven 1958). Deer mice hold a position of similar notoriety in northern California. A caged deer mouse can eat from 250 to 350 Douglas-fir seeds per day (Hooven 1975). At this rate, two deer mice can consume about 40,000 seeds (1 pound) in fewer than 80 days. Trapping for several years after logging on clearcuttings in both the Coast and Cascade Mountain Ranges in Oregon indicated populations of from four to seven deer mice per acre (10 to 17 per hectare).

Small-mammal populations were observed for 11 years in Lane County, west-central Oregon (Hooven 1976). The yearly number of species ranged from 8 to 12 and averaged 10, although 21 species were caught overall during that period. Of these 21 species, 6 comprised 92 percent of all individuals caught. Deer mice accounted for 30 percent of the total, shrews (Trowbridge's shrew and vagrant shrew) 25 percent, Townsend's chipmunks 19 percent, Oregon creeping voles 12 percent, and jumping mice 6 percent.

During the 11-year study, high populations of small mammals generally were related directly to moderate-to-good cone crops of Douglas-fir the previous year. Although the overall number of small mammals increased remarkably, only deer mice and shrews showed a definite, constant increase during any year immediately after a moderate-to-good cone crop. The densities of the other seed-eaters fluctuated, and often did not correspond to an increased availability of seed.

In another western Oregon study, mice (mostly deer mice) and shrews destroyed 41 percent of the naturally disseminated Douglas-fir seed between seed fall and the end of germination the following year (Gashwiler 1970). Birds (predominantly) and chipmunks destroyed another 24 percent, mostly before germination began.

A hot slash burn can kill or drive out all resident mice, but they reinvade within 2 1/2 weeks (Tevis 1956a). However, in a forested area devastated by an intense wildfire that burned about 87,000 acres (35,200 ha) northwest of Yreka, California, mice and kangaroo rats survived the conflagration by burrowing underground, and then fed on insects, or on seeds in hidden stores (Tevis 1956b).

Shrews may consume sizable amounts of Douglas-fir seed; but seeds are not their primary food, and they cannot survive on seeds alone. On the Tillamook Burn in Oregon, shrews consumed the greatest number of Douglas-fir seeds in winter and early spring, when their chief natural foods--insects--were scarce (Kangur 1954). Chipmunks and squirrels sometimes are important seed predators locally, but their overall impact is generally less than that of mice and shrews. Varied thrushes, spotted towhees, mountain quail, golden-crowned sparrows, fox sparrows, and especially juncos all benefit from logging and consume most of the conifer seeds lost on the ground to birds (Hagar 1960).

Direct Seeding

Direct seeding plays only a minor role in current planning for Douglas-fir regeneration. Although not all of the drawbacks of natural seeding apply to direct seeding, adequate protection of the seeds from seed-eating rodents still poses a problem, and unfavorable weather patterns can result in germination failures or early mortality of newly germinated seedlings.

Direct seeding of Douglas-fir is still of interest to some forest managers because large areas can be seeded quickly with a helicopter, and because the initial cost is considerably cheaper than planting. However, the probability of a seeding failure is comparatively high, even under ideal conditions on maritime slopes. If an area must be reseeded one or more times, the cost advantage over planting is lost. The difficulty lies not so much in a lack of knowledge of the requirements for successful seeding, but rather in a lack of control over some key factors that determine success or failure.

Condition of Seedbed

One important factor over which the silviculturist has considerable control is the condition of the seedbed. Seed germination and seedling survival of Douglas-fir were studied on six seedbed types on a south-facing clearcut in the Oregon Coast Range (Hermann and Chilcote 1965). Seedbeds studied were sawdust, litter, charcoal, and soils that were unburned, lightly burned, or Beverly burned. Each seedbed was exposed to three light intensities--100, 75, and 25 percent of full sunlight. Regardless of light conditions, germination was best on charcoal and on severely burned soil. Good germination was attributed to prolonged preservation of moisture at the surface of these seedbeds. Germination differed significantly from that on the other four seedbeds, with better stocking maintained for at least six growing seasons.

Wood ash, on the other hand, may inhibit seed germination by reducing the oxygen supply to seeds, which become buried in the ash (Tarrant 1954). High alkalinity of the wood ash did not inhibit germination, but seedlings suffered heavy damping-off losses a day or two after emergence--a common occurrence on seedbeds with high pH.

Soil type is another factor in successful Douglas-fir regeneration. In northwestern California, more seedlings became established on fine-textured soils that were predominately reddish-brown than on coarser-textured gray-brown soils (Strothmann 197 lb). The specific soil properties responsible for this difference were not identified, but doubtless the greater water-holding capacity of the fine-textured soil was one such property.

Time of Seeding

Timing of direct seeding can contribute to successful regeneration. Seeding in late fall or early winter appears to yield better results than that in late winter or spring (Dick 1962, Lavender 1958a, Strothmann 1971b). Late fall or early winter coincides with natural seed fall, and allows ample time for the chilling required to break seed dormancy.

Spring seeding of stratified (artificially moist-chilled) seed has been suggested as a way to reduce the time that seeds lie on the ground exposed to rodents, birds, and other predators before conditions suitable for germination occur. Seeding in November and December produced the best results, regardless of whether the seeds were stratified (Lavender 1958a). Stratification increased the speed of germination, but not the total amount.

Site Aspect and Temperature

Northerly aspects apparently favor seeding success in most instances (Steele 1953, Lavender 1958b), but some exceptions exist. On fine-textured soils in northwestern California, more seedlings survived and grew on south aspects than on north, although the reverse was true on coarser-textured soils (Strothmann 1971b). Seeds probably germinate sooner on south slopes because soils there warm earlier. This initial advantage on south slopes may persist through the subsequent growing season on fine-textured soils because of slower soil moisture depletion than on coarse-textured soils.

On south aspects, temperature at the soil surface may exceed 150° F (66° C) (Strothmann 1972). Under laboratory conditions, 2- to 12-week-old Douglas-fir seedlings die after 4 hours of exposure at 122° F (50° C) (Silen 1960). Further, the seedbed material, temperature, and duration of exposure interact to affect mortality. On eight clearcut blocks in western Oregon, the melting of a 138° F (59° C) temperature pellet was most closely related to mortality, although the lethal temperature threshold ranged from 125° to over 150°F (52° to 66°C).

In many instances, physiological drought rather than soil surface temperature, per se, may be the actual cause of seedling mortality. In northern California we have observed over the course of many years hundreds of young Douglas-fir seedlings within a few days of death and found no positive evidence--stem lesions at ground line--that mortality was caused by heat damage. Although soil moisture may be available, young seedlings apparently do not have root systems adequately developed to provide the water needed to counter transpirational losses during periods of hot, sunny weather. This condition, coupled with poor foliar control of transpiration in developing foliage, causes seedlings to desiccate and die.

One solution is to provide shade for seedlings on severe sites. On the Hoopa Indian Reservation in northwestern California, a 50 percent shade treatment with a lath framework produced the highest germination and 2-year survival of Douglas-fir seeded on a hot, south-facing cutblock (Strothmann 1972). Plots were not visited frequently enough to pinpoint the causes of mortality.

On production seeding jobs, effective shade can be provided by sowing a nurse crop, such as brown mustard, after slash disposal--a technique used successfully on south slopes in Oregon (Chilcote 1957). The mustard (or any nurse crop) must, however, be sprayed with herbicide the following spring to convert it to dead shade and eliminate its competition for soil moisture after the rainy season ends. Other potentially useful but untested nurse crop species are New Zealand fireweed and Australian fireweed, which are annuals and seed naturally.

Causes of Loss or Damage

Determining the causes of loss or damage to seeds and seedlings is often difficult enough, and unless the site is visited frequently during the critical period of germination and establishment, pinpointing these causes may be impossible. Even before they reach the ground, seeds may be damaged by the seed dispersal mechanism of the seeding aircraft. Germination of a given lot of endrin-treated Douglas-fir seed was significantly lower when disseminated by one helicopter than when disseminated by another (Edgren 1968).

Once seeds reach the ground, numerous causes of loss come into play. A detailed study of February-sown Douglas-fir seed in western Washington showed that only 28 percent germinated, and that almost half of the seeds were destroyed before germination (Lawrence and Rediske 1962). Pregermination losses amounting to 45 percent were attributed to molds (19 pct), insects (11 pct), rodents (8 pct), birds (3 pct), and mechanical injury and unknown (4 pct). Another 27 percent, comprised of whole seeds that showed no evidence of external damage, simply failed to germinate. Postgermination losses totalling 15 percent were caused mainly by damping-off fungi (9 pct). Thus only 13 percent of the sown seeds germinated and became seedlings that survived a full year in the field.

Young seedlings can be damaged in numerous ways. In northern California, local erosion and deposition were the major causes of seedling loss on soils derived from decomposed granite (Roy 1961). Other causes of mortality were drought (10 pct), deer browsing (2 pct), and sunscald or heat injury (1 pct). After two growing seasons, 31 percent of the survivors had been injured by deer browsing and 13 percent by frost.

Seeding Methods and Seed Protection

Techniques for protecting seeds against predators vary, depending upon the seeding method. The spot seeding (or seed spotting) method is the most economical in terms of seed but the most costly in terms of labor. A crew places a few seeds (from 2 to 10) in selected spots throughout the area. The spacing between spots depends largely on expected germination and survival, and on the final stocking density desired.

In spot seeding, seeds usually are covered with a thin layer of soil to improve their chances of germinating. Such covering is inadequate protection against predators. Customarily, seeds are protected either by a coating of repellent-poison, or by conical or dome-shaped hardware-cloth screens.

Besides protecting seeds from rodents and birds, screens also provide a small amount of shade and physical protection from falling debris such as leaves. Screens have serious disadvantages: the high cost of the material; and the costly labor involved in forming it into a conical or hemispherical shape, carrying the screens into the field, installing them, and ultimately removing them to prevent strangulation of the growing seedlings.

To reduce costs, foresters have tried using small, inexpensive berry baskets. They cost only one-fifth as much as, conical hardware-cloth screens, and because they also weigh much less, more can be carried into the field on each trip (Zechentmayer 1971). Also, because the baskets are biodegradable, removing them may not be necessary. They share some of the drawbacks, however, with wire-mesh screens. For example, baskets can be crushed or displaced easily by large animals, and frost-heaving of anchor pins can lift the baskets off the ground and render them ineffective (Utterback and Berry 1977, Zechentmayer 1971).

Even though costs associated with spot seeding may sometimes be reduced, the method is slower and more costly than broadcast seeding--especially aerial seeding. For this reason, aerial broadcast seeding has far greater appeal to the forest manager, particularly if large acreages are involved.

With broadcast seeding, as with spot seeding, success is unlikely unless seeds are protected from rodents and birds. Because mechanical barriers are not feasible with this seed-ing method, the approach has been to use chemicals. In the past, poisoning the area for rodents before seeding was standard practice. The most common materials were thallous sulfate and sodium fluoroacetate (also known as "Compound 1080"). Wheat kernels usually were impregnated with the chemicals and spread over the area several weeks before seeding. Sometimes poisoned wheat was applied again when the conifers were seeded. Usually, a sizable buffer strip was poisoned to prevent reinvasion of the area by rodents.

Although poisoning effectively reduces rodent populations, even in the early days of its use, some of the problems associated with it were recognized: a $^{1}/_{4}$-mile buffer strip is required to prevent reinvasion, a two-stage operation is required for seeding, small areas cannot be seeded economically because of the disproportionate cost of the buffer strip, small mammals other than tree seed eaters may be destroyed, and baits deteriorate over winter and do not provide protection in the spring (Hooven 1955).

The phenomenon of bait shyness to protect untreated seed was tested on the Six Rivers National Forest in northwestern California (Tevis 1956c). A deer mouse population that would eat neither Douglas-fir seeds that were poisoned, but sublethal, nor untreated seeds was developed. Douglas-fir seed served as poisoned bait. The results suggested that developing a population of non-seed-eating rodents in a specific area may be easier and more desirable than trying to eliminate large numbers of animals by the standard poisoning operations then in use.

A more widely supported approach to overcoming the disadvantages of earlier large-scale poisoning techniques was to develop a relatively insoluble repellent or toxic chemical that could be applied directly to tree seeds without destroying their ability to germinate. Among the more promising of the earlier chemicals was tetramine (tetramethylene-disulphotetramine). Tests of this chemical in a Douglas-fir seeding trial in western Oregon produced encouraging results (Hooven 1955); but, in northwestern California, an acetone-tetramine treatment both reduced and retarded germination of Douglas-fir seed (Roy 1957).

When tetramine became increasingly more difficult to obtain in the mid-1950's it was superseded by endrin, a chlorinated hydrocarbon. Endrin was tested as a Douglas-fir seed protectant on the Tillamook Burn in Oregon (Hooven 1957). Six months after seeding, the poorest of the endrin-treated plots had more than three times as many stocked milacre quadrats and seven times as many Douglas-fir seedlings as the control plots. And rodent populations sampled by live trapping both before and after seeding were reduced greatly on the areas sown with treated seeds. Other successes in the Pacific Northwest have been reported from broadcast sowing of endrin-treated Douglas-fir seed (Dick and others 1958, Dimock 1957).

Endrin-arasan treated seeds also were tested in northwestern California and were found to be adequately protected against seed-eating rodents (Roy 1961). The endrin-arasan treatment did not inhibit germination. Subsequent to these early studies, the endrin-arasan coating became the standard seed protectant for direct seeding operations throughout the Douglas-fir region. However, use of the endrin-arasan treatment has been reduced significantly as a result of concerns about toxicity and of occasional instances in which nontarget species have been killed. No satisfactory substitute for endrin has been developed, but research is continuing.

Research also has continued toward developing safer rodenticides for use as area poisons to replace acute toxicants, such as Compound 1080 used earlier. Among the more promising are the anticoagulant rodenticides such as diphacinone. On a Douglas-fir clearcut in northwestern California and in a pine growing area in the Sierra Nevada, consumption of 0.01 percent diphacinone-treated crimped oat groats for a minimum of 3 days was fatal to 80 percent of the deer mice (Howard and others 1970). Longer exposure to the bait frequently produced 100 percent mortality. When 0.01 percent diphacinone bait was broadcast at 2 pounds per acre (2.24 kg/ ha) in two field tests, no deer mice tagged before treatment were recaptured.

Future of Direct Seeding

The odds against successfully regenerating an area by direct seeding are formidable, but success is attainable. In November 1960, seven clearcut blocks totaling 276 acres (112 ha) were helicopter-seeded with Douglas-fir on the Hoopa Indian Reservation in northwestern California (Lusher 1964). Seeding was preceded by thorough site preparation, including felling, bunching, and burning of the residual hardwoods after harvesting the conifers. The ground was in excellent condition at the time of seeding, being settled and firm, but not compacted, and favorably moist from recent rains. Seeding was at the rate of 1 pound per acre (1.12 kg/ ha).

On four of the cutblocks, seed traps were placed before seeding to monitor seed distribution and quantity of seed delivered. Quantities ranged from about 20,000 to 36,000 seeds per acre (49,000 to 89,000/ ha). Milacre plots were established on which the live seedlings on each plot were counted periodically. Milacre stocking at the end of the third growing season was estimated at 43 percent, and number of live seedlings per acre at 1292 (3192/ ha). Thus, aerial sowing of endrin-treated Douglas-fir seeds on a fairly large scale can be successful in the Klamath Mountains Region.

Notwithstanding an occasional success, the future of direct seeding of Douglas-fir in the region is uncertain. Aside from the need to develop a safe and effective seed protectant to replace endrin, direct seeding has numerous other drawbacks that have brought about a decline in interest in this regeneration method. Many failures are doubtless caused by unfavorable climatic conditions. The hot, dry summers that characterize the region place a severe stress on newly germinated seedlings, and many succumb to drought during their first summer. In this respect, coastal locations with their more moderate temperatures and higher humidities are more favorable for direct seeding than sites further inland.

Another drawback of direct seeding--particularly aerial seeding--is the lack of control over tree spacing, which results in stocking voids in some places and overly dense stocking in others. Dense stocking often requires precommercial thinning. Furthermore, direct seeding is not suited for efficiently utilizing genetically improved seed developed in tree improvement programs because it requires many seeds to establish a seedling and wastes seeds. For one or more of these reasons--and the stringent stocking requirements of the Forest Practices Acts of California and Oregon, most land managers rely increasingly on planting as the best way to regenerate their forest lands.

Planting

Planting is by far the most common and most reliable method for regenerating Douglas-fir. Although regeneration can still fail, extensive research has improved considerably the chances of successfully establishing a new forest stand by planting. Careful attention to detail during every phase of the planting operation is important, because numerous variables affect planting success: dormancy, time of lifting, root regenerating capacity, stock handling, stock size, age, top/ root ratio, planting depth, and type of stock (bare root or containerized).

Most of the Klamath Mountains Region is unsuitable for machine planting because the ground often is steep or rocky or both. Traditionally, bare-root nursery stock has been planted by hand. However, container-grown stock also has been used, especially on forest industry lands. Several of the large industrial landowners have developed nurseries in recent years and currently produce large quantities of containerized seedlings, both for their own use and for sale. However, on large acreages of publicly owned lands--particularly National Forests and Bureau of Land Management lands--bare-root stock is the type most commonly planted. Much of this stock is produced by Forest Service nurseries at McKinleyville, California, and Medford, Oregon, and at the State-owned Phipps Nursery near Elkton, Oregon.

Dormancy, Lifting, Storage

In recent years, much has been learned of the interrelationships among seed source, dormancy, food reserves, root growth capacity, lifting dates, and storage of bare-root seedlings, and how these factors affect ultimate field survival of seedlings. Many of the early planting failures can be attributed directly to ignorance of these interactions and the improper timing of key nursery operations.

In California, Douglas-fir showed a marked seasonal periodicity in root-regenerating potential (RRP) (Stone and others 1962). The RRP declined during summer, rose abruptly during September, was high during winter, and dropped sharply during April. RRP, based on month-long test periods in the greenhouse, was primarily an expression only of lateral root elongation rather than of lateral root initiation and elongation. Therefore, considerable effort can be justified in preventing desiccation and injury of short lateral roots when seedlings are lifted and before planting.

Laboratory and field studies in Oregon showed a similar pattern (Lavender 1964). Seedlings lifted before December, or after buds began to swell in spring, were affected adversely by transplanting. Seedling physiology was disrupted, resulting in reduced growth of shoots and roots, and in poor field survival. The disruption lasted at least through the second growing season after planting.

Food reserves and the seasonal growth of Douglas-fir seedlings were measured at biweekly intervals for more than a year at the Wind River Nursery near Carson, Washington (Krueger and Trappe 1967). Seedlings showed a general pattern of alternating root, diameter, and shoot growth. Rapid root growth did not coincide with rapid shoot elongation, but preceded and followed it. Increased root activity was correlated strongly with lowered concentrations of reducing sugars in seedling roots. Many current nursery practices, such as late fall lifting and lifting before spring bud swelling, are in harmony with underlying physiological events. For example, root growth in the nursery peaks just before or at the time of bud burst. As buds begin to swell, root growth diminishes rapidly, hitting a low point when shoots are flushing rapidly. Root growth remains low during rapid shoot growth, then gradually increases to another peak in July or August after top growth tapers off.

The importance of lifting planting stock only when it is fully dormant increases as planting sites become harsher. Generally, sites in the Douglas-fir Region become harsher (in terms of increased moisture stress to seedlings) towards the south (Hermann and others 1972). Moisture stress also may be induced by vegetational competition. An outplanting test near Corvallis, Oregon, compared survival of 2-0 Douglas-fir seedlings on two sites--one with bare soil, and the other with grass and weeds (Zaerr and Lavender 1972). Seedlings planted on the site free of competing vegetation had good survival, even when lifted late (when actively growing) or stored up to 9 weeks. On the other site, late lifting or storage resulted in increased mortality and adversely affected subsequent weight gain of the seedlings.

Cold storage *per se* does not reduce seedling vigor or ability to survive after outplanting. If seedlings are lifted when fully dormant and stored under proper conditions, field survival can be excellent. Cold storage of seedlings lifted when they are dormant helps to extend the period they are highly capable of root growth (Hermann and others 1972). Nondormant stock, on the other hand, does not store well--even for short periods. Cold storage for periods of 2 weeks or longer adversely affected the vigor of Douglas-fir seedlings that were lifted before December or after bud swelling in spring (Lavender 1964).

Studies at the Humboldt Nursery in McKinleyville, California, demonstrated that dormancy of Douglas-fir is seed-source dependent. The calendar periods during which seedlings from different seed sources can be lifted safely and stored vary (Jenkinson and Nelson 1978). These "lifting windows" are fixed by the seed source response to nursery climate and cold storage. Some sources, for example, can be lifted and stored anytime between early November and early March, and outplanted with first-year survival potentials that range from 88 to 98 percent. Other sources have much narrower windows--in some cases only a 6-week period centered around early February.

The onset of dormancy and the "hardening-off" process for seedlings of all seed sources can be either hastened or delayed by certain nursery management practices--especially the timing of irrigation. At the Humboldt Nursery, for example, hardening-off has been accelerated considerably in recent years by cutting back on irrigation as early as July, in contrast to the earlier practice of continuing irrigation through August. Untimely late summer rains, however, occasionally may nullify these efforts.

Stock Characteristics

Over the years, certain characteristics of bare-root planting stock have been regarded as important determinants of successful field survival. Among these are seedling size, weight, stem diameter, top/ root ratio, and the type of root system. Their relative importance may vary under different planting situations.

On shallow rocky soils on south slopes in the eastern foothills of the Oregon Coast Range, the size (shoot length) of Douglas-fir seedlings was not an important factor for first-year survival, provided the seedlings were in good physiological condition when planted (Hermann and Newton 1975). Previous attempts to establish Douglas-fir in the study area had failed. Vegetation consisted of a dense cover of perennial grasses and thimbleberry. Douglas-fir survival was evaluated with and without various site treatments, including irrigation, application of herbicide, shading, and browse-prevention screens. Among these treatments, irrigation was the most effective in improving survival, but was costly and considered not feasible except for special, small-scale projects. In other test plantings in the Oregon Coast Range near Corvallis, first-year mortality was significantly higher for seedlings with fresh weights of less than 4 grams (Zaerr and Lavender 1976).

Evaluation of test plantings on moderate-to-steep, clean, south slopes in the western Cascades, after 4 years showed that transplant stock--both 1-1 and 2-1--survived better and grew taller than 1-0, 2-0, or 3-0 seedlings (Edgren 1977). The differences, however, were not great enough to recommend the exclusive use of comparatively costly transplants over 2-0 seedlings. In these tests, the top/ root ratio, by itself, was a poor predictor of survival. Seedlings that survived best (1-1 stock) and poorest (1-0 stock) both had top/ root ratios of 1.5 to 1.7--values intermediate in the range tested.

In another test planting in a burned-over area in north-central Washington, survival of 2-0 seedlings with large roots was 22 to 26 percent higher than that of seedlings with small roots (Lopushinsky and Beebe 1976). Increase in shoot mass of large-root seedlings was twice that of small-root seedlings, and height growth of large-root seedlings was 1.2 to 1.7 times greater. Thus, the importance of a good root system was again demonstrated.

On a severe site in the Siskiyou Mountains of southwest Oregon, performance of 2-0 bare-root stock, 1-0 plugs, and plug-1 seedlings--a newer stock type--were compared (Hobbs and Wearstler 1983). After 2 years, survival in the field was proportional to root initiation and growth. Root development and survival (91 pct) were greatest for 1-0 plug seedlings, intermediate for plug-1 bare-root seedlings (87 pct survival), and lowest for 2-0 bare-root stock (56 pct survival). Height and diameter growth did not differ.

Special Treatments

The importance of root condition to planting success has led to numerous techniques for stimulating root growth, developing a bushy root system, or improving the root environment of the outplanted seedling. A common nursery practice is to undercut seedlings in the beds so that bushier root systems develop before lifting. Whether a compact, bushy root system is better than a root system with fewer, but longer, deep-reaching roots for seedling survival is uncertain (Trappe 1971).

The *glauca* variety of Douglas-fir, when root-pruned, initiated clusters of new, long roots immediately above the pruning wounds (Trappe 1971). These new roots tended to grow downward rapidly with no lateral branching. Bushiness, therefore, did not increase. In contrast, seedlings of variety *menziesii* initiated few, if any, new roots. Instead, small rootlets that were dormant began to grow. Many mycorrhizae burst their mantles and grew as characteristic for long roots. Consequently, the number of major branch roots increased in the upper root system, while roots on most seedlings did not grow rapidly downward. To improve planting success, we need to learn more about what type of root system is best, and how such a root system can be produced.

A modification of undercutting called "wrenching" has shown promise for improving the ability of outplanted Douglas-fir seedlings to tolerate drought (Koon and O'Dell 1977). Wrenching differs from regular undercutting in that the cutting blade is set at a slight downward angle, whereas for regular undercutting it is horizontal. Thus, in wrenching, not only are the roots severed, but the entire seedling is lifted slightly and the root zone is aerated.

At the Humboldt Nursery in northwestern California, two undercutting depths (6 and 8 inches [15 and 20 cm]), and two time intervals between wrenchings (2 and 4 weeks) were tried on 2-0 Douglas-fir seedlings (Koon and O'Dell 1977). The 8-inch depth was better. At the end of the first summer after outplanting, mortality was significantly less for seedlings that were undercut to 8 inches at either 2-week (44 pct mortality) or 4-week (47 pct mortality) intervals than for unwrenched seedlings (69 pct mortality). Mortality of seedlings undercut at the 6-inch depth was 56 percent--not significantly less than that for unwrenched seedlings. Wrenched seedlings in all treatments had significantly more reductions in shoot weight, stem diameter, and height than did unwrenched seedlings. Root weight, however, remained largely unaffected. Thus, the principal effect of wrenching was to retard top growth. Wrenching also created a noticeably more fibrous root system.

The timing of undercutting or wrenching helps to determine whether growth of tops or roots is stimulated or retarded and, therefore, whether the desired seedling characteristics are achieved. Performing either undercutting or wrenching at the wrong time can reduce stem diameters or root masses or both (Edgren and others 1978).

At the D. L. Phipps State Forest Nursery at Elkton, Oregon, both wrenched and unwrenched seedlings increased substantially in stem diameter and root dry weight between August and January (Stein 1978). Seedlings were wrenched in early August. Between late August and mid-January, seedling diameters increased about 50 percent. Diameter of unwrenched seedlings tended to be smaller at first, but by January little difference was noted between the wrenched and unwrenched seedlings. Average dry weight of unwrenched seedling roots more than doubled from August to January, but for wrenched seedlings it increased fivefold. In late August (24 days after wrenching), roots of the wrenched seedlings weighed only about half as much as those of the unwrenched seedlings, but by mid-January the weight of wrenched seedlings slightly exceeded that of the unwrenched seedlings. However, neither first-season field survival nor height growth were improved by the early August wrenching.

Besides undercutting or wrenching or both, other special treatments have been tried for stimulating early initiation and growth of roots. Two commercial preparations, Gro-fast and Transplantone, were tested in California on root-pruned 2-0 Douglas-fir seedlings (Osburn 1960).[2] The Gro-fast preparation contained 100 ppm giberellins and was applied in separate treatments to tops, to roots, and to both tops and roots. The Transplantone contained naphthylacetamide and vitamin B_1 and was applied only to roots. Although the study had some serious limitations such as a small sample, small stock in poor condition, and planting in rather small containers, some definite response patterns were observed. Gro-fast, regardless of where applied, did not improve growth over the control seedlings. But Transplantone produced a definite and early stimulation of root growth. Improved length and density of the root system of treated seedlings were maintained throughout the second growing season.

Handling Stock

Many planting failures have been attributed to careless handling of stock at the nursery, in transit, or at the planting site. One form of abuse is exposing seedling roots to excessive drying before planting.

[2]Trade names and commercial enterprises or products are mentioned solely for information. No endorsement by the U.S. Department of Agriculture is implied.

To ascertain the effects of drying on subsequent survival of seedlings, a series of root-exposure studies was conducted near Corvallis, Oregon (Hermann 1962, 1964, 1967). The last of these studies tested varying periods of cold storage and exposure on 2-0 Douglas-fir seedlings lifted on three different dates. When seedlings were lifted (November 5, January 28, and March 26), none had buds either open or ready to open, though buds were just beginning to swell in March. Seedlings were treated in one of three ways--no storage, 3 weeks cold storage, or 6 weeks cold storage. Cold storage was at 35°F (1.5°C) in closed polyethylene bags. Before planting, roots from each group were exposed for 0, 5, 15, 30, 60, or 120 minutes, in an illuminated chamber where temperature was maintained at 90°F (32° C) and relative humidity at 30 percent. After exposure, some seedlings from each group were potted and placed in a controlled environment chamber. Most, however, were outplanted in plots, which were kept weed-free but not watered.

Exposure of roots delayed bud-bursting, and the longer the exposure, the greater the delay. Storage further delayed bud-bursting. Bud-bursting was delayed least for the seedlings lifted in January. Survival decreased as root exposure lengthened, but was influenced by lifting date and time of storage. Seedlings lifted in January were less sensitive to exposure than were those lifted in November or March. For all lifting dates, seedling survival was affected adversely by longer storage. Another effect of root exposure was a decrease in height growth, needle weight, needle length, and terminal bud length of surviving seedlings. On the average, growth was best for seedlings lifted in January, not stored, and roots not exposed.

Another approach to reducing seedling damage from root exposure is to coat the roots with a moisture-holding material, such as clay slurry, sodium alginate (a seaweed product), or xanthan gum (a hydrophilic colloid of a polysaccharide). In Oregon, roots of 2-0 Douglas-fir seedlings were dipped in one of these materials (and a control group dipped in distilled water), and then exposed for periods of 0, 10, 20; and 40 minutes, at temperatures between 85° and 90° F (29° and 32° C) and relative humidities between 20 and 25 percent (Owston and Stein 1972a). After root exposure, seedlings were potted individually, placed in a greenhouse, and adequately watered for 4 weeks. Effectiveness of the root-coating treatments then was evaluated by measuring seedling water stress.

Only the control seedlings that had been exposed to root desiccation for 40 minutes showed moderate impairment of water uptake after the 4-week recovery period in the greenhouse. Thus, all coatings provided substantial protection against drying from exposure, with xanthan gum considered the best of the three for Douglas-fir. None of these root-coating treatments was recommended, however, if seedlings were to be stored for an extended period. After 8 weeks' storage, followed by 4 weeks of growing in pots in the greenhouse, seedlings with roots that were coated showed significantly higher moisture stress than those whose roots had been dipped in distilled water and then packed in sphagnum moss for storage.

A transpiration retardant (Foli-gard) and a root coating (Rutex 59) were tested on 1-0 Douglas-fir planting stock lifted and treated at the Forest Service's nursery at Placerville, California (Roy 1966). The four treatments were (1) tops sprayed with Foli-gard, a water-soluble polymer which forms a continuous film upon drying; (2) roots dipped in Rutex 59, a solution of a placticized acrylic-type polymer which has high water-absorbing and -retaining qualities; (3) tops sprayed with Foli-gard and roots dipped in Rutex 59; and (4) control. Control seedlings had the best early-season survival, although by late August their survival averaged the same as those treated with Foli-gard (85 pct). Survival of seedlings treated with Rutex 59, either alone or in combination with Foli-gard, was about 20 percent poorer by late August. Also, Rutex 59 depressed seedling height growth, but Foli-gard significantly enhanced it.

Adverse Sites

Factors that strongly influence regeneration success include aspect, slope steepness, and soil characteristics. Heat and drought on southerly aspects often cause regeneration problems. The least favorable aspect for regeneration of plantations on the Six Rivers National Forest in northwestern California was about 12° west of south (Strothmann 1979).

The value of shade in establishing Douglas-fir regeneration from seed has been pointed out already. On hot, south-facing slopes, shade may also benefit planted Douglas-fir if stock condition is less than optimum, or if seedlings are not planted at the most favorable time.

On several test sites in California, shade decidedly benefited survival of both 1-0 and 2-0 Douglas-fir (Adams and others 1966). Shade was provided by shingles 5 to 7 inches (13 to 18 cm) wide inserted into the ground on the south-southwest side of each seedling. Shingles protruded 8 to 10 inches (20 to 25 cm) above ground and were slanted so that tops were directly over the seedlings. The 1-0 stock was benefited most by shading. No unshaded trees of this age class we5 e alive after 2 years at one locality. For seedlings of both age classes, the benefits of shading were greatest on the driest of the test sites.

Shade helps reduce severe moisture stress, which seedlings may otherwise sustain on south-facing clearcut blocks (Lindquist 1977). Douglas-fir seedling moisture stress, survival, and growth in response to aspect and overstory canopy were studied on granitic soils on the Six Rivers National Forest in Northern California. Seedlings on clearcut blocks had plant moisture stress (PMS) values that exceeded 15 atmospheres at midmorning in June, but seedlings on partial-cut plots did not exceed this level until September. PMS values were highest on the clearcut plot with a south aspect, reaching predawn stresses of 21 atmospheres by September. This plot was the only one on which stocking was inadequate, suggesting that leaving a partial overstory on hot, dry slopes may help survival. Height growth, on the other hand, was best on the south-facing clearcut, indicating that established seedlings grow best in full sunlight.

Type of shade has been found to influence seedling survival. In southwestern Oregon (Minore 1971), planted Douglas-fir seedlings were observed growing under three conditions: (1) in the open with no shade; (2) in the open, but shaded artificially with rocks, logs, or bark (dead shade); and (3) under existing brush (live shade). After two growing seasons, only 10 percent of the unshaded seedlings were alive compared with 47 percent under brush and 60 percent under dead shade. Although dead shade produced the best survival, providing it was time-consuming and expensive. Thus, under some circumstances, planting under existing brush may be the best compromise if the brush species does not compete too severely for soil moisture and nutrients.

The shady side of large cull logs often appears to be a good planting spot; but if logs still have bark on them, they are a potential hazard (Roy 1955b). About 3 years after logging, the bark of cull Douglas-fir logs begins to slough off in large patches. Seedlings upon which these patches fall generally are killed by smothering.

Even though some studies demonstrate the benefits of shade, shade is not essential for successful regeneration of south-facing clearcut blocks when all other facets of a planting operation are favorable. On the Hoopa Indian Reservation in northwestern California, shade of several intensities did not significantly improve survival of either 1-0 or 2-0 Douglas-fir seedlings planted on a 50 percent south-facing clearcut slope (Strothmann 1972). Survival after 2 years was good (83 pct or better) for all treatments, from 0 to 75 percent shade. Good survival was attributed to good planting stock, careful planting, a deep loamy soil, and the removal of competing vegetation. Although shade did not significantly affect survival, it reduced the growth of the planted trees. Best growth (in terms of height, stem diameter, weight of top, weight of roots, and root length) generally was associated with the least shade.

In the Siskiyou Mountains of southwestern Oregon, Douglas-fir grew best in full sunlight, and rarely grew where light intensity was less than 10 percent (Emmingham and Waring 1973). Maximum shoot elongation generally was found on trees in bare areas with little competing vegetation, or where seepage water was available.

A different approach for improving survival of Douglas-fir on hot, dry sites is selecting strains with inherently high drought resistance. An Oregon study found a decided difference in this characteristic between Douglas-fir seedlings from a moist coastal site (mean annual precipitation of 60 inches [152 cm]), and a dry inland site (mean annual precipitation of 20 inches [51 cm]) (Heiner and Lavender 1972). Seeds from the moist area were collected from numerous trees (though from a single stand) and pooled as a single lot. Five seed lots from the dry area were collected from five individual trees. Seeds were sown in a nursery near Corvallis, and 2 years later some seedlings from each lot were lifted and transplanted to a lysimeter where moisture conditions were controlled. The soil was wetted to field capacity at time of transplanting, and then allowed to dry naturally during the growing season. Rain was excluded by a plastic cover.

At the end of the growing season, seedlings from the dry source showed significantly better survival (55 to 70 pct) than those from the humid source (16 pct). Also, seedlings from the dry source all had much earlier and more complete bud burst than did those from the humid source. Differences in shoot:root ratio or cuticle thickness among seedlings of the six different lots were not significant.

A word of caution should be added, however, about taking seedlings that are genetically adapted to one environment and planting them in another. In most instances, the fundamental rule that regeneration should be accomplished with planting stock from local seed sources is still the safest guide and normally will produce the best long-term results.

Modifications of the planting technique comprise another approach for improving the survival or growth of trees planted on hot, droughty sites. One modification is deep planting--planting the seedling deeper in the ground than it grew in the nursery. The primary purpose is to get the roots deeper into the soil, where more moisture is usually available. A secondary purpose is to bury some of the foliage to reduce transpiration losses during the critical period of establishment. This technique has been used most often in the droughty sites of the southern pine region where it frequently has resulted in improving height growth (McGee and Hatcher 1963, Shoulders 1962, Slocum and Maki 1956).

In a trial in southwestern Oregon, 2-0 Douglas-fir was deep-planted in hopes of improving survival in an area where normal planting success was poor (U.S. Dep. Agric., Forest Serv. 1957). Survival did not improve, however, and averaged only 38 percent for both normal and deep planting.

In northern California, deep planting of 2-0 Douglas-fir at two different depths was tested against planting at normal depth, on a hot south-facing slope with a gravelly loam soil (Strothmann 1971a). In one treatment the trees were planted with 25 percent of their stems buried, in the other with 50 percent buried. Neither treatment significantly improved survival over that of normal planting, but early height growth benefited, especially when 50 percent of the stem was buried. Although the superior growth rate continued for 3 years after planting, the deep-planted trees took this long to overcome their initial height handicap and catch up to the trees that were planted at normal depth. After 10 growing seasons, differences in survival attributable to planting technique were not significant (Strothmann 1976). Also, height growth differences among the several planting methods were no longer significant. Thus, deep-planting Douglas-fir in southwestern Oregon or northwestern California produced no long-term benefit.

Another modification of bare-root planting is "sandwich" planting, a technique tried with 2-0 Douglas-fir seedlings on the Lower Trinity Ranger District of the Six Rivers National Forest (Schubert and Roy 1959). This method consisted of encasing a seedling's roots between two pieces of stiff, water absorbent, fibrous material (about 3 by 8 inches [7.6 by 20.3 cm]) stapled together. And the stiffness of the sandwiches forced workers to set seedlings in the ground properly, because the roots could not be bent in shallow planting holes. The control was bare-root seedlings planted with planting hoes. Similar stock was planted in sandwiches that had been soaked in water for 4 hours, and seedling roots had been puddled in a slurry of forest soil (Hugo clayey loam). The third treatment was the same as the second, except that the sandwich material was soaked in a fertilizer solution ($1^1/_2$ oz [42.5 g] of 7-9-5 fertilizer per gallon [3.78 liters] of water) and seedling roots were puddled in a fertilized slurry of forest soil (18 oz [510 g] of uramite, 38-0-0, added to 4 gallons [15.14 liters] of mud).

Planting Douglas-fir in sandwiches without fertilizer at first seemed beneficial, but any early-season benefit vanished by July 28: the soil near the surface dried, and the roots probably did not grow out of the sandwiches and deeper into the soil where moisture was still available. Final results showed no advantages for sandwiches over bare-root planting. The greatest mortality was found among seedlings in sandwiches to which fertilizer had been added.

Plantings sometimes fail on certain soils because workers have difficulty preparing an adequate planting hole with conventional tools such as the hoedad and planting bar. Power soil augers, which are becoming increasingly popular, overcome this problem. Augers have been used operationally on some National Forests and other ownerships for more than a decade, and many of the earlier problems associated with them have been solved. The newer models are safer to use and mechanically more reliable than earlier models; and they perform better in rocky soils. Some users have reported about 15 percent better survival of trees planted with the auger than with conventional hand tools.

On steep ground, dry ravel and debris movement sometimes kill seedlings. One possible solution tested on the H. J. Andrews Experimental Forest in western Oregon is using large 3-0 planting stock (Berntsen 1958). The test site was situated on a slope of about 50 percent at 2000 feet (610 m) elevation. Significantly more 3-0 Douglas-fir stock survived than did the normally planted 2-0 seedlings at the end of both the first and second growing seasons. Movement of surface materials (soil, rock particles, litter, and rotten wood) killed many more 2-0 seedlings (23 pct) than 3-0 seedlings (8 pct) during the first season.

Other practices that minimize seedling loss caused by soil and debris movement include these (Franklin and Rothacher 1962): planting on the flattest available microsites, such as uphill from stumps and uprooted trees; and planting near the outside rather than the inside edges of benches. Other favorable planting spots are the downslope side of stumps, well-anchored rocks, or other objects which help divert moving debris from seedlings.

Containerized Stock

Container-grown seedlings have been planted for many years for landscaping and for certain special forestry applications such as erosion control. However, their widespread use in reforestation programs is more recent.

Container-grown seedlings have both advantages and disadvantages. One major advantage is the negligible disturbance to the seedling's root system when outplanted. Even under the best conditions, bare-root stock undergoes "planting check" (a temporary reduction in top growth) when outplanted. In British Columbia, undisturbed 2-0 Douglas-fir in the nursery grew the following year at an average rate of 0.8 inch (2 cm) per inch (2.54 cm) of height at the start of the season. By contrast, the growth rate of trees that were carefully lifted and outplanted was only about 0.16 inch (0.4 cm) per inch of height at time of planting, or only 20 percent of that of the undisturbed trees (Smith and Walters 1963).

The biological soundness of containerized planting and the excellent growth potential possible with the method were demonstrated in Oregon (Owston and Stein 1972b). In early August, $1\ ^1/_2$-year-old nursery-grown Douglas-fir seedlings were potted into four types of containers; 7-inch (18 cm)-deep peat pots, 1-quart milk cartons, 10-inch-long (25 cm) plastic mesh tubes, and 10-inch-long cardboard containers that were slightly tapered and impregnated with resin. After growing several months outdoors, the trees were outplanted in late fall and also in spring, along with 1-1 and 2-0 seedlings on a site in the Cascades.

First-year height growth of containerized trees averaged about $2^1/_2$ times that of bare-root stock. Survival of all stock was relatively good, but significantly higher for the containerized trees (95 pct) than for the bare-root seedlings (83 pct). Survival of Douglas-fir seedlings did not differ significantly among container types, but height growth was best in the plastic mesh tubes, and poorest in the milk cartons. Although this study used much larger containers than those used in production planting, and the trees were not started from seed in the containers, it demonstrated the basic advantage of moving a tree to a field environment without major disturbance of its root system.

In a British Columbia study of experimental plantations on a variety of forest sites, the biological performance of $4\ ^1/_2$-inch (11.4 cm) Walters' bullet, a $4^1/_2$-inch plug, and bare-root stock were compared (Arnott 1971). After 3 years, on medium elevation sites, the average survival (percent) of Douglas-fir seedlings was plug, 84; bare-root, 80; and bullet, 68. After 2 years, on high-elevation sites, survival of bare-root seedlings was best (97 pct), with survival of plug seedlings also good (85 pct).

One of the claimed benefits of using containerized stock is it lengthens the normal planting season, allowing both earlier and later planting than would be possible with bare-root stock. Several trials in Humboldt County, California, evaluated the effect on tree survival of planting as early as September or as late as May. The recommended planting season for bare-root stock in this area is mid-December to mid-March (Schubert and Adams 1971). Containerized Douglas-fir seedlings were planted on two coastal sites and two sites a few miles inland during two planting seasons (1974-75 and 1975-76). Precipitation was nearly normal the first season, and about 15 percent below normal the second season.

First-year survival exceeded 83 percent for the September plantings on both coastal sites, but was only about 75 percent on one interior site and less than 60 percent on the other. October plantings had better survival, averaging about 87 percent for the inland sites and 93 percent for the coastal sites. The May plantings in the season with normal rainfall had excellent first-year survival (91 pct) for both the inland and the coastal site. May planting in the drier year, however, resulted in lower first-year survival on both the coastal site (79 pct) and the inland site (60 pct). By comparison, first year survival of trees planted in January exceeded 92 percent for all four sites and for both planting seasons. Whether bare-root seedlings might have performed similarly is not known, because they were not included in this study.

The findings suggest that the use of containerized Douglas-fir will permit moderate extensions of the normal planting season without significantly increasing mortality on coastal sites. However, on inland sites with drier climatic regimes, or during years of subnormal rainfall, such extensions may reduce survival by as much as 30 percent.

Many questions concerning the relative merits of container-grown versus bare-root seedlings remain unanswered. Some answers should be forthcoming within the next few years when the results of various field trials currently underway are analyzed and published. Some earlier field trials may have compared the two types of stock unfairly because containerized seedlings were relatively small and bare-root seedlings were much larger (Stein 1976). In these comparisons on severe sites in the Pacific Northwest, container stock usually has not matched the performance of bare-root stock. Tissue differences between young containerized seedlings and older, more woody, bare-root seedlings may put the former at a disadvantage with respect to animal damage. In several instances, container-grown seedlings have been damaged more heavily than adjacent bare-root seedlings (Stein 1976). Our present state of knowledge indicates that either of these two planting methods will work if their basic requirements are not compromised, and if each is used under conditions for which it is best suited.

CARE OF YOUNG STANDS

Planting trees or getting seedlings to germinate is far from the final step in regenerating an area. Starting almost immediately, numerous problems beset the young trees. Some of these problems-such as desiccating winds, prolonged drought, untimely frosts, or other meteorological variables--are, for all practical purposes, beyond the forester's control. Other factors are amenable to varying degrees of control, though effective control may be limited at times by environmental constraints, lack of adequate technical information, or simply by costs that are too high to be economically feasible.

Basically, the factors over which the forester has some measure of control are those which involve plants or animals. Because of intertwining ecological relationships, one factor can sometimes be controlled by controlling or manipulating the other.

Reducing Vegetative Competition

Whether vegetative competition will pose a serious threat to conifer regeneration in a given plantation depends on many factors, including the plant species present, their density and abundance, the fertility of the site, how wet or dry it is, and how thoroughly the site was prepared. Competition from grass will be discussed first, not because it is necessarily of greatest importance, but because treatment is required soon after planting where potential problems exist.

In Oregon, where the competing vegetation was grass, first-year survival of 2-0 Douglas-fir was considerably improved by application of atrazine (Bickford and Hermann 1967). It was applied at three rates ($1^2/_3$, $3^1/_3$, and 5 lbs per acre [1.87, 3.73, and 5.60 kg/ ha]) at the end of March, after planting on five different dates during the preceding fall and winter. A fourth series of plots received no atrazine. At the end of the first growing season, the lowest application rate had increased survival twofold, and the two higher rates had increased it nearly fivefold over that on the untreated plots.

In southwestern Oregon, 10 chemicals were tested to determine their relative effectiveness for grass and forb control in three plantations of young Douglas-fir 6 to 15 inches (15 to 38 cm) tall (Gratkowski 1976). Two study areas were on wet sites on the Siskiyou National Forest, and the third was on a dry site in the foothills of the Cascade Range east of Roseburg. Atrazine at 4 pounds a.i. (active ingredient) per acre (4.5 kg a.i./ha), and Terbacil at 2 pounds a.i. per acre (2.2 kg a.i./ha) were the most effective. Foliage sprays of both chemicals controlled grasses without permanent damage to Douglas-fir seedlings. Terbacil damaged a few conifers during the first summer after spraying, but no trees were killed and all were healthy and vigorous at the end of the second summer. Granular Dichlobenil at 4 to 6 pounds a.i. per acre (4.5 to 6.7 kg a.i./ ha) was excellent in controlling grasses and forbs for two summers, but it consistently damaged young Douglas-fir trees.

Sometimes, several herbicides in combination are more effective in controlling grass competition than are the same herbicides applied singly. The appropriate combinations also may be less injurious to Douglas-fir seedlings. Dalapon injured Douglas-fir when used alone, but was applied safely with beneficial effects when combined with atrazine and 2,4-D at rates of up to 3 (atrazine) and 4 pounds (2,4-D) per acre (3.36 and 4.48 kg/ ha) (Newton and Overton 1973). In these combinations, dalapon did not harm Douglas-fir seedlings, even when applied at rates up to three times that needed for adequate control of grasses. Combinations of dalapon, atrazine, and 2,4-D also have successfully controlled weeds in two seed orchards, and in a reforestation study in Mendocino County, California (Adams 1979).

Although grass and forbs can be serious competitors--especially when conifer seedlings are small--brush is generally a more serious long-term problem, partly because many brush species reproduce by sprouting when the older stems are cut or damaged. The new sprouts often can outgrow associated conifer seedlings for 10 to 15 years or longer.

The height growth of sprouts of five of the more common hardwood brush species that often occupy forest land in northwestern California after fire or logging was measured (Roy 1955a) (*table 1*). In descending order of height growth, the species were bigleaf maple, Pacific madrone, Oregon white oak, tanoak, and Pacific dogwood. Within each species, the greater the diameter of the parent tree, the more numerous, taller, and the larger were the sprouts. Bigleaf maple is restricted mainly to streambanks or other places with abundant soil moisture. Dogwood grew in a separate area from the others, and was the only species subjected to heavy browsing by deer (Roy 1955a). Although the growth rate of tanoak sprouts was exceeded by three of these species, it is the most important competitor because of its longevity, ultimate size, and widespread distribution throughout the region.

Effect of Brush Competition

Opinions differ among foresters as to the extent to which brush may retard the growth of conifers. That the answer depends on the species involved seems clear. Few studies in the Klamath Mountains Region have specifically tested the degree to which various species of brush retard growth of young Douglas-fir.

Table 1--*Average growth characteristics of sprouts in live hardwoods that commonly compete with Douglas fir, after three growing seasons, northwestern California*

Species	Sprouts		
	Height	Crown diameter	Number in clump
	----*Feet (meters)*---		
Bigleaf maple	13 (4)	15 (4.6)	37
Pacific madrone	10(3)	8(2.4)	13
Oregon white oak	9(2.7)	8(2.4)	10
Tanoak	7(2.1)	7(2.1)	12
Pacific dogwood	6(1.8)	5(1.5)	14

In one study on Brush Mountain on the Lower Trinity District of the Six Rivers National Forest, the site was tractor-logged in 1952 and prepared that same fall by broadcast burning. Douglas-fir 2-0 seedlings were planted the following year. In 1958, the trees on part of the area were released by hand-cutting competing shrubs--primarily tanoak, madrone, and snowbrush. The resprouting shrubs on the released portion were sprayed in fall 1959 with 2,4,5-T.

In the 17 years after the initial release in 1958, the released trees steadily increased their height advantage over those not released. At the outset they had the same average height--4.5 feet (1.37 m). For the first 4 years the gain from release was small, but it increased with time:

Years after release:	Height gain by released trees
	Feet (meters)
4	0.5 (0.15)
6	2.9 (0.88)
8	5.0 (1.52)
10	6.9 (2.10)
17	12.4 (3.78)

After 17 years, the released trees averaged 38.4 feet (11.70 m) tall and the unreleased only 26.0 feet (7.92 m). The two groups also differed in tree vigor. Criteria of vigor were needle complement, needle color, and needle length. When the study began, all trees were classed as vigorous. After 17 years, all released trees were still in this category, but only 55.6 percent of the unreleased trees were classed as vigorous, 18.5 percent as medium in vigor, and 25.9 percent as poor.

As to the relative severity of competition afforded by snowbrush and tanoak, Douglas-fir trees began to grow through the snowbrush in 1964--12 years after logging and the same year that some snowbrush plants died. Individual snowbrush plants have continued to die since that time, especially following severe damage from snow breakage during winter 1964-1965. Tanoak, on the other hand, is providing increasingly severe competition.

A 5-year study in southwestern Oregon indicated that a dense overstory of varnishleaf ceanothus definitely retards height growth of young Douglas-fir in the understory (Gratkowski 1969). All degrees of release from varnishleaf ceanothus resulted in increased height growth of the conifers, and complete exposure to sunlight provided the longest lasting release for young Douglas-fir. On plots where varnishleaf ceanothus had been basal-sprayed, growth of Douglas-fir was 1.3 to 1.5 times that of similar trees under unsprayed live brush. A similar increase in growth of Douglas-fir was noted under standing dead ceanothus on aerially sprayed areas. Growth of completely released trees, where ceanothus was lopped and stump-sprayed, was more than 1.8 times that of trees under live ceanothus.

The beneficial and detrimental influence of snowbrush ceanothus on several species of conifers has been studied on the west slope of the Oregon Cascades (Zavitkovski and others 1969). The survival and height growth of both planted and natural Douglas-fir seedlings were observed in 12 stands of snowbrush, which ranged in age from 0 to 15 years. The two benefits sometimes claimed for snowbrush--its nitrogen-fixing capacity and its functioning as a nurse crop--were more than offset by its suppressing effect on seedling growth. Only when planted immediately after slash burning as 2-0 or 2-1 stock of local origin could Douglas-fir overcome the competitive challenge of the developing snowbrush.

Snowbrush and red alder in Oregon have different effects on Douglas-fir (Newton 1964). On a typical xeric site in the Cascade Mountains, open-grown Douglas-fir grows more than twice as fast as Douglas-fir under a canopy of snowbrush. However, snowbrush reaches its maximum height in about 15 years, and, after another 3 years, suppressed, slow-growing Douglas-fir trees eventually emerge through the brush canopy. In contrast, red alder grows so rapidly on a mesic coastal site that it hopelessly outdistances Douglas-fir competing with it. In only 7 years, alder may attain a height of 40 feet (12 m), whereas the height of Douglas fir, even without competition, would be less than 10 feet (3 m) at this age. The possibility of Douglas-fir overcoming such an unfavorable initial position for light is remote, and the only trees with any chance of surviving without assistance are those in openings.

The impact of vegetative competition on planted Douglas-fir also was studied on a tract near the Oregon coast, about 7 miles (11.3 km) southeast of the town of Florence (Ruth 1956). The area was clearcut in 1947, and slash was broadcast-burned that fall. The burn was excellent, but because of poor Douglas-fir seed crops it, both 1947 and 1948 the anticipated natural regeneration failed to materialize. By the time the area was planted in March 1949 with 3-0 Douglas-fir seedlings, brush resprouting was well underway. Three months after the Douglas-fir seedlings were planted, competing vegetation averaged 2 feet (0.6 m) tall. Five years later it averaged 5 to 6 feet (1.5 to 1.8 m) tall compared with an average height of slightly over 3 feet (0.9 m) for the Douglas-fir. After the fifth growing season, the principal competing brush and tree species listed in declining order of importance were salmonberry, western thimbleberry, red alder, Pacific red elder, willow, and vine maple.

Increasing shade intensity to 75 percent did not reduce Douglas-fir survival, but progressively reduced height growth. When shade intensity exceeded 75 percent, both height growth and survival were adversely affected. At the end of five growing seasons, annual height growth of overtopped trees averaged only 8 inches (20 cm) compared with 25 inches (63 cm) for unshaded trees.

Controlling Brush and Hardwoods

Since the late 1950's, much research has been directed toward developing techniques for effectively controlling brush and hardwood competitors of young Douglas-fir. Most of this work has dealt with chemical control methods because of their biological effectiveness and their cost advantages over other methods. In recent years, however, increasingly stringent regulations have eliminated some of these chemicals from the forester's choices, and have restricted considerably the use of others. Consequently, a growing interest has developed in alternative methods of conifer release-especially manual methods, such as handcutting of brush.

Tanoak and Pacific Madrone--Douglas-fir can be released effectively from tanoak and madrone by an aerial application of a low volatile ester of 2,4-D in early spring just before or during budbreak of Douglas-fir (Gratkowski 1961a, 1975). The recommended dosage is 3 pounds a.e. (acid equivalent) per acre (3.36 kg a.e./ha). If necessary, a second, milder application of 1.5 to 2 pounds a.e. per acre (1.68 to 2.24 kg a.e./ha) can be applied I or 2 years later. Research in California showed that late fall application of low-volatile esters of 2,4-D and 2,4,5-T effectively controlled tanoak sprouts. Sprout clumps sprayed after mid-October did not resprout, whereas some clumps sprayed in July and August did (Roy 1956).

Tanoak and madrone also can be controlled effectively by treating individual stems with the cut-surface (hack-and-squirt) method. In northern California, stems of tanoak and madrone 3 to 4 inches (7.6 to 10.2 cm) in diameter were treated by severing the bark around the base of each tree with a hatchet (Radosevich and others 1976). Each cut then received approximately 0.06 ounces (2 ml) of either undiluted 2,4-D, 2,4,5-T, or picloram. Some trees were left untreated. Ten years later, mortality of the treated hardwoods in response to application of these chemicals was as follows: 2,4-D, 86.6 percent; 2,4,5-T, 78.6 percent; and picloram, 94.1 percent. None of the untreated hardwoods had died. Basal area growth of the released understory Douglas-fir trees, expressed as a percent of growth of the unreleased trees, was increased by 260 percent (2,4-D), 451 percent (2,4,5-T), and 405 percent (picloram). The relatively lower growth response of the conifers in the 2,4-D treatment was attributed to greater mutual competition among the Douglas-fir trees.

Triclopyr has proven to be an effective herbicide for control of tanoak, both as a cut-surface treatment on standing trees and for application to freshly cut stumps to reduce sprouting (Warren 1980). Two growing seasons after treatment with triclopyr applied to cuts in the cambium on centers 4 to 5 inches (10 to 13 cm) apart, 94 percent or more of the treated tanoak trees were killed. None of the intermingled Douglas-fir trees showed any evidence of herbicide damage. Scrub tanoak is classified as "resistant" to chemical treatment (Gratkowski 1959). Of six herbicides tested, the most effective were low-volatile esters of 2,4-D and 2,4,5-T, but even these caused only partial die-back of the stems and branches. No treated plants were killed.

Ceanothus--*Ceanothus* species commonly regarded as competitors of young Douglas-fir are snowbrush, varnishleaf ceanothus, mountain whitethorn, blueblossom, and deerbrush. Of these, only deerbrush is rated as highly susceptible to chemical control with a foliage spray of low-volatile esters of 2,4-D in water (Gratkowski 1959, 1978). The other species are less susceptible to chemicals, but nevertheless are affected significantly by low-volatile esters of 2,4,5-T sprayed on foliage from early spring throughout the growing season (Gratkowski 1975). This treatment kills aerial parts, but does not eliminate resprouting, although it greatly curtails it for varnishleaf ceanothus (Gratkowski 1978).

Chinkapin and Canyon Live Oak--Two forms of chinkapin--giant (or golden) chinkapin and golden evergreen-chinkapin--are recognized as competitors of Douglas-fir in portions of the Klamath Mountains Region (Gratkowski 1959, 1978). Both forms are regarded as resistant to chemical control--i.e., only parts of the stems and branches die back after being sprayed with herbicides. Low-volatile esters of 2,4,5-T are the most effective for releasing Douglas-fir from these species.

Canyon live oak is another common competitor that also is resistant to chemical control. Unlike the chinkapins, however, it was more susceptible to low-volatile esters of 2,4-D than to 2,4,5-T, but neither chemical achieved complete top kill (Gratkowski 1959, 1978).

Manzanita--Among species of manzanita that compete to varying degrees with Douglas-fir seedlings, three are readily killed with low volatile esters of 2,4-D (Gratkowski 1959). These include hairy manzanita, hoary manzanita, and Howell manzanita--sometimes identified as the non-sprouting form of greenleaf manzanita (Gratkowski 1978). The sprouting form is by far the most important species of manzanita in the Coast Ranges and Siskiyou Mountains, not only because of its wide range and abundance, but also because of its resistance to silvicultural control (Gratkowski 1978). Greenleaf manzanita forms a conspicuous burl at the root crown, and when the aerial parts are killed by cutting, fire, or chemicals, numerous new sprouts develop from dormant buds in the burl. The recommended treatment for controlling this species is a foliage spray of 2,4-D in a light oil-in-water emulsion (Gratkowski 1978).

Salmonberry and Western Thimbleberry--Salmonberry and western thimbleberry, found on coastal Douglas-fir sites in California and Oregon, are classed as being only moderately susceptible to herbicides (Gratkowski 1978). The recommended control for areas where both species grow is a late foliar spray of low-volatile esters of 2,4,5-T applied in an emulsion carrier (Gratkowski 1971, 1975). On salmonberry alone, amitrol-T was more effective than 2,4,5-T in both early and late foliar sprays (Stewart 1974a). However, amitrol-T does not control western thimbleberry. Because most stands of salmonberry also contain thimbleberry, the use of amitrol-T frequently releases thimbleberry, thus permitting it to increase its occupancy of the site.

Red Alder and Vine Maple--The treatment for effectively releasing Douglas-fir from red alder depends upon the height of the alder when treated (Gratkowski 1975). If the alder is 15 feet (4.6 m) or less in height, a single budbreak spray usually will be sufficient. If the alder exceeds 15 feet in height, two sprays may be needed: a budbreak spray and a late foliar spray. For the budbreak spray, a mixture of 2,4-D and 2,4,5-T in diesel oil is recommended; and for the late foliar spray, only 2,4-D in water (Gratkowski, 1975). The foliar spray should be applied 1 to 2 years after the initial spray, or when the alder has enough foliage to intercept most of the spray.

Acceptable kill to release Douglas-fir from vine maple can be obtained with early spring aerial application of low-volatile esters of 2,4,5-T in diesel oil (Gratkowski 1975, Stewart 1974b). The spray should be applied just before or during budbreak of Douglas-fir. As with alder, an oil carrier is necessary for budbreak spraying because these species are then leafless, and the herbicide must enter through the bark.

Douglas-fir Sensitivity to Herbicides

The sensitivity of conifers to damage by herbicides must always be considered. In southwestern Oregon, 2,4-D and 2,4,5-T had no pronounced effect on Douglas-fir (Gratkowski 1961b). However, season of application and the carrier used had major effects on damage and mortality. With all tested formulations, the amount of damage from autumn application was noticeably less than from the same spray applied in summer. Also, adding oil to the carrier caused a substantial increase in damage and mortality when the chemicals were applied during the summer. In autumn, however, Douglas-fir was relatively resistant to either herbicide--even in emulsion carriers.

Similar results were obtained in a study that tested the seasonal tolerance of six coniferous species to eight foliage-active herbicides (Radosevich and others 1980). Each herbicide was applied on three different dates: April 14, July 7, and September 23, 1977. The trees were still dormant at the first application, were actively growing during the second application, and had ceased seasonal growth before the September application. All conifer species were most tolerant when herbicides were applied in September, and most susceptible to damage when the chemicals were applied in July. No injury to Douglas-fir was observed when either 2,4,5-T or diclorprop was applied in the fall, although some mortality resulted from fall application of Silvex. Also, fall application of glyphosate caused some injury to Douglas-fir.

The seasonal nature of herbicide selectivity in coniferous species probably is caused by differential absorption through leaves and restricted distribution after absorption (Radosevich and others 1980). As conifer leaves become more sclerophyllous with age, less herbicide is likely to penetrate them--an effect enhanced as the growing season progresses, because herbicide distribution would be restricted as moisture stress increases.

Preventing Animal Damage

Deer

Among the animals that damage or kill young Douglas-fir trees in northwestern California, deer rank as the most injurious agent (Packham 1970). Mule deer and black-tailed deer are both subspecies of the only species (*Odocoileus hemionus*) native to California. In the Pacific Northwest, deer are responsible for most animal damage to reforestation (Black and others 1969). Such damage by deer represented about 56 percent of all animal damage recorded.

The apparent interrelationship among brush, deer, and Douglas-fir was investigated in three areas in northern California: Slate Creek, about 7 miles (11.3 km) north and slightly east of Weaverville; Brush Mountain, about 3 miles (4.8 km) west of Salyer; and the Swanson Unit, about 2 miles (3.2 km) east and 1 mile (1.6 km) south of Salyer (Roy 1960b). At Slate Creek, deer browsed lightly on conifers because of the abundance of bigleaf maple seedlings and dogwood sprouts, which they prefer.

At Brush Mountain, deer browsing on Douglas-fir seedlings was moderately severe because more highly preferred browse species were not abundant. Repeated browsing reduced height growth appreciably. Trees browsed four times during the 6 years after planting lost 2.3 years of growth; those browsed five times lost 2.7 years of growth.

On the Swanson Unit, proximity to tanoak sprout clumps afforded Douglas-fir seedlings some physical protection from browsing. Six years after planting, deer browsing had reduced the height of unprotected seedlings by an amount equivalent to 3.6 years of growth compared with seedlings protected by brush clumps. The protected seedlings averaged 39.7 inches (101 cm) in height; unprotected seedlings averaged only 11.0 inches (28 cm).

On the Coast Range of Oregon, browsing by black-tailed deer, and also by mountain beaver and perhaps brush rabbits, reduced height growth of Douglas-fir (Ruth 1956). Some trees were not browsed at all, some only once, and others two or three times. The average heights of the surviving trees after 5 years were as follows: not browsed, 55.9 inches (142 cm); browsed once, 40.1 inches (102 cm); browsed twice, 16.5 inches (42 cm); and browsed three times, 8.3 inches (21 cm). Few trees were killed by browsing alone; but reduced height growth and loss of vigor from browsing contributed to overtopping by brush and herbs, and many trees subsequently died.

Substantial retardation of height growth of Douglas-fir as a result of deer browsing also was noted in western Washington (Hartwell 1973b). On each of three plantations that had already been subjected to deer browsing for I to 5 years, some trees were caged to prevent further deer browsing, and others were left uncaged. At the beginning of the study, the trees on each plot were uniformly shrub-like and slightly over 1 foot (30 cm) in mean height. After 6 years, the mean height of the caged trees was about $2^1/_2$ feet (0.76 m) greater than that of the uncaged trees on each of the study areas.

Although some evidence suggests that browsing may reduce height growth of seedlings significantly as long as the terminal shoots remain within reach of the deer, other evidence suggests that after terminals grow out of reach, browsed trees tend to catch up to their unbrowsed counterparts. This possibility was explored during a 16-year period on the Brush Mountain Unit near Salyer on the Six Rivers National Forest in northwestern California. Browsing began during the second growing season and peaked in the fourth season when 59.4 percent of the trees were browsed. The maximum height of browsing was 5.83 feet (1.78 m). Almost 18 percent of the trees were never browsed, but over 57 percent were browsed one to three times, and 25 percent were browsed four or more times. Two trees were browsed in 10 of the 16 years.

Sixteen years after trees were planted, browsing up to six or seven times appeared to have no effect upon their height. Browsed trees, which had fallen behind in height growth at 6 years after planting had, in general, caught up to unbrowsed trees. In fact, browsing up to five times seemed to stimulate height growth. However, until it is known whether browsed trees have some nutritional advantages over unbrowsed trees, a cause-and-effect relationship should not be assumed.

Even heavy browsing is unlikely to affect seriously either tree volume or quality of Douglas-fir at rotation age (Mitchell 1964). Average reduction in tree height attributable to animal feeding in heavily browsed plantations varied from $^1/_2$ foot to 2 feet (0.15 to 0.61 m) over an 8- to 10-year period, on Vancouver Island, British Columbia. Exposed trees were browsed more heavily than those protected by vegetation or logging slash.

An Oregon study led to similar conclusions: deer browsing will probably be of little consequence in reducing growth over the length of an entire rotation (Crouch and Paulson 1968). Over a period of 7 years, however, the trees that had been protected from browsing since time of planting averaged about $1^1/_2$ feet (0.46 m) taller than the unprotected trees. The unprotected trees showed no sign of catching up--even though they were not browsed during the last 3 years of observation.

Until the effects of deer browsing on quantity and quality of Douglas-fir yield are determined more clearly, land managers have several choices for coping with the problem of browsing damage. Such measures include the use of mechanical barriers, chemical repellents, habitat modification through cultural practices, and genetic modification.

Mechanical Barriers-- Mechanical barriers have proven effective. They can be high fences that exclude deer from an entire plantation, small cages that protect individual trees, or even smaller devices that protect only the terminal leader or terminal bud during a critical stage. The chief disadvantage of the larger mechanical barriers is cost, because they must be installed, maintained, and--in most cases--eventually removed (Longhurst and others 1962). Therefore, most interest has been directed toward the smaller mechanical devices, such as protective sleeves for terminal shoots.

Plastic sleeves have performed well in protecting Douglas-fir seedlings from browsing damage (Campbell and Evans 1975). They can be formed from various materials and tailored to meet specific needs. Polyethylene sleeves are available in either rigid or flexible form, in different colors, and biodegradable at different rates. One type degrades within 1 year; other types remain intact for periods up to 10 years or more.

Mechanical and chemical means of deterring browsing of Douglas-fir were compared on the Tillamook Burn in western Oregon (Hines 1971). The effectiveness of a polyethylene sleeve slipped over the terminal shoot, and that of tetramethyl thiuram disulfide (TMTD), a commercial repellent, were tested inside a deer enclosure where heavy browsing pressure could be maintained. In both years of observation, terminal browsing of untreated trees was significantly greater than that of trees protected by either of the two treatments. The polyethylene sleeves provided significantly better protection than the repellent.

Chemical Repellents--One of the chemicals tested for the ability to discourage deer from browsing on young conifers is BGR (Big Game Repellent)--a formulation of putrefied eggs. It has met with varying success, with degree and duration of protection influenced by weather and other factors. Most externally applied repellents such as BGR and TMTD, however, share a common drawback--they afford relatively little protection to newly elongating shoots.

A systemic repellent that is readily absorbed and translocated to all parts of a seedling, including the newly developing shoots, is needed. To date no completely successful systemic has been found. One that showed promise is OMPA (octamethyl-pyrophosphoramide) (Rediske and Lawrence 1964). First symptoms of phytotoxicity were observed at 1500 ppm, with lethality reached between 3000 and 4000 ppm tissue. OMPA was translocated readily in seedlings, both up and down the stem, when applied to the roots or the foliage. Bioassays indicated that the material was effective as a systemic repellent at foliage concentrations of 400 to 1000 ppm. Test rabbits clearly differentiated between untreated and treated seedlings, which they rejected as food. Thus, because the threshold for effective repellency is approximately 400 ppm, and because it is not phytotoxic to the seedling at concentrations below about 1500 ppm, OMPA showed promise of being an effective systemic repellent. The test did not include deer, however, and when others tested OMPA, the results were often disappointing.

Another way to discourage deer from browsing Douglas-fir trees is to spray a spatial repellent. One of the more promising materials of this type is putrefied fish. Among five materials tested, putrefied salmon gave the best results (Hartwell 1973a). Applying the material to balls of cotton placed about 10 inches (25 cm) below terminal buds when bud swelling began in late April greatly reduced deer browsing of the rapidly growing terminal shoot after bud burst. However, the spatial aversion resulting from this technique did not extend to nearby untreated trees, nor did it last to the end of the growing season.

The possibility of reducing animal damage by manipulating the habitat may have increasing appeal. By appropriate cultural treatments, the habitat can be made less desirable for a given animal species and more suitable for a given plant species. In a study aimed at achieving these ends, combinations of several herbicides (atrazine, dalapon, Silvex, and 2,4-D) were applied to one-half of each of three clearcuttings 30 to 70 acres (12 to 28 ha) in size, and from 8 to 12 years since logging (Borreco and others 1972). Two of the study areas were located south of Cottage Grove, Oregon, and the third was a few miles southeast of Kings Valley, Oregon. All were characterized by uniform, gentle topography, southerly exposures, and heavy deer usage.

The application of herbicides caused profound changes in vegetation. Grasses were reduced, but growth of shrubs and trees was promoted. Survival and growth of Douglas-fir were greater on the treated plots. Changes in vegetation affected the seasonal pattern of deer usage as determined by pellet-group counts, which indicated more activity on treated plots during the growing seasons. However, the amount of browsing did not differ significantly as a result of the habitat changes. Thus, both deer and Douglas-fir seemed to benefit by the altered habitat.

The possibility of luring deer away from Douglas-fir by seeding or planting other highly preferred browse species also has been tried, but results generally have been disappointing. Browse preference studies in northwestern Oregon suggest that, while the intensity of browsing of Douglas-fir seedlings may vary from season to season and year to year, this species ranks high enough on the food preference list so that some browsing can be expected regardless of the apparent abundance of other preferred forage (Crouch 1966).

Cultural Practices--Another approach to reducing the impact of animal damage on Douglas-fir involved testing whether large planting stock might be more resistant to wildlife damage than small stock because of its greater height and stem diameter (Hartwell 1973c). The tests were conducted at four localities in Grays Harbor County, Washington. The two main animal species causing damage were black-tailed deer and mountain beaver. All trees were treated with TMTD animal repellent before they were lifted from the nursery. Large stock was planted with a shovel, and small stock with a planting hoe. Wildlife feeding injuries and tree heights were recorded periodically for about 5 years after plot installation.

The study results could not be considered conclusive because only a few trees were observed. Nevertheless, the data strongly suggested that, under certain conditions, use of large stock can substantially reduce the impact of wildlife damage. When planted, the large stock varied in mean height among plots from 3.1 to 4.2 feet (0.94 to 1.28 m); the small stock varied from 1.1 to 1.3 feet (0.34 to 0.40 m). Five years later, the large stock varied from 5.5 to 11.0 feet (1.68 to 3.35 m); the small stock varied from 3.6 to 4.8 feet (1.10 to 1.46 m). The greatest benefit from using large stock was gained on plots with the densest ground cover. In areas where mountain beaver, rather than deer, posed the chief animal damage problem, even small stock had high survival with only one TMTD repellent application.

Existing evidence indicates that the application of fertilizer--specifically nitrogen--to young Douglas-fir trees increases not only their growth but also their susceptibility to deer browsing. This theory was tested in Mendocino County, California, on a soil which was highly deficient in nitrogen, with deficiencies in phosphorus and sulfur also noted (Oh and others 1970). These elements were applied on different plots in the following forms and dosages: nitrogen as urea (45 pct nitrogen) at the rate of 100 pounds of nitrogen per acre (1.12 kg/ ha); phosphorus as concentrated superphosphate (24 pct phosphorus) at 100 pounds of phosphorus per acre; and sulfur as gypsum (17 pct sulfur) at the rate of 100 pounds of sulfur per acre.

Observations showed a highly seasonal pattern of deer browsing on Douglas-fir in the study area, with heaviest browsing coinciding with the period of bud burst and rapid growth of new shoots. The preference of deer for nitrogen-fertilized trees was clear. Deer browsed 90 to 100 percent of new shoots on the nitrogen-treated plots during the first growing season, and 50 to 75 percent during the second season. On the plots not receiving nitrogen, deer browsed only 0 to 10 percent of new shoots during the first season, and 0 to 5 percent during the second growing season. Nitrogen fertilization of Douglas-fir seedlings increased the growth, protein content, acceptability to deer, and rumen microbial fermentation. Even in the second season after fertilization, the deer preferred fertilized trees, although differences in fermentability between foliage from fertilized and unfertilized trees were no longer detected.

Genetic Modification--Additional research at the Hopland Experiment Station, Hopland, California, demonstrated significant differences in rumen microbial fermentability between two Douglas-fir stocks of different genetic origin. Others have also probed the chemical makeup of seedlings from different sources in a quest for differences that may be associated with browsing preference. In western Washington, 10-year-old Douglas-fir clones resistant to deer browsing had lower dry-matter and cellulose digestibilities; essential oils with greater inhibitory action on rumen microbial activity; higher contents of fats, total phenols, flavanols, and leucoanthocyanins; and lower levels of chlorogenic acid (Radwan 1972). Results suggest that these resistance characteristics, especially the chlorogenic acid content, might be useful for screening Douglas-fir breeding stock for resistance to deer browsing.

Other Animals

Other animals can damage Douglas-fir reproduction seriously. Regionally, they damage fewer trees than do deer, but often their impact on a specific plantation can be more devastating. The pocket gopher is one of the major animal pests (Packham 1970). These animals feed on roots, stems, and branches of seedlings and saplings, usually killing the tree. They gnaw roots throughout the year, but the damage sometimes goes unnoticed until the young trees begin to lean or fade. Stems and branches are gnawed primarily in winter in areas where snow cover provides concealment. Results usually are observed the following spring or summer as completely girdled trees fade, or as the remaining stubs are found.

Several species of meadow mice can injure plantations in grassy areas by gnawing off the bark of seedlings and saplings. Girdling may extend from the root collar up the stem a foot or more, and trees several inches in diameter may be girdled. Most trees are damaged during the fall and winter in years of peak animal populations, but meadow mice are a threat to young trees at any time (Packham 1970).

Less serious animal threats to Douglas-fir regeneration, except on a local basis, are posed by the mountain beaver, elk, black bear, and the dusky-footed woodrat, although this last species could prove to be a serious threat in precommercially thinned stands. Domestic cattle and sheep also cause damage to young plantations through browsing and trampling.

GENERAL RECOMMENDATIONS

This section offers general recommendations applicable to Douglas-fir forests in northern California and southwestern Oregon. These recommendations are general guides for forest managers and other practitioners. They are based on research on Douglas-fir regeneration carried out since the early 1950's, with emphasis placed on the practical aspects of the results.

Seed Production

Apply nitrogen fertilizer to young stands in the nitrate form rather than in the ammonium form to increase seed production. Efforts to stimulate seed production in old-growth Douglas-fir by adding fertilizer have been generally unsuccessful and are not recommended. Seed production also can be increased by stem girdling. The best time to apply this technique is at the onset of flowering, but only in years when natural flowering is scant.

Site Preparation

Restrict mechanical site preparation, including use of a tractor with a rake or brush blade, to sites that are relatively flat. Tractors working on slopes steeper than about 30 percent can increase erosion on some sites. Also, on certain soil types when soil moisture is high, tractors can seriously compact the soil. On suitable sites, tractors can prepare a high proportion of plantable ground. Toothed blades can be pushed through the upper layers of soil to uproot brush while minimizing topsoil movement. Hold down costs by keeping the tractor moving forward as much as possible, working around obstructions instead of attempting complete brush eradication.

On slopes too steep for tractors, burning now is the only feasible way to reduce the large accumulation of logging debris left on many cutblocks. Recent advances, which use helicopters to provide rapid, precise ignition, allow much better control of burning patterns and fire behavior--and greater safety for the crew--than the hand-carried drip-torch method.

Severe burning (intense, prolonged heat that consumes all duff and changes the color of the upper layers of mineral soil) changes both the physical and chemical properties of soil. Whether to burn a given site must be decided carefully to determine if the improvements in ease of planting, reduction of competition, and reduction in fire hazard outweigh the possible adverse impacts on the site. On steep slopes on certain soil types, the retention of vegetation and duff is essential for preserving soil stability. Burning that destroys these protective elements may lead to increased soil movement. Also, burning stimulates germination of seeds of certain brush species, that later compete seriously with young conifers.

The chemical method of site preparation exposes no mineral soil, but effectively can retard competing vegetation. Herbicides, alone, are effective for site preparation only when the target species are highly susceptible, slash density is low, litter is light enough to permit seeding, or brush is sparse enough to allow planting at reasonable cost.

Herbicides often are used most effectively in conjunction with either mechanical clearing or prescribed burning. In dense stands of susceptible brush, herbicides can kill or weaken a substantial portion of the brush. Without additional treatment, however, the area is still unplantable because of the density of the standing dead brush. This physical impediment can be removed by mechanical clearing, burning, or both, but sufficient time should be allowed after chemical treatment to achieve maximum root kill and stem desiccation. Resprouting will be less than if either mechanical clearing or burning had been used alone.

Natural Regeneration

Natural regeneration plays only a minor part in the overall Douglas-fir regeneration effort. To keep all parts of the harvested area within reasonable distance of a seed source, limit cutblocks to less than 8 chains (160 m) wide. The side shade cast by the surrounding uncut forest also aids seedling establishment.

Various species of rodents and birds consume large quantities of Douglas-fir seed. Even if conditions are favorable for natural regeneration, high populations of seed-eating rodents or birds can prevent success unless measures, such as poisoning, are used to control these predators.

Direct Seeding

Interest in direct seeding has declined considerably in recent years because the probability of failure is relatively high and control over stocking and spacing is poor. Nevertheless, direct seeding has sufficient potential as a viable option for some landowners on some sites--if care is taken to follow the best known practices.

A mineral soil seedbed, prepared either mechanically or by a clean burn, is generally best. Douglas-fir seed can also germinate well in charcoal. Regeneration success is more likely on fine-textured than on coarse-textured soils. Sow Douglas-fir seed in late fall or early winter rather than late winter or spring. In general, northerly aspects are more favorable than southerly aspects, although good results can be produced on the latter on fine-textured soils. On southerly aspects, germination and early survival are favored by moderate shade (about 50 pct).

The same species of rodents and birds that reduce the success of natural regeneration also threaten the success of direct seeding. Therefore, do not attempt regeneration by direct seeding without providing some form of protection for the seeds. On small areas that can be hand-seeded, protect the seeds with either a repellent or poison coating, or with metal or plastic screens. The screening technique is more expensive because of the additional labor and materials required.

The only feasible method of regenerating large areas by direct seeding is to aerially broadcast repellent-coated seed. Approximately 1 pound of seed per acre is normally sufficient. Sow seeds on thoroughly prepared sites, after autumn rains have wet the upper soil horizons amply and settled loose surface soil.

Planting

Planting is by far the most common and most reliable method of regenerating Douglas-fir in the Klamath Mountains Region. Success, however, requires careful attention to detail during every stage of the process, from using the proper seed source to field planting. Seed from the proper source is essential to ensure that the planted trees will be adapted genetically to the environmental conditions at the planting site.

Lift bare-root seedlings from nursery seedbeds only when fully dormant. Dormancy in Douglas-fir is seed-source dependent. Some seed sources have a wide "lifting window" and others a very narrow one. Seedlings can be placed in cold storage until planting time. Cold storage under proper conditions does not impair seedling vigor or field survival if the seedlings are lifted when fully dormant and have a high capacity for root growth.

A fibrous, well-developed root system is one of the most important seedling attributes that favors regeneration success. To minimize first-year mortality, make sure that total fresh weight (top and roots) is at least 1.4 ounces (4 g). A low top/ root ratio is generally favorable, although this ratio alone is not a reliable predictor of survival.

Seedling morphology can be modified by various nursery techniques. Wrenching--a special form of undercutting can stimulate root growth and retard top growth if done at the proper depth and proper time. This treatment sometimes reduces early mortality of outplanted seedlings.

Careful handling of stock, both at the nursery and at the planting site, will help increase survival. Prolonged root exposure to high temperature and low humidity is especially harmful and should be avoided. Such exposure delays bud-bursting and decreases height growth, needle length, needle weight, terminal bud length, and survival.

On harsh south or southwesterly aspects, shade sometimes improves survival of planted seedlings. Dead shade (from rocks, logs, shingles, etc.) is best, but live shade (from brush or a partial overstory of trees) may also improve survival. However, good survival is possible without shade, even on south aspects, if careful attention is given to all phases of the planting operation. Once established, seedlings nearly always grow best where shade is least.

On steep slopes, soil or debris movement may reduce survival of seedlings by bending them down or burying them. Therefore, plant large seedlings, and carefully choose planting spots on the flattest available microsites, or on the downslope side of stumps or well-anchored rocks.

Container-grown seedlings can be useful in the overall planting program when planted on appropriate sites--principally those characterized by stable soils, and without heavy brush competition or serious animal damage problems. On severe sites the larger bare-root stock generally survives better because of its greater height and diameter, greater proportion of woody tissue (less palatable to animals), and larger root system. On more favorable sites, container-grown stock performs well, and because of the inherent advantage of an intact and relatively undisturbed root system, it can extend the normal planting season moderately.

Vegetative Competition

On some sites, grass can compete seriously with Douglas-fir seedlings soon after they are planted. Atrazine and Terbacil are two chemicals that effectively control grass with little or no damage to Douglas-fir. Dalapon also effectively controls grass when combined with atrazine and 2,4-D, but can injure Douglas-fir when used alone.

Various species of brush and hardwoods provide serious competition for young Douglas-fir trees. The suppressing effects of tree-form hardwoods--such as tanoak, madrone, and red alder, as well as of the taller, denser shrubs such as snowbrush and varnishleaf ceanothus--continue for many years. Species that sprout when cut, burned, or otherwise injured, present a special challenge because of their typically rapid growth rates.

For shade intensities of up to 75 percent, the principal effect of competing vegetation is to reduce vigor and height growth of young Douglas-fir. When shade exceeds this intensity, tree survival also is reduced. Height growth can be reduced as much as 7 feet (2.1 m) during a 10-year period of suppression by competitors such as tanoak and snowbrush.

To control most hardwood and shrub competitors of Douglas-fir, apply low-volatile esters of phenoxy herbicides--2,4-D or 2,4,5-T. When application is properly timed, economical, effective brush control is possible with little or no damage to Douglas-fir. (The 2,4,5-T form is currently banned by the U.S. Environmental Protection Agency, and no fully satisfactory substitute has been found as yet.)

Animal Damage

On a regional basis, the most serious animal damage problem is deer browsing. Numerous approaches have been devised to prevent or reduce browsing, including the use of mechanical barriers, chemical repellents, large planting stock, habitat modification, and genetic modification. Mechanical barriers include devices such as high fences around entire plantations, poultry netting around individual trees, and polyethylene sleeves that protect only the terminal leader. All are effective as long as they remain intact and in place.

Chemical repellents include materials formulated from a variety of substances whose odor or taste are repugnant to wildlife. They are usually less costly than mechanical barriers, but also less effective in terms of duration of protection (repellents deteriorate with weathering, and new growth has no chemical sheath).

Use of large planting stock has received less attention as a means of reducing the impact of animal damage, but it appears to be useful. Large stock is more expensive, however, both to produce and to plant, than is stock of normal size.

Habitat modification and genetic modification of Douglas-fir are, still largely in the experimental stages. Both may ultimately become useful methods for reducing deer damage to young trees.

Fertilization, especially with nitrogen, seems to increase palatability of Douglas-fir to deer and, therefore, the likelihood of browsing. The increased susceptibility of Douglas-fir seedlings to browsing extends at least into the second year after fertilization.

After browsed trees finally grow above the reach of deer, they tend to catch up in height to their unbrowsed neighbors. Consequently, growth loss caused by browsing may be insignificant over a rotation. If this proves to be true, efforts to prevent browsing damage may be unnecessary unless tree survival is endangered.

Summary

- Increase seed production in young stands by (a) applying nitrogen and phosphorus, each at the rate of 200 pounds per acre (224 kg/ha); and by (b) stem girdling.
- Prepare sites for regeneration by mechanical or chemical treatment, prescribed burning, or a combination of such treatments.
- If natural regeneration is attempted, schedule harvesting--if possible--to coincide with a good seed year.
- If using direct seeding, follow generally accepted practices.
- Attend carefully to all details during each stage of the planting process--from growing trees from proper seed sources to planting in the field under the most suitable conditions.
- Control vegetative competition to seedlings and young trees with approved herbicides.
- Control damage by animals, chiefly deer, with mechanical barriers or chemical repellents; or use large planting stock.

APPENDIX

Plant and Animal Names

Australian fireweed	*Erechtites prenanthoides* DC.
Bigleaf maple	*Acer macrophyllum* Pursh
Black bear	*Ursus americanus*
Black-tailed deer; also mule deer	*Odocoileus hemionus*
Blueblossom	*Ceanothus thyrsiflorus* Eschsch.
Brown mustard	*Brassica juncea (L.)* Cosson.
Brush rabbit	*Sylvilagus bachmani*
California hazel	*Corylus cornuta* var. *californica* (A.DC.) Sharp
California honeysuckle	*Lonicera hispidula* var. *californica* (Dougl.) Jepson
California red fir	*Abies magnifica* A. Murr.
Canyon live oak	*Quercus chrysolepis* Liebm.
Cone moth or fir coneworm	*Dioryctria abietella* Dennis and Schiffermüller
Cone scale midge	*Contarinia washingtonensis* Johnson
Deerbrush ceanothus	*Ceanothus integerrimus* H. & A.
Deer mouse	*Peromyscus maniculatus*
Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*
Douglas-fir cone midge	*Contarinia oregonensis* Foote
Douglas-fir cone moth	*Barbara colfaxiana* Kearf.
Douglas-fir seed chalcid	*Megastigmus spermotrophus* Wachtl
Dusky-footed woodrat	*Neotoma fuscipes*
Elk	*Cervus canadensis*
Fox sparrow	*Passerella iliaca*
Giant chinkapin	*Castanopsis chrysophylla* (Dougl.) A. DC.
Golden-crowned sparrow	*Zonotrichia coronata*
Golden evergreen-chinkapin	*Castanopsis chrysophylla* var. *minor* Benth.
Greenleaf manzanita	*Arctostaphylos patula* Greene
Hairy manzanita	*Arctostaphylos columbiana* Piper
Hoary manzanita	*Arctostaphylos canescens* Eastw.
Howell manzanita	*Arctostaphylos hispidula* Howell
Incense-cedar	*Libocedrus decurrens* Torr.
Jeffrey pine	*Pinus jeffreyi* Grev. & Balf.
Jumping mouse	*Zapus trinotatus*
Kangaroo rat	*Dipodomys* sp.
Knobcone pine	*Pinus attenuata* Lemm.
Meadow mouse	*Microtus* sp.
Mountain beaver	*Aplodontia rufa*
Mountain hemlock	*Tsuga mertensiana* (Bong.) Carr.
Mountain quail	*Oreortyx picta*
Mountain whitethorn ceanothus	*Ceanothus cordulatus* Kell.
Narrow-leaved buckbrush	*Ceanothus cuneatus* (Hook.) Nutt.
New Zealand fireweed	*Erechtites arguta* DC.
Oceanspray	*Holodiscus discolor* (Pursh) Maxim.
Oregon creeping vole	*Microtus oregoni*
Oregongrape	*Berberis nervosa* Pursh
Oregon junco	*Junco oreganus*
Oregon white oak	*Quercus garryana* Dougl. ex Hook.
Pacific dogwood	*Cornus nutallii* Audubon
Pacific madrone	*Arbutus menziesii* Pursh
Pacific red elder	*Sambucus callicarpa* Greene
Pacific rhododendron	*Rhododendron macrophyllum* D. Don ex G. Don
Pocket gopher	*Thomomys* sp.
Poison oak	*Rhus diversiloba* T. & G.
Ponderosa pine	*Pinus ponderosa* Dougl. ex Laws
Port-Orford-cedar	*Chamaecyparis lawsoniana* (A.Murr.) Parl.
Red alder	*Alnus rubra* Bong.
Rose	*Rosa* sp.
Salmonberry	*Rubus spectabilis* Pursh
Scrub tanoak	*Lithocarpus densiflorus* var. echinoides (R. Br.) Abrams
Snowbrush ceanothus	*Ceanothus velutinus* Dougl.
Spotted towhee	*Pipilo maculatus*
Squirrel	*Sciurus* sp.
Sugar pine	*Pinus lambertiana* Dougl.
Tanoak	*Lithocarpus dens florus* (Hook. & Arn.) Rehd.
Townsend's chipmunk	*Eutamias townsendii*
Trowbridge's shrew	*Sorex trowbridgii*
Vagrant shrew	*Sorex vagrans*
Varied thrush	*Ixoreus naevius*
Varnishleaf ceanothus	*Ceanothus velutinus* var. *laevigatus* (Hook.)T.& G.
Vine maple	*Acer circinatum* Pursh
Western hemlock	*Tsuga heterophylla* (Raf.) Sarg.
Western thimbleberry	*Rubus parviflorus* Nutt.
White fir	*Abies concolor* (Gord. & Glend.) Lindl.
White-footed deer mouse	*Peromyscus maniculatus*
Willow	*Salix* sp.

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Information on the regeneration of Douglas-fir, one of the most valuable timber species in the United States, is summarized, from seed production to care of young stands. General recommendations are given to guide the practitioner. Seed production can be increased by applying fertilizer and by stem girdling. To prepare sites for planting, mechanical, burning, chemical or a combination of treatments should be used. All details during each stage of the planting process should be followed. Steps should be taken to control vegetative competition and animal damage to seedlings and young trees. If direct seeding is used, generally accepted practices should be followed. And if natural regeneration is attempted, harvesting should be scheduled to coincide, if possible, with a good seed year.

Retrieval terms: seed production, site preparation, natural regeneration, artificial regeneration, direct seeding, planting. *Pseudotsuga menziessi* (Mirb.) Franco var. *menziessi,* California, Oregon